ASSESSMENT OF THE ADOPTION OF INNOVATIVE BUILDING MATERIALS (IBM) FOR SUSTAINABLE CONSTRUCTION IN THE NIGERIAN CONSTRUCTION INDUSTRY

BY

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ABSTRACT

The construction industry in Nigeria plays a substantial role in shaping the country's economy and environment. In recent years, there has been a growing interest in using innovative building materials (IBM) to accomplish sustainable construction practices. This study aims to assess the adoption of IBM for sustainable construction in the Nigerian construction industry (NCI). The study has five objectives, including determining the level of awareness of some available IBM, identifying drivers and barriers to adoption, evaluating the benefits of using these materials, and providing strategies for successful adoption. This study was conducted using quantitative research method. A survey was undertaken among professionals involved in the construction sector in Nigeria, comprising architects, builders, engineers, and quantity surveyors, to gather information on their awareness, usage, drivers, barriers, benefits, and strategies for adopting IBM. Out of 363 sample sizes, 282 responses were obtained and found suitable, making the overall response rate for this study 77.6%. This research comprehensively analyses the current state of IBM adoption for sustainable construction in Nigeria. The data was analysed using the following descriptive analyses: mean item score (MIS), relative importance index (RII), ranking and frequency and inferential analysis (ANOVA, KMO and Bartlett's, factor analysis and chi-square test). Using six (6) selected IBM; pigmented/coloured concrete, light-generating concrete, cross laminated timber (CLT), timbercrete, smart glass windows, and three-dimensional (3D)-printed graphene. The findings indicated that respondents are very aware of four IBMs: smart glass windows, CLT, pigmented/coloured concrete and 3D-printed graphene, while considering all six IBMs relevant. For application, smart glass windows are the most adopted material out of the six (6) IBMs in the construction industry. According to the respondents, all 14 drivers are very significant. Clients' requirements, government regulations, availability of IBM suppliers and developments in

ICT/technology-push are the top drivers of IBM adoption. This study highlights the importance of government support and regulations in promoting the use of IBM. The study also found significant barriers to IBM adoption in the study area: lack of awareness and knowledge, learning /training period, cost and economic viability, and lack of qualified staff. Sustainable and environmentally friendly practices, efficient energy use, environmental protection, and increased use of recycled waste as building materials were the top benefits of IBM adoption. The study also noted that the respondents found all 18 benefits very significant, and the top three benefits are sustainable and environmentally friendly, efficient use of energy and environmental protection. Based on these findings, the study recommends owner/client support, appraisal of building codes and establishment of sustainable building codes, provision of sustainable material selection criteria, and mandatory governmental policies and regulations encouraging the use of IBM as the top strategies for IBM's successful adoption of sustainable construction practices in Nigeria, which will contribute to the sustainable development of the country. This study contributes to the current knowledge base by offering additional insights on awareness, drivers, barriers, benefits, and strategies for adopting IBM, which could enhance the effectiveness of IBM in the construction industry in Nigeria and beyond.

Keywords: innovative building materials (IBM), sustainable construction, sustainable development, sustainable materials, adoption

DECLARATION

I, **MOGAJI ISEOLUWA JOANNA,** declare that this thesis is the culmination of my investigation and research study. I also declare that the sources used in this research have been acknowledged in the reference list and adequately cited in the body of the thesis. Copies of this study have in no way been submitted elsewhere for any similar purpose. This research was conducted at the Durban University of Technology as a requirement to obtain a **MASTER OF THE BUILT ENVIRONMENT** degree in Construction Management under the supervision of Dr. M. C. Mewomo.

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DEDICATION

This dissertation is dedicated to the One who created and sustained me, the Lord God Almighty. I am eternally grateful for His guidance, support, and strength throughout this journey. I accomplished this work through God's grace and am humbled by the privilege of dedicating it to Him. This dissertation is also dedicated to the people who have been my pillars of strength and support throughout my life: my parents, brother, and sisters. Their unwavering love, encouragement, and prayers have been instrumental in helping me reach this moment, and I am eternally grateful for their support. To them, this work is dedicated to the most profound love and affection.

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LIST OF PUBLICATIONS

Book chapter

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Conference papers

1. Mogaji, I. J., Mewomo, M. C. and Toyin, J. O. (2023). *Key Barriers to the Adoption of 3D Printing Innovation in Construction: A Review of Empirical Studies.* The Thirteenth International Conference on Construction in the 21st Century (CITC-13). **Accepted**
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Journal papers

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LIST OF ABBREVIATIONS

3D	- Three-dimensional
ANOVA	- Analysis of variance
CIOB	- Chartered Institute of Building
CLT	- Cross-laminated Timber
CSR	- Corporate social responsibility
DOI	- Diffusion of Innovations
DUT	- Durban University of Technology
FA	- Factor Analysis
IBM	- Innovative Building Materials
KMO	- Kaiser-Meyer-Olkin
LTC	- Light-Emitting Concrete
MIS	- Mean Item Score
NCI	- Nigerian construction industry
NIA	- Nigerian Institute of Architecture
NIOB	- Nigerian Institute of Building
NIQS	- Nigerian Institute of Quantity Surveying
NSE	- Nigerian Society of Engineers
PCA	- Principal Component Analysis
RII	- Relative Important Index
SC	- Sustainable Construction
SME	- Small and Medium-sized Enterprises
SPSS	- Statistical Package for Social Science

TAM	- Technology Acceptance Model
TPB	- Theory of Planned Behavior
TVE	- Total Variance Explained
UTAUT	- Unified Theory of Acceptance and Use of Technology

LIST OF APPENDICES

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Introduction

This chapter provides an introduction, highlighting the research background and associated problems. This brief background led to identifying gaps in previous studies that this research intended to fill. The chapter presents the significance of the study and an outline of the thesis structure. Following that, the chapter states the aim and outlines the study's objectives, defines the research's scope, and describes the research methodology employed in the investigation.

1.2. Background of the study

The construction industry significantly impacts global greenhouse gas emissions and the depletion of resources (Chen *et al.* 2022; Chen *et al.* 2023). As a result, there is an increasing need for environmentally friendly building practices and materials to tackle this issue. Shittu (2021) reports that the construction industry in Nigeria is also facing the challenge of increasing levels of carbon dioxide emissions and environmental pollution. Sambo (2014) points out that the Nigerian construction sector predominantly employs non-sustainable building materials such as Portland cement, gravel, and sand and non-renewable energy sources like hydrocarbons. Innovative building materials (IBM), which outperform traditional materials regarding environmental performance and cost savings, are at the forefront of this movement (Patil and Patil 2017). Significant volumes of waste are created at each stage of the building process (Dajadian and Koch 2014). The design and construction of buildings consume 20—50% of natural resources and materials, according to their environment (Egmond 2019). Materials are needed and used for building construction to be possible. Building materials can make up as much as 40% of the overall expenses of construction projects (Andrade *et al.* 2018; Bamigboye *et al.* 2019), whereas Safa *et* *al.* (2014) indicated they could constitute approximately 50 to 60% of the overall project expenditure. Even as construction operations improve people's lives, they have a detrimental effect on the environment. Building materials have a substantial direct and indirect impact on the global environment, because of extensive energy consumption and tremendous greenhouse gas emissions (Delgado *et al.* 2015; Schmidt *et al.* 2020).

The production of construction materials involves using energy, which releases greenhouse gas emissions (Delgado *et al.* 2015). According to Son *et al.* (2011); Berardi (2013); Low, Gao and Tay (2014), the construction industry utilises significant natural resources. Specifically, it consumes 12—16% of the available water, 40% of energy production, and 40% of all raw materials, both renewable and non-renewable. The industry also contributes to the depletion of timber, accounting for 32—25% of it, and produces a considerable amount of solid waste, estimated to be between 30—40%. Additionally, industry is responsible for a large amount of carbon dioxide emissions globally, estimated to be between 35—40%.

Sustainable construction will be accomplished by implementing greater adoption of reused, reclaimed, and recycled materials for construction coupled with reduced utilization of energy and other natural resources (Eze, Sofolahan and Omoboye 2023). The primary goal of sustainable construction is to establish an improved built environment that enhances the quality of human existence (Zabihi, Habib and Mirsaeedie 2012). In order to accomplish this objective, it is crucial to place a heightened emphasis on sustainability techniques. Sustainable materials and innovative building materials constitute integral components of sustainable construction. In addition to technological advancements and prevailing trends, incorporating innovative building materials substantially contributes to the progression of construction innovation.

Sustainable materials and innovative building materials constitute integral components of sustainable construction. New building materials and innovative technology help improve the construction process's efficiency. According to Delgado *et al.* (2015), the latest advanced materials can transform the process of building and renovating structures while simultaneously offering value by enhancing the performance and functionality of the building.

Innovative building materials are constantly being developed. Examples of such materials include sandstone that is 3D-printed, foam and aluminium, concrete reinforced with bamboo, bio-receptive concrete, bricks made from pollutants, plaited microbial cellulose, and super plasticisers (Kapliński 2018). They also include sustainable materials like laminated timber, timbercrete, self-healing concrete, rammed earth, pigmented (coloured) concrete, and hollow clay bricks. Adopting these materials (most of which are the construction industry's waste products) will save disposal cost and space and reduce harmful environmental pollutants. Carbon reduction in building materials starts in the manufacturing phase, when energy-efficient procedures and waste or recycled materials can be generated (Delgado *et al.* 2015).

Kumar and Kumar (2016) pointed out that the new material has several advantages, such as cost and time. However, it still lacks critical properties that make it marketable in the same manner that older materials do. Traditional building materials hold advantages over innovative ones regarding factors such as labour availability, cost, and reliability for consumers; it is only now that a significant number of clients and contractors are promoting the use of innovative materials in construction. Therefore, this research aims to assess the barriers to adopting IBM for sustainable construction.

1.3. Problem Statement

The exceptional nature of this research gap, both from a global perspective and within the specific confines of Lagos, Nigeria, originates in the intersection of factors influencing the adoption of

IBM for sustainable construction practices. The distinctive characteristics of Lagos and the broader Nigerian construction sector distinguish this circumstance from those encountered in other countries and regions. Nigeria, the most populous nation in Africa and a significant oil producer on the continent has experienced rapid and substantial transformations following the implementation of economic reforms in 2003 (Akadiri 2015). These transformations have reverberated across various sectors of the economy, encompassing the construction domain. Identified as a vital sector of the Nigerian economy, the construction industry plays a crucial role in contributing to the country's gross domestic product (GDP) (Owolabi and Faleye 2019). However, the construction industry is also one of the largest consumers of natural resources and energy (Egmond 2019), significantly contributing to environmental degradation. Currently, the construction sector holds a notable position, contributing approximately 5% to Nigeria's annual gross domestic product and representing a considerable proportion of one-third of the nation's aggregate fixed capital investment (Akadiri 2015). Furthermore, it is a source of employment for approximately 8% of the Nigerian workforce (Dada and Akpadiaha 2012).

Within this complex landscape, Lagos emerges as one of Africa's fastest-growing urban centres, intensifying the importance of sustainable construction practices in tackling the challenges arising from urbanization. The complexities associated with Lagos' urban expansion, encompassing infrastructural demands, resource scarcities, and environmental strains, accentuate the urgency of adopting sustainable building materials. Furthermore, Lagos' unique cultural, regulatory, and economic intricacies substantially influence the feasibility and dynamics of incorporating Innovative Building Materials, introducing specific challenges and opportunities within this urban context.

In Nigeria, the environmental effects stemming from construction activities have witnessed a notable surge, paralleling the nation's economic reforms and rapid urban expansion dating back to the early 1990s (Akadiri 2015). However, the precise magnitude of this impact remains a subject of ongoing discussion, primarily due to the absence of a comprehensive and methodical approach to collecting and analyzing information and data about the environmental impacts linked to the construction sector (Akadiri 2015). The global promotion of sustainable construction practices has been driven by the necessity to minimise the adverse effects of construction activities on the environment, as noted by Sagini, Dianga and Mbiti (2016).

Stakeholders engaged in building construction bear a crucial responsibility in mitigating the adverse impact of constructed spaces on the environment. In doing so, they play a pivotal role in advancing the overarching objectives of sustainability, encompassing its three fundamental dimensions: economic, environmental, and social. Given the considerable influence wielded by the construction industry, adopting sustainable materials emerges as a pragmatic starting point for building professionals as they embark on integrating sustainable principles into their construction projects (Akadiri and Olomolaiye 2012).

In recent years, sustainable or innovative building materials has been introduced into the construction industry to promote sustainable construction practices (Mandala 2019). These materials have the potential to significantly reduce the environmental impact of construction by reducing the use of natural resources and energy, minimising waste, and promoting sustainable development (Bamigboye *et al.* 2019). However, adoption of these materials in the Nigerian construction industry has been slow. The construction industry faces potential risks to its long-term sustainability due to the recognized insufficient adoption of innovation within its practices (Gambatese and Hallowell 2011).

Therefore, there is a need to evaluate the extent to which IBM is being adopted in the Nigerian construction industry to promote sustainable construction practices. Although research has been conducted on the topic in developed countries, more information on adopting IBM in the Nigerian construction industry is needed. The slow adoption of IBM in the Nigerian construction industry can be attributed to several factors, including a lack of awareness and knowledge about IBM among construction professionals and stakeholders, the high cost of IBM, the lack of regulations and standards for IBM in Nigeria, and the absence of local production and supply of IBM in Nigeria.

The slow adoption of sustainable or innovative building materials in the Nigerian construction industry has significant implications for sustainable development (Umar, Lembi and Emechebe 2021). Eze *et al.* (2021) argue that the failure to implement sustainable construction practices will result in the construction industry's ongoing contribution to environmental degradation, potentially leading to severe consequences for Nigeria's economy and society. In agreement with this notion, Owolabi and Faleye (2019) emphasise that the Nigerian construction sector has the potential for significant growth by embracing innovative practices.

Consequently, this study aims to bridge this knowledge gap by presenting empirical data on the present status of IBM implementation within the Nigerian construction sector. Furthermore, the study aims to recognise the factors that drive and hinder the adoption, benefits and practical strategies for promoting sustainable construction practices in Nigeria. The distinctive attributes of the Nigerian construction industry and the context of Lagos contribute to the uniqueness of the identified research gap. Factors such as economic prominence, rapid urbanization, resource availability, and regulatory intricacies combine to create a setting where the adoption of IBM for sustainable construction carries specific challenges and opportunities. Given the environmental impact, global warming, excessive resource consumption, waste generation, and pollution associated with the construction industry, sustainable technologies are increasingly critical for achieving the 17 United Nations' sustainable development goals (United Nations Department of Global Communications 2020). Notably, Goal 11 (sustainable cities and communities) and Goal 9 (fostering innovation) are particularly relevant and receive particular emphasis.

1.4. Research Aim

This research aims to assess the extent to which innovative building materials (IBM) are adopted for sustainable construction in the Nigerian construction industry. The research aims to gather information and insights regarding the current level of awareness, drivers, barriers, and benefits associated with adopting IBM in sustainable construction practices. Additionally, the research intends to provide recommendations and strategies for successfully implementing IBM in the Nigerian construction industry.

1.5. Research Questions

This research aims to provide answers to the following questions:

1. What is the level of awareness of some current available IBM used for sustainable construction in the Nigerian construction industry?
2. What drivers can improve the adoption of IBM for sustainable construction in Nigeria?
3. What are the barriers that affect the adoption of IBM for sustainable construction in the Nigerian construction industry?
4. What are the benefits of adopting IBM for sustainable construction in Nigeria?
5. What are strategies required for to successful adoption of IBM for sustainable construction in the Nigerian construction industry?

1.6. Research Objectives

This study's objectives are to:

1. Assess the level of awareness of some current available IBM used for sustainable construction in the Nigerian construction industry.
2. Investigate the drivers that can improve the adoption of IBM for sustainable construction.
3. Assess the barriers that affect the adoption of IBM for sustainable construction in the Nigerian construction industry.
4. Examine the benefits of adopting IBM for sustainable construction in Nigeria.
5. Determine strategies for successfully adopting IBM for sustainable construction in the Nigerian construction industry.

1.7. Scope of the study

This research project evaluates the implementation of IBM in sustainable construction within the Nigerian construction industry. The study is limited to registered construction professionals such as architects (Nigerian Institute of Architects (NIA)), builders (Nigerian Institute of Building (NIOB)), engineers (Nigerian Society of Engineer (NSE)), and quantity surveyors (Nigerian Institute of Quantity Surveyor (NIQS)) operating in Lagos State, located in the southwestern region of Nigeria. Lagos State was chosen as the research scope due to its status as Nigeria's economic and technological hub, which reflects the country's construction industry's progress and potential.

1.8. Significance of the study

The general perception is that adopting IBM for sustainable construction will lead to various environmental, economic, and social benefits. The concept of sustainability in construction involves implementing suitable approaches for material choice, sourcing, building methods, and design philosophy to enhance efficiency, diminish the environmental impact, minimise waste, and promote eco-friendliness, as Abolore (2013) stated. Energy efficiency, sound waste management, and carbon emission control are commonly emphasised in sustainable construction, which are valuable but relatively limiting approaches (Hazarika and Zhang 2019). Combining innovative concepts and environmental sustainability would stimulate inventive actions that prioritise environmental demands while promoting new developments and improvements in construction and building projects (Hazarika and Zhang 2019).

1.9. Structure of chapters

Chapter 1: General Introduction

This chapter contains and delivers the background of the study, the problem statement, the research questions, the aim and objectives, the significance of the study, the scope of the study and the structure of the thesis or dissertation.

Chapter 2: Literature Review

This chapter extensively reviews the literature on the Nigerian construction industry, sustainable construction, innovative building materials, drivers, benefits, barriers, and strategies for successfully adopting IBM for sustainable construction.

Chapter 3: Research Methodology

This chapter contains the methodology that was adopted to achieve the project's aims. It explains why the chosen research design, population, sample size, data collection instruments, data collection procedure, data presentation method and analysis were appropriate for the research questions and objectives.

Chapter 4: Data Analysis, Interpretation Results and Discussion of Findings

The focus of this chapter is to present a detailed analysis of the collected data. The collected data was analysed, interpreted and presented using IBM SPSS. The methods used were descriptive statistics and inferential statistics. This chapter also provides an in-depth discussion of the research study's findings. The findings are scrutinised and discussed against the contents of existing literature. This chapter also confirms that all the identified objectives were researched and that all research questions were answered.

Chapter 5: Conclusions and Recommendations

The final chapter of this research comprises a comprehensive summary of the research findings and the conclusions drawn based on the data analysis. Moreover, recommendations for implementing the research findings are provided, and suggestions for further research in this field are presented.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter reviewed several research studies conducted on innovative building materials. Firstly, this chapter discusses sustainable construction, the concept of innovative building materials, an explanation of six (6) selected innovative building materials and the drivers for adopting IBM for sustainable construction. Furthermore, this chapter examines the barriers affecting the adoption of IBM and the benefits of the adoption of IBM for sustainable construction. Lastly, this chapter looks deeper into the strategies for successfully adopting IBM for sustainable construction in the Nigerian construction industry.

2.2. Nigerian Construction Industry (NCI)

The Nigerian construction industry (NCI) has consistently played a significant role in the country's socioeconomic growth by facilitating infrastructure delivery. Oke, Aghimien and Adedoyin (2018) characterised the industry as a driving force behind Nigeria's economy. Saka and Lowe (2010) emphasised that its contribution is instrumental in driving economic development, as it makes a noteworthy contribution to the nation's GDP and generates substantial employment opportunities. In Nigeria, the construction sector plays a significant role by contributing more than 3% to the yearly gross domestic product and ranking as the fourth largest employer of workforce in the country (Onyia, Egbu and Ebohon 2022). The Nigerian construction industry exhibits a high level of complexity due to its diverse clients and contractors (Adamu, Bioku and Kolawole 2015). The NCI includes public and private clients and contractors such as main contractors, sub-contractors, one-person firms, and international companies. The industry encompasses diverse expertise, from low-technology firms to specialised professionals, including builders and civil engineers. It can be divided into two main divisions: building construction and civil engineering construction. The industry's activities are typically project-based and can occur within an organisation or as part of a construction programme (Adamu and Kolawole 2011).

Complex projects in the IBM often involve the participation of the federal government, such as road, sea, and airport construction, as well as heavy engineering projects. Approximately 64.9% of executed projects are undertaken by the federal government, followed by the state government, which is responsible for around 22.7% of the projects in the industry (Adamu, Bioku and Kolawole 2015). The industry's professionals, including architects, builders, engineers, estate surveyors, project managers, and quantity surveyors, form temporary and functional teams to carry out projects. These professionals must possess the necessary tools, knowledge, techniques, and skills, to achieve project objectives.

Despite its nature and significance, the construction industry has been observed to have a negative impact on the environment due to its reliance on non-renewable natural resources for production. This has resulted in environmental degradation, increased energy consumption, and pollution in many countries worldwide (Egmond 2019; Shittu 2021; Chen *et al.* 2022). Consequently, there is a growing demand for more sustainable construction (SC) practices. SC practices aim to deliver construction projects in a manner that is economically, socially, and environmentally responsible (Abidin 2010). The significance of advocating sustainability becomes paramount to ensure future generations' ability to fulfil their requirements while optimally utilizing the available finite natural resources (Brundtland Report 1987).

2.3. Sustainable construction (SC)

The conceptual evolution of sustainable development and its implementation in the construction industry has precipitated the emergence of sustainable construction practices (Koko and Bello 2020). Sustainable construction involves incorporating sustainable development principles into every stage of a building's life cycle, which includes planning, construction, sourcing and processing of raw materials, use, demolition, waste management, and production of construction materials (Yilmaz and Bakis 2015). Sustainable construction is an innovative approach adopted by the construction industry in response to concerns over increasing consumption patterns and the earth's limited capacity to sustain life (Dania 2016). Sustainable construction is the creation of an environmentally friendly and resource-efficient structure throughout its life. Sustainable construction aims to preserve the environment and improve people's social and economic welfare near construction projects (Willar *et al.* 2021). The pursuit of sustainability in the construction sector necessitates the diligent application of suitable practices during the selection and procurement of materials, the execution of construction methodologies, and the architectural design process (Abolore 2013). This goal aims to optimize performance, address environmental concerns, minimize waste generation, and advance environmental friendliness (Abolore 2013). Sustainability aims to avert the depletion of raw materials, energy, and water resources while mitigating environmental degradation throughout the life cycle of infrastructure and facilities (Buckley 2020). A sustainable construction project incorporates practices such as water conservation, energy efficiency optimisation, natural resource preservation, waste reduction, and providing healthier spaces for occupants while minimising construction activities' impact on human health and the environment (Kanika *et al.* 2016).

2.4. Innovative building materials (IBM)

The modern construction approach encompasses various aspects, including innovative building materials (IBM), innovative building technology, and innovative project finance, all closely intertwined with the principle of sustainability (Mewomo *et al.* 2023). Sustainable building materials, which are often synonymous with innovative building materials, form a crucial component within this context (Mesároš and Mandičák 2015). According to Umar, Khamidi and Tukur (2012), sustainable materials are economically and environmentally friendly and thermally sustainable; they require less energy consumption than conventional materials, emit low levels of harmful carbon (iv) oxide, and use renewable resources. Onyegiri and Ugochukwu (2016) contend that innovative building materials have no harmful environmental impact, can be substantially reused or recycled, and are considered eco-friendly. IBM has gained considerable attention in recent years for achieving sustainable construction. Adopting these materials is expected to enhance environmental sustainability, improve building performance, reduce construction waste, and promote energy efficiency (Bamigboye *et al.* 2019).

Badr (2013) identifies three sets of criteria used to evaluate the sustainability of building materials based on their life cycle. Furthermore, incorporating these characteristics in building materials ensures the environmental friendliness of the constructed buildings.

1) The pre-building phase (manufacture) entails pollution prevention, waste reduction, utilization of recycled content, consideration of embodied energy in materials, and incorporation of natural materials.
2) The building phase (use) involves minimizing construction waste, utilizing locally sourced materials, promoting energy efficiency, conserving water, selecting non-toxic materials, integrating renewable energy systems, and opting for durable materials.
3) The post-building phase (disposal) emphasizes the design for materials' reusability, recyclability, and biodegradability.

Additionally, Bamigboye *et al.* (2019) conducted a study examining approximately 150 innovative building materials, considering various design considerations such as performance, physical properties, environmental characteristics, installation requirements, and maintenance factors. Figure 2.1 illustrates some of the properties associated with IBM.

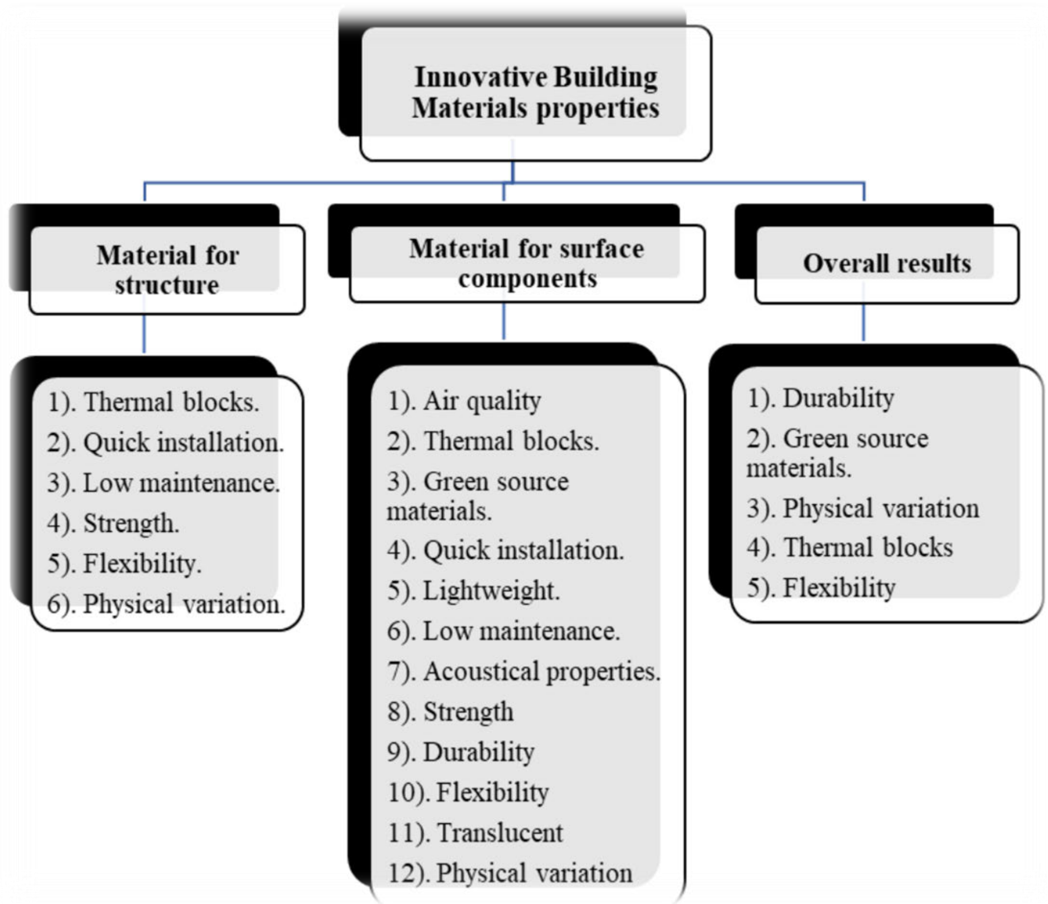

Figure 2. 1: The properties of IBMs (Mandala 2019)

IBM examples provided by Kapliński (2018) encompass a range of materials, including 3D printed ceramics, 3D printing technology, bamboo reinforced concrete, aluminium foam, laminated wood, pollution-absorbing concrete, bricks made from pollutants, superplasticisers, and plaited microbial cellulose.

To be more particular, the understudied material was shortlisted for six innovative building materials.

2.4.1. Pigmented concrete

Pigmented concrete is an innovative and sustainable building material that provides numerous benefits for sustainable construction and the built environment's future. It is an appealing option for many construction projects because it combines sustainability, design, and durability. Pigmented or coloured concrete is used to make excellent surfaces in civil construction (EL-Awadly, Sharobim and Hussein 2015). The capacity to colour concrete with a spectrum of colours ranging from yellow, orange, red, and blue to green enhances the visual appeal of architectural forms. It offers intriguing possibilities for creative design exploration. The employment of digitally supervised and precisely calibrated dosage technology facilitates the attainment of uniform pigmentation levels (EL- Awadly, Sharobim and Hussein 2015). Colouring concrete enhances the local environment, yielding an urban panorama characterized by its bold, luminous, and inspiring attributes. The constituents of pigmented concrete are cement, fine aggregates, coarse aggregate, and pigment. Coloured concrete with various colours has recently been employed in constructing new structures or restoring existing buildings and quadrangles. This coloured pigment concrete has the same features as ordinary concrete, such as durability, high strength, and weather resistance (Maruthachalam *et al.* 2020). Coloured concrete requires a unique method of finishing and curing to produce uniform colour and maintain uniform moisture content across the surface of the concrete (EL- Awadly, Sharobim and Hussein 2015). Pigmented concrete is used in several places, such as indoor and outdoor buildings, crosswalks, and quadrangles.

The advantages and disadvantages of pigmented concrete, as outlined by EL- Awadly, Sharobim and Hussein (2015), encompass:

Advantages of pigmented concrete

1. Employing coloured pigments does not entail any construction-related risks.

2. A minor concentration of colour yields a compressive strength value closely approximating that of the control mix.
3. Even a tiny proportion of pigments can substantially alter concrete colour, transforming it from grey to a different colour.

Disadvantages of pigmented concrete

1. When a substantial quantity of coloured pigments is introduced, there is an observable decline in the material's compressive strength.
2. Elevating the concentration of coloured pigments within the concrete mixture can diminish its slump and induce alterations in workability.
3. The employment of white cement results in a more vivid and robust concrete colouration; however, formulations incorporating white cement exhibit a diminished capacity for compressive strength.

2.4.2. Light-generating concrete

Artificial light consumption, particularly in urban areas, contributes to carbon footprints and global warming. Light-generating or light-emitting concrete (LTC) allows light to pass through opaque concrete, lowering building energy consumption. The conventional concrete used in the construction sector is grey and has a high density with a suitable hydrate microstructure; due to this, light cannot pass through it (Sawant, Jugdar and Sawant 2014; Sundari and Shriswarnambigai 2021). Light-generating concrete, light-emitting concrete or transparent concrete, translucent concrete or light-transmitting concrete is a building material made from concrete that has the unique property of emitting light through optical elements such as optical fibres (Kavya, Karthik and Sivaraja 2016; Reddy, Rama Prasad and Jogi 2020; Luhar *et al.* 2021). Materials used for light-emitting concrete are cement, fine aggregate, coarse aggregate, and optical fibre (Kavya, Karthik and Sivaraja 2016; Kumar *et al.* 2018; Sundari and Shriswarnambigai 2021). In Figure 2.2, a concrete wall with light-emitting properties is depicted.

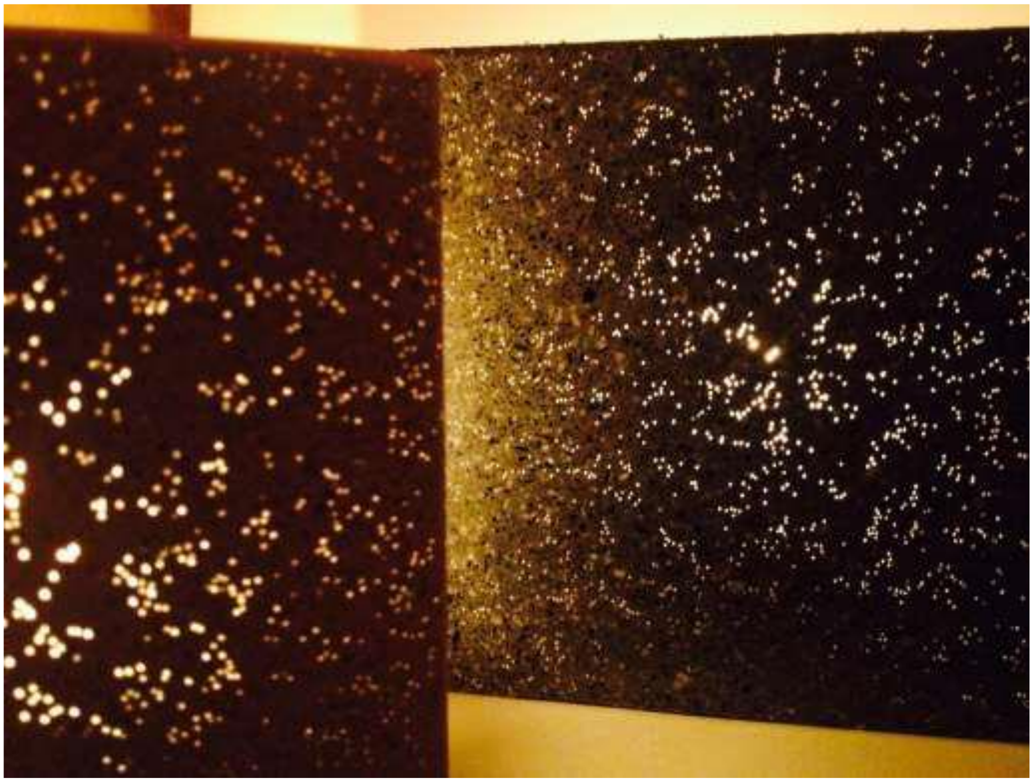

Figure 2. 2: Light-generating concrete/light-transmitting concrete. Adopted from (Reddy, Rama Prasad and Jogi 2020).

According to Gandhi (2018), light-generating or light-transmitting concrete can be utilised in various ways, including:

1. As walls for both interior and exterior settings.
2. It can also be used in facades and interior partitions as thin panels.
3. The concrete enhances visibility in dark subway stations and can be incorporated into aesthetic furniture.
4. Light-transmitting concrete can illuminate sidewalks during nighttime hours.
5. It can be used as walls in restaurants, clubs, and other establishments to show the number

of customers inside.

Advantages of Light-generating concrete

According to Gandhi (2018),

1. It provides excellent architectural features for a good visual view of the building.
2. Due to its light transmission properties, it is entirely environmentally friendly, and energy usage may be decreased. It is also a necessity for green construction.
3. The use of translucent concrete in construction can help save energy.

According to Valambhiya, Tuvar and Rayjada (2017),

4. Contributes positively to energy savings.
5. The light-transmission property of concrete is independent of its thickness.
6. Concrete is embedded with optical glass fibres flowing in a matrix while retaining the concrete's strength.
7. White or colourful illumination elements can generate special light and colour effects. Designers and architects may use light-transmitting concrete to turn new concepts into gorgeous realities.

Disadvantages of Light-generating concrete

Regarding the setbacks of light-generating concrete, according to Gandhi (2018) and Patil and Patil (2015), the material is a precision material, and proper methods must be followed. Ensuring the continuity of optical strands in the event of breakage within the product is of paramount importance, as neglecting this aspect could become a significant concern for the overall property (Patil and Patil 2015; Jayaraman *et al.* 2020). Also, due to the limited uses and lack of market awareness of light-generating concrete, the cost of light-generating concrete on a small scale is prohibitive (Patil and Patil 2015; Valambhiya, Tuvar and Rayjada 2017).

2.4.3. Cross -laminated timber

Cross-laminated timber (CLT) is an innovative engineered wood-based building product with substantial economic and environmental benefits over conventional building materials. Gong (2019) states that this substance is a viable alternative to concrete, masonry, and steel frameworks for specific applications. Additionally, it serves as a complement to the current light frame and heavy timber options available. According to Sanborna *et al.* (2019), CLT is a moderately strong and stiff material that can satisfy the requirements for constructions subjected to a wide range of loading situations. Wang and Yin (2021) noted that cross-laminated timber (CLT) typically comprises uneven layers, including 3, 5, 7, and possibly more. The layers have widths ranging from 0.6 m to 3 m, lengths up to 18 m, and thicknesses up to 508 mm. CLT is used in floors, walls, and other structural components. CLT structures are sustainable from raw material extraction to production up to usage, disposal, and recycling (Sandoli *et al.* 2021). According to Bharathi, Dhanalakshmi and Manickam (2020), the merits of CLT include design flexibility, eco-friendly, prefabrication, light building material and lightweight material. Figure 2.3 depicts Cross-laminated timber (CLT) arranged in five distinct layers, while Figure 2.4 showcases buildings constructed using Cross-laminated timber (CLT).

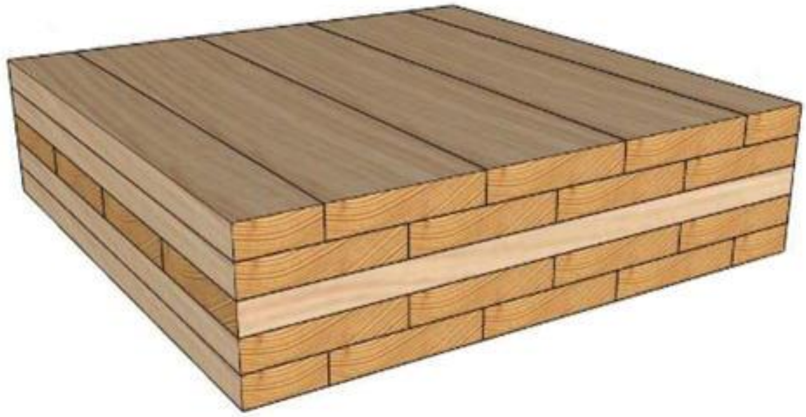

Figure 2. 3: Cross-laminated timber (CLT). Adopted from (Wang and Yin 2021)

Figure 2. 4: CLT Buildings. Adopted from (Bharathi, Dhanalakshmi and Manickam 2020)

The main advantages of CLT, according to Sandoli *et al.* (2021), are:

1. CLT panels have a higher load-bearing capability in proportion to their weight than most other construction materials, allowing for the construction of high-rise structures with

lower masses.

2. The cross-laminated structure of CLT offers load-bearing ability in both in-plane and out-of-plane directions, making it suitable for use as vertical shear walls (membranes), floors (plates), and other structural applications such as bridges, sports arenas, curved elements, and more.
3. CLT panels exhibit high levels of strength and stiffness in the in-plane direction, even when the panel is divided into longitudinal and transverse orientations.
4. Good dimensional stability against moisture variations: Crossing layers prevent shrinkage and swelling compared to timber-based products.
5. CLT is characterised by its high energy efficiency and capacity to store moisture and thermal energy.
6. CLT is an eco-friendly, recyclable, and renewable building material with a long service life, provided it is suitably safeguarded against moisture.
7. Architectural design is not limited by workability, slenderness, or diverse sizes.

2.4.4. Timbercrete

With its environmentally friendly, sensitive, and sustainable properties, timbercrete has received several awards as a building material and masonry product for creating bricks, blocks, panels, and pavers (Timbercrete Pty. Ltd 2015; Hammood 2020). It has many advantages over concrete, sandcrete blocks, or bricks. Timbercrete comprises a blend of carefully selected sand, a cementitious binder (cement), water, and cellulose materials such as sawmill waste (sawdust). The principal component of timbercrete is cellulose, a lightweight material obtained from sources such as sawdust. The product has various distinct advantages such as aesthetics, low cost, thermal efficiency, user friendliness, low carbon content, fire resistance, and low capital equipment cost

(Timbercrete Pty. Ltd 2015), apart from just using sawdust to achieve a lightweight material. Using sawdust in timbercrete, which involves blending sawdust without burning it, is an acceptable way of disposing of waste (sawdust).

Burning sawdust breaks down the material and releases carbon dioxide into the atmosphere, contributing to greenhouse gases. These emissions harm the environment. Excess carbon in the atmosphere leads to various health hazards. Using timber waste to produce timbercrete prevents the destructive cycle of burning sawdust and releasing carbon dioxide into the atmosphere. Timbercrete acts as a carbon trap, preserving the cellulose waste (sawdust) within the concrete and preventing it from breaking down. As a result, timbercrete is an environmentally sustainable building material that helps reduce carbon emissions. Timbercrete's embodied energy is reduced as it does not require kiln firing. The need for artificial drying processes, which consume significant energy and generate a poisonous mixture of sulphuric, carbon monoxide, and carbon dioxide gases is also eliminated. Moreover, the manufacturing process of timbercrete requires less energy due to the use of less equipment and locally sourced raw materials, such as sand and sawdust (Timbercrete Pty. Ltd 2015). Figure 2.5 illustrates timbercrete bricks in various colours, sizes, and shapes. In Figure 2.6, an image showcases structures constructed using timbercrete as the primary building material.

Figure 2. 5: Timbercrete in various colours, sizes and shapes. Adopted from (Timbercrete Pty. Ltd 2015)

Figure 2. 6: Timbercrete buildings. Adopted from (Timbercrete Pty. Ltd 2015)

The benefits of timbercrete, according to Timbercrete Pty. Ltd (2015), are:

- captures carbon that would otherwise become greenhouse gases in the atmosphere.
- has a significantly lower embodied energy compared to clay bricks,

- has better insulation value (R) compared to traditional masonry bricks, panels and blocks.
- has workable thermal mass for storing and releasing thermal energy.
- has superior engineering characteristics, including improved resilience and higher breaking load resistance compared to non-reinforced clay and concrete products.
- is significantly lighter, weighing 2.5 times less than concrete and clay.
- has a distinct quality of workability that enables it to be nailed and screwed like timber while retaining the advantages of conventional masonry.
- offers superior fire resistance and surpasses the highest achievable fire rating (FRL240/240/240) when it has a thickness of 190 mm, outperforming standard construction materials like concrete blocks, clay, timber, and steel.

2.4.5. Smart glass windows

Smart glass is a novel material that modulates its heating properties based on how heat and air conditioning are utilised in the home. Smart glass can help with sustainable construction by lowering the demand for artificial lighting and heating, enhancing building performance, and contributing to a more energy-efficient and sustainable built environment. Furthermore, smart glass improves a building's aesthetic appeal by offering a sleek and modern appearance while simultaneously performing a functional purpose. According to analysts, smart glass allows for decreased heat losses, cheaper ventilation and lighting expenses and is an alternative to louvre shades and curtains (Gamayunova, Gumerova and Miloradova 2018). Figure 2.7 displays Smart glass window.

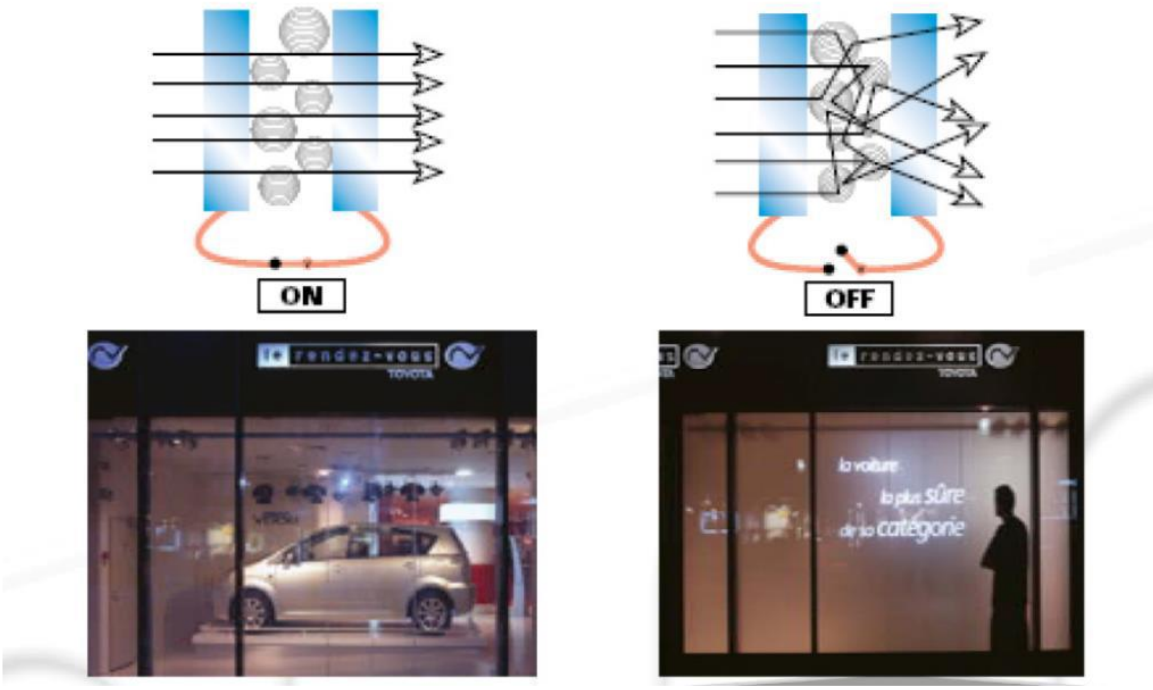

Figure 2. 7: Smart glass window. Adopted from (Gamayunova, Gumerova and Miloradova 2018).

Smart glass products have several environmental benefits (Sottile 2011); they include:

1. Smart glass saves energy by regulating solar energy and capturing sunshine.
2. It also enhances occupant well-being, productivity, and facility security.
3. Smart glass is essential to high-performance buildings that are healthy, enjoyable, and safe places to work and live while consuming minimal energy.
4. Anti-eavesdropping and radio frequency (RF) shielding features are also available for smart glass devices.
5. By definition, smart glass windows, doors, skylights, and dividers provide immediately visible security.
6. Smart glass solutions also help to improve indoor air quality, which has health advantages, especially in in-patient care settings where nosocomial infections are a concern.

7. Smart glass that harvests daylight can cut energy costs while improving occupant well-being.
8. Smart glass products may harvest heat on cold days (saving energy for heating) and reject heat on hot days (saving energy for cooling), thus reducing energy for cooling.

2.4.6. Three dimensional (3D) printed graphene

3D graphene has the potential to be an innovative building material. Graphene, a one-atom-thick two-dimensional carbon material, exhibits exceptional mechanical, thermal, electrical, and physicochemical capabilities (Silva *et al.* 2021). The development of 3D graphene, a structure composed of multiple graphene layers, expands on these properties and opens up new avenues for its application in the construction industry. Graphene is one of the emerging materials with a high potential for mechanical property improvement. Since the discovery of graphene by Novoselov et al. in 2004 (Novoselov *et al.* 2004), it has received a great deal of interest in the field of materials. Graphene oxide is one of the most widely researched chemical derivatives of graphene due to its water solubility and simple, scalable synthesis. The 2D and 3D printing of nanomaterials, such as graphene oxide and its composites, is a fast-increasing research field (Fernandes, Lynch and Berry 2020). 3D graphene has been discovered to have high mechanical strength and thermal conductivity, making it a viable alternative to traditional building materials like concrete and steel. Furthermore, its electrical conductivity and energy storage potential make it an appealing option for building applications that require energy generation or storage.

3D printing, also known as additive manufacturing (AM), has transformed the manufacturing process by creating complex objects with unique properties previously challenging to accomplish with traditional processing methods (Guo, Ruicong and Bai 2019). It provides several benefits, including near-complete design freedom, flexibility, complexity, and high sustainability. Almost any material, including metals, ceramics, and polymers, may be utilised as raw materials for 3D printing to create various stereoscopic structures (Guo, Ruicong and Bai 2019).

2.5. Drivers for the adoption of IBM for sustainable construction

The construction industry has a significant environmental impact, and as a result, there is a growing demand for more sustainable building practices (Isang 2023). One of the primary motivators for adopting IBM is reducing construction's environmental footprint and promoting a more sustainable future. With this in mind, using these materials is becoming increasingly popular as they provide various benefits that help address the challenges associated with traditional construction methods. Tunji-Olayeni *et al.* (2018) outlined five key factors that significantly drive sustainable construction. These encompass the demand of clients, international pressure, the role of corporate social responsibility, competitive dynamics, and the efficiency of cost management. Owolabi and Faleye (2019) highlighted seven fundamental elements that foster innovation: client demands, advancements in information and communication technology (ICT), emerging design trends, heightened productivity, cost reduction, enhanced efficiency, environmental sustainability, and governmental regulations. Ozorhon *et al.* (2010) and Gambatese and Hallowell (2011) also found that cost reduction, competitive advantage, improved quality, and increased productivity drive the adoption of IBM technology for sustainable construction in developed nations and can inspire innovation within the industry. The economic benefits of innovative building materials are also a significant motivator for their widespread use. With the rising cost of traditional building materials, using more sustainable alternatives can help reduce construction costs and make sustainable building practices more accessible and affordable to a broader range of clients (Kaburu 2017). Brandon and Lu (2008) extensively studied the role of clients and end-users in theoretically and empirically contributing to innovation. Educating clients on the advantages of using IBM can drive demand and growth in the IBM market and sustainable construction. The contribution of building component firms and building materials companies to driving innovation in the construction industry is significant.

Research and development activities play a significant role in exploring the drivers of IBM in the construction industry. Other factors, such as promoting environmental sustainability through reducing waste, energy consumption, and carbon emissions, are also drivers of innovation (Ozorhon *et al.* 2010; Qi *et al.* 2010). Reducing carbon emissions connected with construction is one of the key drivers for adopting new building materials. This is especially significant given the growing concern about climate change and the need to minimise greenhouse gas emissions. Materials with a reduced carbon footprint than standard concrete and steel, such as cross-laminated timber (CLT) and engineered wood products, appeal to companies wishing to reduce their environmental impact. Table 2.1 lists 14 drivers for promoting IBM adoption in the construction industry.

Table 2. 1: Summary of the drivers of the adoption of IBM

Code	Drivers	References
D1	Client's requirement	Owolabi and Faleye (2019); Kulatunga et al. (2011); Ozorhon et al. (2010)
D2	End-user requirement	Kulatunga et al. (2011); Ozorhon et al. (2010)
D3	Demand-pull (client) vs capability-push (contractor)	Ozorhon et al. (2010)
D4	Availability of manufacturing firms	Kulatunga et al. (2011); Ozorhon et al. (2010)
D5	Developments in ICT/Technology-push	Owolabi and Faleye (2019); Ozorhon et al. (2010)
D6	Design/Aesthetics trends	Ozorhon et al. (2010); Owolabi and Faleye (2019)
D7	Increase performance and productivity (cost saving, desired duration, improved quality)	Owolabi and Faleye (2019); Ozorhon et al. (2010); Gambatese and Hallowell (2011)
D8	Reduction in cost	Owolabi and Faleye (2019)
D9	Availability of IBM suppliers	Kulatunga et al. (2011); Ozorhon et al. (2010)
D10	Procurement system for IBM	Kulatunga et al. (2011); Ozorhon et al. (2010)
D11	Improved efficiency of the firm	Gambatese and Hallowell (2011); Ozorhon et al. (2010); Owolabi and Faleye (2019)

Code	Drivers	References
D12	Environmental sustainability	Ozorhon et al. (2010); Owolabi and Faleye (2019)
D13	Government regulations	Kulatunga et al. (2011); Ozorhon et al. (2010); Owolabi and Faleye (2019)
D14	Competitive advantage	Owolabi and Faleye (2019); Gambatese and Hallowell (2011)

Author's compilation (2023)

2.5.1 Roles of Stakeholders

Meng and Brown (2018) highlight that a construction project requires the involvement of various participants, such as project clients, design teams, management consultants, main contractors, subcontractors, and suppliers. These participants execute various roles in a building project, according to the Chartered Institute of Building's (CIOB) Code of Practice for Project Management for Building and Development (Chartered Institute of Building 2010). The client establishes the project's objectives and needs. The main contractor and subcontractors deliver products, while the design team and management consultant provide services.

Sustainable development and green design require the participation of all relevant stakeholders. According to Iwaro and Mwasha (2013), stakeholders in this field can be categorised into five groups: government, clients, researchers corporate institutions, and professional bodies. Their understanding or lack of understanding of sustainable practices can impact the promotion of sustainability and shape the demand for sustainable construction and IBM. Clients drive green design and construction projects based on their sustainability needs but often need more knowledge (Pitt *et al.* 2009). Corporate institutions are active in sustainability research and have created guidelines for corporate social responsibility (CSR), which can improve their reputation and competitiveness. The government's role in promoting sustainable design and construction is crucial, but it often relies on input from corporations and professional bodies. Professional bodies, such as architects, engineers, and planners, have a high level of knowledge in green design and construction due to formal training and are responsible for educating clients, corporations, and the government (Nikyema and Blouin 2020). Researchers are essential in guiding sustainable development by providing evidence-based insights (Pitt *et al.* 2009). Evaluating the understanding and opinions of all stakeholders involved in sustainability, sustainable design, and construction, including the adoption of IBM technology, is crucial for the complete adoption and implementation of sustainable development practices.

2.6. Barriers affecting the adoption of IBM for sustainable construction

Research on barriers to adopting innovative/sustainable/green building materials seeks to define, comprehend, and suggest remedies for those barriers. These studies have revealed that barriers exist in developed and developing nations (Abadi 2014; Xue *et al.* 2014; Kaburu 2017; Nikyema and Blouin 2020; Eze *et al.* 2021). The construction industry uses IBM but still faces many challenges in its implementation (Eze *et al.* 2021).

The construction industry in Nigeria is rapidly expanding, and there is an urgent need to adopt sustainable building practices and materials to reduce the industry's environmental impact (Aghimien *et al.* 2018). IBM is essential to this transition, providing better environmental performance and cost savings over traditional materials. Even with their numerous advantages, the use of innovative building materials in the NCI still needs to be improved.

A lack of awareness and understanding of these materials, limited access to financing, and a need for a supportive regulatory environment are all impeding the adoption of IBM in Nigeria (Alabi 2012). Implementing sustainable construction is hampered by the fact that most key actors do not know its potential benefits (Aigbavboa, Ohiomah and Zwane 2017). Traditional building materials are still preferred in many cases due to a lack of familiarity with innovative materials and the perception that IBMs are more expensive. Furthermore, the construction industry in Nigeria is dominated by small and medium enterprises (SMEs), which frequently need more resources, knowledge, and expertise to incorporate innovative materials into their projects.

Another significant impediment is the need for a supportive regulatory environment (Owolabi and Faleye 2019). Building codes and standards in Nigeria are frequently outdated and must adequately reflect the most recent innovations in building materials and technologies. This can make it difficult for construction companies using more sustainable materials to obtain the necessary approvals and certifications.

Also, the cost of IBM, particularly for SMEs, can be a substantial obstacle for many construction enterprises. While the long-term expenses of these materials are frequently lower due to their better performance and durability, the initial expenditure might be significant. On many occasions, construction firms need access to the capital necessary to make this investment.

Also, the fragmented nature of the construction industry, according to Ozorhon *et al.* (2010); Gambatese and Hallowell (2011); Eze *et al.* (2019); Owolabi and Faleye (2019) can make it challenging to ensure consistent and standardised use of IBM across different projects. This can result in a lack of confidence in these materials, as building professionals and owners may need to be more familiar with their performance and behaviour. Table 2.2 lists 31 barriers to IBM adoption in the construction industry.

Table 2. 2 Summary of the barriers to the adoption of IBM.

Code	Barriers	References
BA1	Lack of awareness and knowledge	Abidin (2010), Owolabi and Faleye (2019), Eze et al. (2019), Ozorhon et al. (2010), Nikyema and Blouin (2020), Abisuga and Oyekanmi (2014), Hwang and Tan (2012), Hwang and Ng (2013), Ayarkwa et al. (2022)
BA2	Lack of top management commitment	Abidin (2010), Eze et al. (2019), Abisuga and Oyekanmi (2014)
BA3	Cost & economic viability	Abidin (2010), Owolabi and Faleye (2019), Abisuga and Oyekanmi (2014)

Code	Barriers	References
BA4	Lack of industry regulations and codes	Ozorhon et al. (2010), Gambatese and Hallowell (2011)
BA5	Characteristics of the construction industry: Project-based nature and Price-based competition	Ozorhon et al. (2010), Gambatese and Hallowell (2011)
BA6	Risk of failure	Gambatese and Hallowell (2011)
BA7	Passive culture	Abidin (2010), Owolabi and Faleye (2019)
BA8	Lack of local authority and government involvement	Abidin (2010), Ozorhon et al. (2010), Gambatese and Hallowell (2011), Nikyema and Blouin (2020), Abisuga and Oyekanmi (2014), Hwang and Tan (2012), Hwang and Ng (2013)
BA9	Lack of public interest and buyers' demand.	Abidin (2010), Abisuga and Oyekanmi (2014), Hwang and Tan (2012), Hwang and Ng (2013)
BA10	Employees' resistance	Ozorhon et al. (2010)
BA11	Status quo in rules and regulations	Abidin (2010), Owolabi and Faleye (2019), Ozorhon et al. (2010), Gambatese and Hallowell (2011)
BA12	Availability of green/ sustainable building materials.	Abidin (2010), Dzokoto and Dadzie (2013), Nikyema and Blouin (2020), Abisuga and Oyekanmi (2014)
BA13	Learning/training period.	Abidin (2010), Nikyema and Blouin (2020), Abisuga and Oyekanmi (2014)
BA14	Associating sustainable concepts with luxury living.	Abidin (2010)
BA15	Cultural aversion to change	Owolabi and Faleye (2019)
BA16	Project delivery method	Ozorhon et al. (2010), Gambatese and Hallowell (2011)
BA17	The perception that the industry is doing well without it	Owolabi and Faleye (2019), Ozorhon et al. (2010)
BA18	Poor funding for research and development, training and education.	Owolabi and Faleye (2019), Eze et al. (2019), Ozorhon et al. (2010), Nikyema and Blouin (2020), Abisuga and Oyekanmi (2014), Hwang and Tan (2012), Hwang and Ng (2013), Ayarkwa et al. (2022)
BA19	Lack of end-user involvement	Owolabi and Faleye (2019), Eze et al. (2019), Ozorhon et al. (2010), Abisuga and Oyekanmi (2014)
BA20	Poor technical knowhow	Owolabi and Faleye (2019), Eze et al. (2019), Gambatese and Hallowell (2011), Abisuga and Oyekanmi (2014)
BA21	Temporary nature of construction (one-off construction industry)	Owolabi and Faleye (2019), Eze et al. (2019), Gambatese and Hallowell (2011)
BA22	Fragmented nature of construction	Owolabi and Faleye (2019), Eze et al. (2019), Ozorhon et al. (2010), Gambatese and Hallowell (2011)
BA23	Lack of qualified staff	Eze et al. (2019), Ozorhon et al. (2010), Nikyema and Blouin (2020), Abisuga and Oyekanmi (2014), Hwang and Tan (2012), Hwang and Ng (2013)

Code	Barriers	References
BA24	Lack of government policy	Eze et al. (2019)
BA25	Poor innovation motivators in an organisation	Eze et al. (2019)
BA26	Excessive subcontracting of construction works	Eze et al. (2019)
BA27	Poor coordination and communication among project participants	Eze et al. (2019), Gambatese and Hallowell (2011), Hwang and Tan (2012), Hwang and Ng (2013), Ayarkwa et al. (2022)
BA28	Lack of clear benefits	Owolabi and Faleye (2019), Ozorhon et al. (2010), Gambatese and Hallowell (2011), Nikyema and Blouin (2020), Hwang and Tan (2012), Hwang and Ng (2013)
BA29	Lack of sustainability measurement tools	Dzokoto and Dadzie (2013)
BA30	Lack of exemplar demonstration projects	Dzokoto and Dadzie (2013)
BA31	Unwillingness to change	Eze et al. (2019), Ozorhon et al. (2010), Gambatese and Hallowell (2011)

Author's compilation (2023)

2.7. Benefits of the adoption of IBM for sustainable construction

Employing IBMs offer several advantages that help reduce construction's environmental impact and promote a more sustainable future. The advantages of IBM are not limited to cost savings. However, they should also include the reuse of materials, reduced environmental impact, thermal efficiency, the utilisation of renewable resources, low harmful emissions, and economic sustainability. This study builds upon the findings of Darko *et al.* (2018), highlighting the key advantages associated with IBM-incorporated buildings, including reduced lifecycle costs, decreased energy consumption, enhanced occupant well-being and comfort, increased overall productivity, as well as environmental preservation. Simpeh and Smallwood (2018), identify one of the primary benefits of integrating IBM in construction: decreased operating expenses, increased asset value and profitability, improved well-being and comfort of occupants, and enhanced employee productivity and job satisfaction. Plessis (2002) emphasizes that enhancing the construction product quality, improving construction process efficiency, and ensuring safety standards are among the critical strategies for sustainable construction.

Building operations can promote energy efficiency and conservation by using non-toxic materials with a longer lifespan and with proper waste management. This leads to the adoption of biodegradable, recyclable, and reusable building materials. Using these innovative materials can lower transportation costs, decrease carbon emissions, and reduce material costs while providing employment and skill development opportunities.

Increasingly, construction activities negatively impact the environment. Sustainable building innovation can be accomplished by exploring ways to increase resource efficiency and environmental protection (Qi *et al.* 2010). One of the significant benefits of new building materials is their ability to reduce carbon emissions associated with traditional construction methods. Compared to traditional concrete and steel, materials such as cross-laminated timber (CLT) and engineered wood products have a reduced carbon footprint (Sandoli *et al.* 2021). These materials can also help improve building energy efficiency by lowering the energy required for heating and cooling and the carbon emissions associated with energy production.

In addition to their environmental benefits, innovative building materials can also improve the overall quality of construction, that is, improved construction project outcomes (Plessis 2002; Abolore 2013; Darko *et al.* 2018; Eze *et al.* 2021). For example, materials such as CLT offer high structural strength and stability, making them ideal for use in tall buildings and large-scale construction projects (Bharathi, Dhanalakshmi and Manickam 2020). This can help improve the safety and longevity of buildings, reduce the need for maintenance and repairs and provide a more secure and sustainable built environment.

Also, it is crucial to encourage partnerships and collaboration among the numerous players involved in the construction sector to ensure the successful adoption of IBM. Collaboration between the government, the commercial sector, academic institutions, and building professionals can be used to encourage the development of sustainable building materials and their increased use in the construction industry.

In conclusion, adopting IBM is essential to the growth of a sustainable construction industry. These materials provide a variety of benefits that help to promote a more sustainable future for the built environment, among them including environmental protection (Plessis 2002; Abolore 2013; Darko *et al.* 2018; Eze *et al.* 2021), sustainable and environmentally friendly (Abolore 2013; Bamigboye *et al.* 2019); efficient use of materials (Eze *et al.* 2021); low operating and maintenance cost (Simpeh and Smallwood 2018) and efficient use of energy (Darko *et al.* 2018). Table 2.3 presents a list of 18 benefits of promoting IBM adoption in the construction industry based on a careful literature review.

Table 2. 3: Summary of benefits of the adoption of IBM

Code	Benefits	References
BE1	Sustainable and environmentally friendly	Bamigboye et al. (2019); Abolore (2013)
BE2	Low operating and maintenance cost	Eze et al. (2021); Plessis (2002); Bamigboye et al. (2019); Simpeh and Smallwood (2018)
BE3	Increase employees' productivity and reduce absenteeism	Abolore (2013); Simpeh and Smallwood (2018); Eze et al. (2021)
BE4	Reduction of building material wastage	Plessis (2002); Abolore (2013)
BE5	Increasing the use of recycled waste as building materials	Plessis (2002); Bamigboye et al. (2019)
BE6	Improved quality of air	Eze et al. (2021)
BE7	Lower lifecycle costs	Darko et al. (2018); Eze et al. (2021); Plessis (2002)
BE8	Improves the quality of life	Simpeh and Smallwood (2018); Plessis (2002); Eze et al. (2021)
BE9	Efficient use of energy	Darko et al. (2018); Plessis (2002); Eze et al. (2021)
BE10	Efficient use of materials	Abolore (2013); Eze et al. (2021);
BE11	Water conservation	Plessis (2002)

Code	Benefits	References
BE12	Waste minimisation	Eze et al. (2021); Plessis (2002); Bamigboye et al. (2019); Abolore (2013)
BE13	Environmental protection	Bamigboye et al. (2019); Eze et al. (2021); Plessis (2002); Abolore (2013)
BE14	Protection of the ecosystem and biodiversity	Eze et al. (2021)
BE15	Improved construction project outcomes	Plessis (2002); Eze et al. (2021); Abolore (2013), Darko et al. (2018)
BE16	Preventing global warming	Eze et al. (2021)
BE17	Partnering with countries with a better green rating and exchange of know-how	Eze et al. (2021)
BE18	Allows for integration of technology into construction	Eze et al. (2021)

Author's compilation (2023)

2.8. Strategies for successfully adopting IBM for SC in the Nigerian construction industry.

The Nigerian construction industry has the potential to significantly impact the country's economy, employment, and environment. However, the industry must employ IBM, which provides sustainable alternatives to traditional construction methods. Careful planning and strategic implementation are required to adopt these materials and achieve their benefits successfully. According to Hwang and Tan (2010), adopting sustainable construction practices and green building techniques can alleviate these challenges.

Education and raising awareness among essential stakeholders are the critical strategies for successfully adopting IBM. This involves construction professionals, contractors and the public at large, in order to guarantee that they understand the benefits and potential of these materials. This can be accomplished through the utilisation of training programs, workshops, and seminars, as well as marketing and communications materials.

Another effective strategy is to promote research and development (Shittu 2021) in environmentally friendly building materials. This can broaden the choice of available construction materials and improve their performance and quality. To accomplish this, the government and private sector can work together to provide support and funding for research and development activities and stimulate the establishment of research organisations and university programs.

The industry can also benefit from establishing national standards and laws that promote using IBM. This will help guarantee that these materials are utilised consistently and safely and provide a framework for their development and deployment. Furthermore, providing incentives, such as tax credits and grants, can encourage the broader adoption of these materials and promote their incorporation into mainstream construction practices. Table 2.4 lists 14 proposed strategies for promoting IBM adoption in the Nigerian construction industry.

Table 2. 4: Summary of strategies for the adoption of IBM

Code	Strategies	References
S1	Owner/client support	Gambatese and Hallowell (2011)
S2	Public awareness creation through workshops, seminars, and conferences	Sagini (2020); Chan, Darko and Ameyaw (2017); Mairami, Sanni and Jibrin (2020)
S3	Mandatory governmental policies and regulations encouraging the use of IBM	Ozorhon et al. (2010); Chan, Darko and Ameyaw (2017); Marut, Anigbogu and Daniel (2020); Mairami, Sanni and Jibrin (2020)
S4	Promotion of sustainable construction by the construction industry	Shittu (2021)
S5	Appraisal of building code and establishment of sustainable building code	Sagini (2020); Shittu (2021); Mairami, Sanni and Jibrin (2020)
S6	Reducing resistance due to fear of changing traditional building materials	Mairami, Sanni and Jibrin (2020)
S7	Availability of institutional framework for effective implementation of IBM	Chan, Darko and Ameyaw (2017)
S8	Adequate training centres with adequate funding for research and development	Shittu (2021)
S9	Supportive work environment	Ozorhon et al. (2010)
S10	Establishment of enticements to inspire invention in sustainable construction	Shittu (2021)
S11	Regular inspections and monitoring of works with set rules and legislations.	Shittu (2021)
S12	Use of resources from a more sustainable source	Shittu (2021)

Code	Strategies	References
S13	Provision of sustainable materials selection criteria	Shittu (2021)
S14	Reducing costs through improving the supply of IBM	Chan, Darko and Ameyaw (2017); Mairami, Sanni and Jibrin (2020)

Author's compilation (2023)

2.9. Acceptance theories in IBM adoption

The adoption of IBM in the Nigerian construction industry, like in any other context, can be influenced by various acceptance theories. There exist multiple approaches for adopting technology, with the most prominent ones being the Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT), as highlighted by Zhou, Lu and Wang (2010), alongside various other models. These theories elucidate the psychological and contextual underpinnings that influence the adoption process of innovative building materials in Nigeria.

a). Theory of Planned Behavior (TPB)

The Theory of Planned Behavior (TPB) is a foundation for understanding the intentions behind adopting IBM. According to TPB, an individual's intention to engage in a specific action, such as adopting these materials, is shaped by their attitude toward the action, perceived control over it, and the influence of subjective norms (Faisal Shehzad *et al.* 2022). For instance, the favourable perception of the sustainability benefits of IBM, combined with the belief that adopting these materials is manageable and influenced by the expectations and opinions of relevant peers, can collectively impact the intention to incorporate these materials into construction projects.

b). Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM) offers another lens to comprehend the dynamics of material adoption. Developed by Davis in 1989, this model underscores the significance of attitude, intention, and behaviour in the context of accepting or rejecting new technologies (Davis 1989). Regarding IBM adoption, TAM suggests that external factors influence the perceived ease of use, usefulness, and general attitude toward innovative building materials (Faisal Shehzad *et al.* 2022). This attitude subsequently shapes the behavioural intention to integrate these materials, ultimately influencing the actual usage behaviour in construction projects.

c). Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT) amalgamates multiple theories to predict technology adoption behaviours, including TAM and Diffusion of Innovations (DOI). This framework acknowledges the influence of facilitating conditions, social influence, performance expectancy, effort expectancy, behavioural intention, and use behaviour (Faisal Shehzad *et al.* 2022). This theory's applicability in the context of IBM adoption emphasizes the role of various factors, including the drivers of IBM, expected benefits, and the resources available for adopting IBM.

d). Diffusion of Innovations (DOI)

The Diffusion of Innovations (DOI) theory, as proposed by Rogers and York (1995), highlights the determinants of innovation diffusion, focusing on attributes such as observability, complexity, compatibility, trialability, and relative advantage. In the context of IBM adoption, this theory suggests that the perceived benefits, compatibility with existing practices, and the feasibility of experimenting with IBM play pivotal roles in their successful uptake.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Introduction

This section outlines the methods and techniques that the researcher used to achieve the study's objectives. This chapter covers the research design, sampling method, study area, study population, sample size, data collection instrument, procedure for data collection and method of data analysis. The research methodology flowchart is illustrated in Figure 3.1. The figure depicts that a comprehensive literature review was carried out, which resulted in the retrieval of pertinent secondary data to develop the survey questionnaire. The survey data that was valid was analysed and discussed, and conclusions were drawn. The study then made significant recommendations based on the findings.

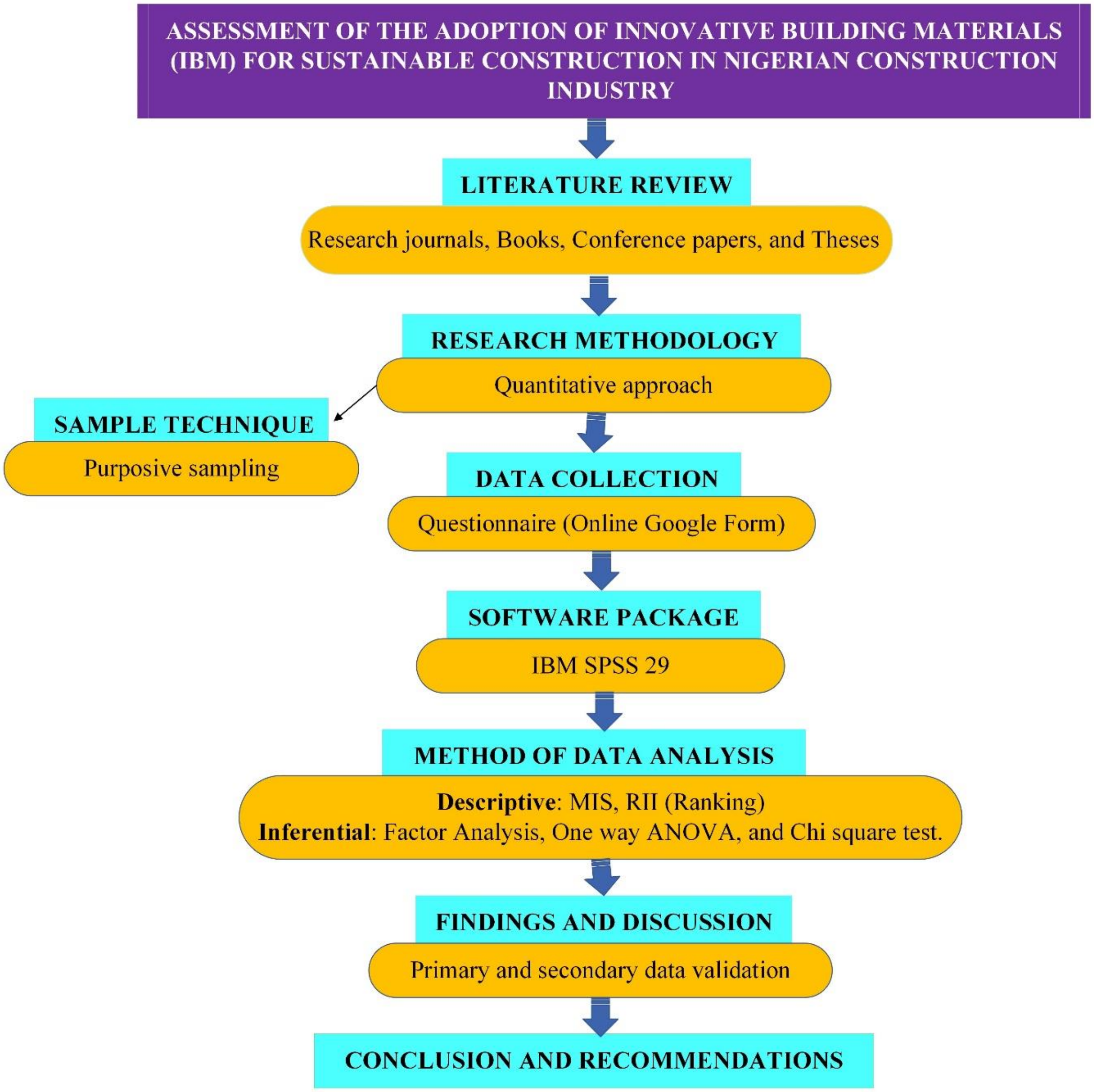

Figure 3. 1: Research methodology flowchart source: (Author 2023)

3.2. Research Philosophy

Research philosophy can be defined as a "collection of beliefs and presumptions regarding the advancement of knowledge" (Saunders, Lewis and Thornhill 2016). In this context, there is an exploration of four fundamental philosophical assumptions: ontological, epistemological, methodological, and axiological. These assumptions underpin the basis for contrasting diverse philosophical frameworks (Creswell 2013).

a). Ontological assumptions

In social science, ontological assumptions pertain to reality's fundamental nature and inherent qualities (Creswell 2013). According to Saunders, Lewis and Thornhill (2016), ontology is a "branch of philosophy that delves into assumptions concerning the fundamental nature of reality or existence." While there exists a certain level of consensus regarding the concept of ontology, its interpretation in the context of the social world is multifaceted. Consequently, determining a research study's ontological stance necessitates carefully considering the nature of the phenomenon, entity, or social reality under investigation (Mason 2002).

Ritchie *et al.* (2013) posit that social science research is underpinned by two primary ontological positions: realism and idealism. Realism, on the one hand, posits that reality within the social sphere exists independently of the individuals participating in it. Advocates of realism contend that reality is apprehended through sensory experiences (Matthews and Ross 2010). Conversely, idealism asserts that the mind fundamentally influences reality. It suggests that reality is, in essence, "mind-dependent" and can be comprehended through societal constructs and human reasoning (Ritchie *et al.* 2013).

b). Epistemological Assumptions

Epistemology, defined as the "theory of knowledge and its acquisition" (Matthews and Ross 2010), becomes a pivotal focus in social science research. According to Ritchie *et al.* (2013), identifying optimal pathways to acquiring knowledge is a critical epistemological concern. This chiefly involves recognizing the dynamic between those with knowledge (respondents) and the researcher striving to attain it (Ponterotto 2005). Generally, epistemology aligns with methods of generating new knowledge, thereby enhancing the body of understanding. Consequently, researchers must justify their assertions concerning novel concepts while providing reasonable rationales for their research methodologies. Such an approach fosters constructive evaluation and decision-making regarding the knowledge generated (Quinlan *et al.* 2015).

c). **Methodological Assumptions**

Hay (2002) contends that research ontology takes precedence, followed by research epistemology, which subsequently shapes research methodology. Correspondingly, Fleetwood (2005) emphasizes the interdependence of these philosophical underpinnings: the perception of reality (ontology) by researchers influences the producible knowledge about that reality (epistemology), and this knowledge is amenable to exploration through diverse methods (methodology). Quinlan *et al.* (2015) define methodology as "the comprehensive approach to the research project; the execution of research activities; a means of buttressing the philosophical foundations that underlie the research project."In this context, methodology encompasses the entire spectrum of research considerations, from formulating research inquiries to presenting research outcomes. Consequently, literature on methodology address many aspects of research, including logical reasoning, approach, strategy, and techniques (Aldawod and Day 2017). Within the scope of this paper, an exploration of postmodernism methodology is limited to three core methodological considerations: research approach, strategy, and techniques.

d). **Axiological Assumptions**

Axiology, as described by Saunders, Lewis and Thornhill (2016), is a "philosophical field centred on values and ethical considerations within research." This prompts exploration into how researchers navigate their values and those of participants (Saunders, Lewis and Thornhill 2016). Such values play a significant role across various research stages, including formulating research questions, selecting a research paradigm, constructing the theoretical framework, determining data collection and analysis methods, selecting the research environment, addressing pre-existing values within that environment, and deciding on findings presentation approaches (Lincoln, Lynham and Guba 2011).

3.3. Research Design

Conradie (2020) suggested that research design encompasses goals such as identifying data sources, data collection and analysis methods, data accessibility, participant location, and financial considerations. According to Manyathi (2019), a research design is a process that transforms ideas, research questions, and interests into meaningful research in the social sciences. It is a framework that outlines the how, when, and where of data collection and analysis (Creswell and Poth 2016). Leedy and Ormrod (2013) also propose that study design offers a potential solution to the research problem by providing the researcher with a clear strategy. According to Holmes, Dahan and Ashari (2005), a research design is divided into qualitative and quantitative types.

3.3.1. Quantitative Research Design

This study employed quantitative research design. Quantitative research is based on measuring quantities and applies to phenomena that can be expressed numerically (Kothari 2011). This suggests that it involves a statistical or numerical approach to research design. Experimental research involves assessing the impact of a particular treatment on an outcome, while non-experimental research offers numerical descriptions of patterns, attitudes, or opinions of a participant (Creswell 2014).

The quantitative research design was deemed suitable for this study. It involved gathering data from a large sample population and several individuals to help meet the research goal of evaluating IBM in the Nigerian construction industry and recommending a practical strategy for its adoption. The primary data source in this study was a well-structured questionnaire administered via survey by the researcher to elicit information based on the research questions and objectives. Quantitative data sources include interviews, observation and participant observation (fieldwork) and questionnaires, among others. An electronic questionnaire was employed in this research. Professionals in the built environment were contacted (through a Google Form) to offer relevant information for the research. The researcher obtained the contact details for Nigerian construction professionals through WhatsApp, Telegram, and LinkedIn groups, of which the researcher is a registered graduate member of the NIOB.

3.3.2. Primary data sources

Primary data refers to information that is gathered firsthand. It has not been published previously and is considered more dependable, genuine, and unbiased. Primary data remains unaltered by human influence, making it more valid compared to secondary data (Kabir 2016). Experiments, surveys, questionnaires, interviews, and observations are examples of primary data sources. To conduct this study, primary data was directly collected from the targeted participants using a questionnaire. Questionnaires can be administered in different formats, such as paper-and-pen-based or web-based. The latter format is more precise in generating quantitative data and this method was adopted in this study. Web-based questionnaires automatically store the collected data and information in Excel spreadsheets, allowing for easy importation into analysis software. Conversely, paper-and-pen-based data necessitates extensive coding before analysis can take place.

3.3.3. Secondary data sources

Secondary data refers to information that has already been published in any format. When conducting research, the examination of existing literature relies on secondary data. This data is collected by others for different purposes but is utilised by the researcher for their own investigation. Secondary data is crucial because it allows for the capture of past changes and developments that cannot be replicated through new surveys (Kabir 2016). Some sources of secondary data include books, research articles from other researchers (journals), databases, published censuses or statistical data, and internet articles. For this study, secondary data sources were acquired from scientific databases such as Scopus, Science Direct, and Web of Science, which contain a wide range of materials, including books, journal articles, conference papers, and theses. Additionally, local and international institutional repositories were explored through the DUT library.

The research execution process is illustrated in Figure 3.2, outlining the flow chart procedure. The collected primary data was meticulously reviewed to assess the scope and limitations of previous research and to determine the variables to be included in the questionnaire.

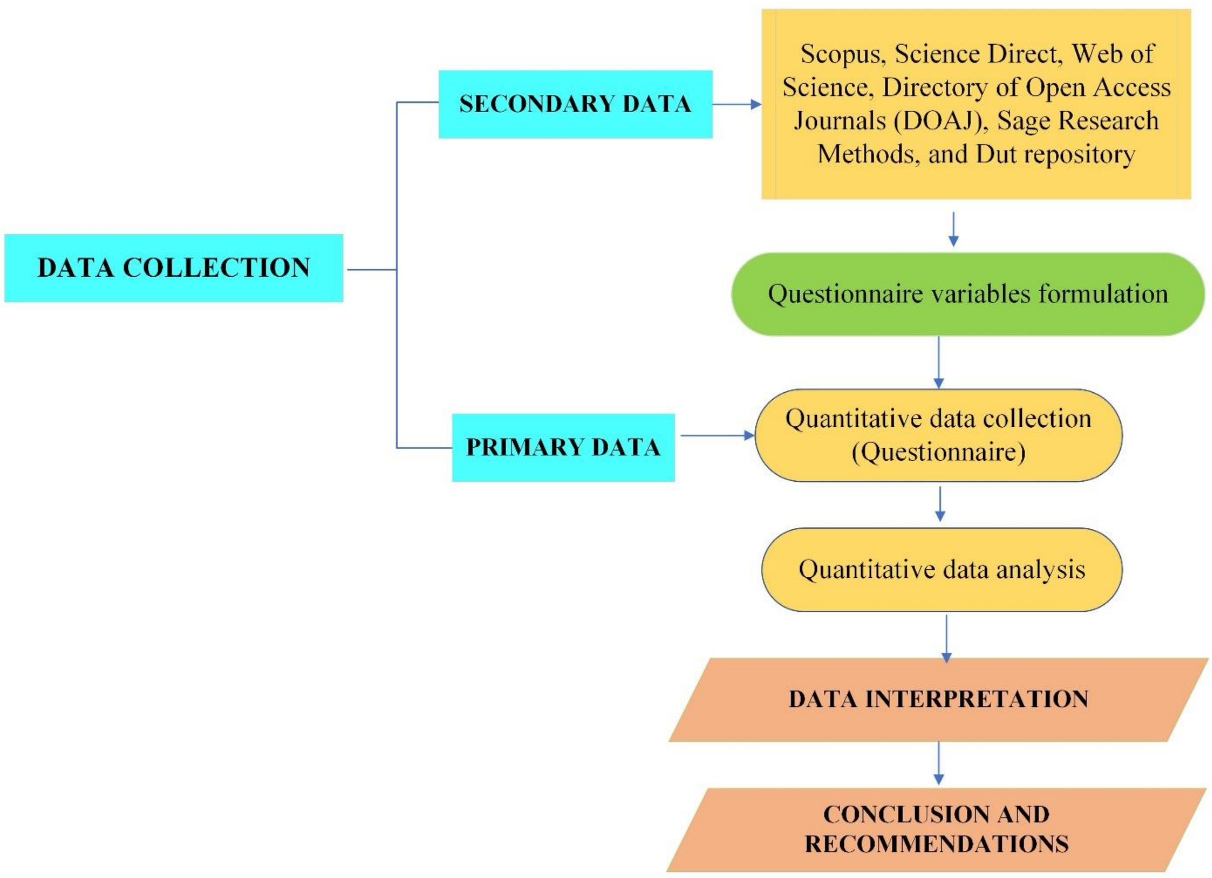

Figure 3. 2: Research design flowchart. (Author 2023)

3.4. Sampling Method

Khan (2014) categorises sampling into two methods: probability and non-probability sampling. The sampling process entails selecting a portion of the representative population and using the collected data as research information. Researchers can choose from a variety of sampling methods, depending on the type of study being conducted. For this study, the researcher used purposive sampling to gather quantitative data. Purposive sampling is a type of non-random sampling technique. As defined by Kelly (2010), purposive sampling is a technique used to select respondents who are most likely to provide relevant and valuable information.

Purposive sampling was used to get reliable information from the participants involved in building construction, management, and maintenance of building facilities in Nigeria. The purposive sampling approach is intended to deviate from random sampling methods and guarantee that particular cases are incorporated into the final research study sample. This approach operates under the assumption that individuals with distinctive and critical perspectives concerning the concepts and issues being examined must be included in the sample, considering the study's objectives (Robinson 2014).

3.5. Study Area

Lagos State is among the 36 states constituting the Federal Republic of Nigeria. With a population of 15 178 425 million, it is the most populated state in Nigeria, the third in Africa, and the sixteenth in the world (World Population Statistics 2023). Situated in southwestern Nigeria, Lagos State has a southern boundary stretching 180 kilometres along the Atlantic coastline, and it shares a western border with the Republic of Benin (Merem *et al.* 2018). Lagos State is Nigeria's smallest but most densely populated state, with a total landmass of about 3 345 km^2 (0.4%) of the country's total land area (African Development Bank 2013; Apoko 2014).

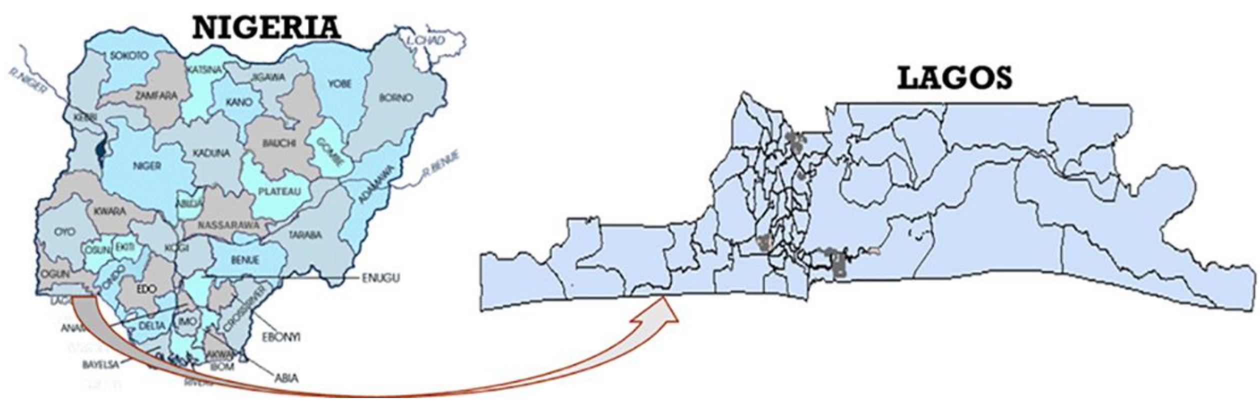

Figure 3. 3: Study area, Lagos, Nigeria (Shobiye *et al.* 2021)

Lagos State, Nigeria, was deemed the most suitable location for this research. The decision was based on several factors, including the city's industrialised environment, which makes it an ideal location for studying the adoption of IBM in an industrial setting. Additionally, Lagos State has a high concentration of construction professionals, indicating a high level of construction activity and the employment of a large workforce in the sector. Despite the high demand for construction in Lagos, there is a significant need for sustainable construction practices to be adopted, making it an excellent opportunity to investigate the extent of IBM adoption towards achieving sustainable construction in the Nigerian construction industry.

3.6. Study Population

According to Mugenda and Mugenda (2003), the population is the total number of individuals, objects, or instances that share similar observable characteristics. Also, Bornstein, Jager and Putnick (2013) define "study population" as the complete set of elements being observed, encompassing all objects or individuals in any field of investigation. In any field of inquiry, the population of a study refers to all individuals or elements that satisfy a particular set of criteria and are, therefore, relevant and contribute to the study's objectives. For this research, the target population is registered built environment professionals in Nigeria. The target respondents were the built environment professionals primarily involved in building construction, management, and maintenance in Nigeria.

Table 3. 1: Sample population for registered built environment professional in Lagos State (2020)

Professionals body	Professions	Population
Nigerian Institute of Architecture (NIA)	Architects	958
Nigerian Institute of Building (NIOB)	Builders	610
Nigerian Society of Engineers (NSE)	Engineers	2670
Nigerian Institute of Quantity Surveying (NIQS)	Quantity surveyors	870
Total	**Total**	**5,108**

Source 2020: NIA, NIOB, NSE, NIQS

3.7. Sample Size

A sample is precisely a part of the population (Asika 2005). It is a small part of the population intended to be representative of the whole. For this study, a considerable number representing the entire population was adopted.

According to the population size data presented in Table 3.1, the total number of registered professionals in Nigeria is **5 108**, comprising **958** architects, **610** builders, **870** quantity surveyors, and **2 670** engineers. Then, applying a formula derived by Yamane in 1997,

$$\boldsymbol{n = \frac{N}{1 + N * (e)^2}}$$

where,

e = level of precision or standard accuracy, which is 10%

n = sample size

N = total population

Total population registered (architects, builders, engineers, and quantity surveyors) = 5108

The total sample size for Lagos/Nigeria= architects: **91**, builders: **86**, quantity surveyors: **90**, and engineers: **96** = **363 participants.**

Table 3. 2: Sample size of registered built environment professionals in Lagos State

Professions	Population size	Sample size
Architects	958	91
Builders	610	86
Engineers	2670	90
Quantity Surveyors	870	96
Total	**5 108**	**363**

3.8. Data collection instrument

Questionnaires are research tools through which individuals are requested to respond to a similar arrangement of questions in a pre-determined order (Hennick, Hutter and Bailey 2011). Abawi (2013) defines a survey questionnaire as a necessary means of collecting data that involves a series of sequential questions with diverse answer options intended to gather information from participants. In this study, the questionnaire was employed as a research instrument to collect data from potential research participants. The survey questionnaire is designed to fulfil the abovementioned goals by gathering data on the use of IBM in Nigeria. The questionnaire is divided into six sections. The questionnaire takes between 20 and 25 minutes to complete. The questionnaire contains information to elicit the respondents' background information and questions that address each study objective on a 5-point Likert-type scale to allow granularity in the responses. The questionnaire was distributed and collected electronically. There was no personal contact between the researcher and the participants.

The questionnaire was divided into six sections: A, B, C, D, E, and F (**Please see attached the**

questionnaire, Appendix 3);

1. Section A: Demographic information of respondents and organisation.
2. Section B: Level of awareness of some current available IBM used for sustainable construction (a total of six items).
3. Section C: Drivers adopting IBM for sustainable construction (a total of 14 items).
4. Section D: Barriers to adopting IBM for sustainable construction (a total of 31 items).
5. Section E: Benefits of adopting IBM for sustainableconstruction (a total of 18 items).
6. Section F: Strategies for successfully adopting IBM for sustainable construction (a total of 14 items).

The instrument was structured on a 5-point Likert-type scale, ranging from "**5** = Very High (VH)","**4** = High (H)", "**3** = Neutral (N)", "**2** = Low (L)" to "**1** = Very Low (VL)". Respondents were instructed to respond according to their level of agreement with the statements contained in the instrument.

3.9. Procedure for distribution of questionnaires and data collection

The responses from the respondents were collected via Google Forms. The e-questionnaire links were sent to the email addresses and WhatsApp accounts of the respondents, and they were expected to fill out the questionnaire and submit via the same link, ensuring a prompt, easy, and reliable response. The survey applications were designed to automatically collate results in an appropriate coding format for further analysis. The questionnaire was distributed online through Google Forms, and the email addresses of the built environment professionals were obtained from professional bodies' websites. The Nigerian Institute of Builders (NIOB), Nigerian Institute of Quantity Surveyors (NIQS), Nigerian Institute of Architecture (NIA), and Nigerian Society of Engineers (NSE) were also contacted to distribute the research link to various prospective respondents' email addresses, and recruitment was conducted through professional bodies. The researcher reported that out of 363 targeted participants, 282 responses were obtained from architects, builders, quantity surveyors, and engineers (structural, electrical, and mechanical) involved in building construction, management, and maintenance of building facilities in Nigeria. The targeted participants were contacted via Google Forms to provide relevant information for the research.

3.10. The procedure for obtaining informed consent and questionnaire

The questionnaire was administered and collected using Google Forms. For this research, **the letter of information** and **the informed consent** were part of the information provided to the participants (**Please see Appendix 1 and 2 respectively**). However, since the questionnaire was to be distributed electronically, the participants were initially required to read the informed consent form and confirm their voluntary participation. Also, the questionnaire was designed so the participants would not haveaccess to it without confirming that they had been duly informed about the research and that their participation was voluntary. The link for the questionnaire survey, along with the information and consent letter, was forwarded to the participants through their respective professional bodies.

3.11. Inclusion and exclusion criteria

Architects, builders, estate surveyors, land surveyors, quantity surveyors, town planners, and engineers (structural, electrical, and mechanical) are all examples of built professionals.

- **Inclusion criteria**

Only registered built professionals such as architects, builders, quantity surveyors, and engineers (including structural, electrical, and mechanical) who are primarily involved in building construction,management, and maintenance were included.

- **Exclusion criteria**

Other professionals not involved in building construction and maintenance, such as town planners, land surveyors, and estate surveyors, were not included.

This study only covers registered built professionals (architects, builders, quantity surveyors, and engineers (structural, electrical, and mechanical)). This study excludes any professional who is not a registered member.

3.12. Ethical Consideration

One of the essential aspects of research is ethical consideration. The following was considered to ensure ethical considerations are identified and addressed most appropriately in this research (**please see Appendix 1 – Letter of information**).

1) Assurance of the confidentiality of the information supplied by research participants and the anonymity of respondents.
2) Full consent was obtained from the participants prior to the study.
3) Research participants were not subjected to harm in any way whatsoever.
4) Respect for the dignity of research participants was prioritised.
5) The maintenance of the dignity of participants was ensured.
6) The protection of the privacy of research participants was ensured.
7) Any communication concerning the research was done with honesty and transparency.
8) There was no risk of harm to the environment.
9) Voluntary informed consent by the participants was obtained.
10) Appropriate publication and dissemination of research results were done.

3.13. Assurance of confidentiality and anonymity of participants

The collected participant data was treated anonymously, and the survey results were used solely for research purposes. However, no existing or anticipated risks exist for any research participant in this study. As an ethical obligation that recognises the rights of the participants, the researcher took on the role of protecting them. The researcher prioritised the confidentiality and anonymity of the research participants.

1) No personal information about research participants was requested, such as names, ID numbers, or mobile phone numbers.
2) No names were required.
3) The responses cannot be tracked to any specific participant because the online survey (Google Forms) is set by default not to collect participant email addresses.
4) There were no sensitive biographical questions in the questionnaire that might reveal who the participant is.
5) The data collection process did not require access to confidential personal data.
6) Participation was voluntary, and participants could withdraw at any moment without penalty. This was stated in both the information letter and the consent letter.
7) The data can never be linked to the research participant who provided it.

3.14. Procedure for research data management

1) All information received was kept confidential and password-protected following the authorised DUT data management information.
2) All survey questionnaire data was analysed by the researcher and submitted as part of the dissertation, which will be stored on DUT premises for five (5) years before destruction.

3) The participant can withdraw from the research at any time and will continue to receive the appropriate quality of care.

3.15. Pilot Study

Bazeley (2013) defines a pilot study as an experiment that involves testing the program on a small sample from the community where the research will occur. Neuman (2000) argues that structured questionnaires should undergo a pilot test before they are employed in the preliminary examination. Chapman and McNeill (2005) also suggested that when conducting questionnaire-based research, the stage of carrying out a pilot survey should always be included. The survey questionnaire was given to five experts in the field (academic and professional) to advise on its rationality, appropriateness, and ability to do the job it was designed for. Comments were requested from the experts in the following areas to enhance the questionnaire (**please see Appendix 4 - pilot study request letter**)

1) The cover letter.
2) The rationality and appropriateness of the questions.
3) The overall appearance of the questionnaire.
4) Time taken to complete the questionnaire.
5) The layout of the questions.

The data collection tool and gatekeeper permission approval letters were comprehensively evaluated by the DUT Institutional Research Ethics Committee (DUT-IREC). Following this rigorous assessment, the DUT-IREC granted its full approval for the commencement of data collection. Supporting evidence of this approval can be found in **Appendix 5 (DUT-IREC Approval letter**).

3.16. Validity and reliability test

1). Validity test

According to Hays and Singh (2012), validity is the accuracy of findings and conclusions based on the interaction between the researcher and participant regarding a particular subject. Validity describes how well the data collected covers the actual area of investigation (Ghauri and Gronhaug 2005). Validity pertains to the degree to which a measure, indicator, or data collection method is deemed reliable and accurate based on available evidence. There are several categories of validity, including content, conclusion, external, and internal. In this study, emphasis was placed on content validity, which assesses how well an instrument measures the intended factors. Specifically, content validity was concerned with the accuracy of the questions in eliciting sought-after information. A pilot study was conducted to evaluate the research instrument's content validity.

2). Reliability test

The process of testing for reliability is essential since it pertains to the consistency of a measuring instrument's components (Huck 2007). Among the various measures of internal consistency, Cronbach's alpha coefficient is the most widely used (Chan *et al.* 2018). This coefficient is considered the most appropriate measure of reliability when Likert scales are employed (Whitley 2002). For this survey, Cronbach's alpha test was used to determine the reliability of the quantitative data and the consistency of the questionnaire results. The reliability of a research instrument is the degree of its consistency, which measures its attributes. Cronbach's alpha test guaranteed that the questionnaire being administered was reliable. Based on the formula (Cho and Kim 2015),

$$\alpha = \frac{K}{K-1} * \left(1 - \frac{\sum_{i=0}^{K} s_i^2}{s_t^2}\right)$$

Cronbach's alpha coefficient:

where; α = Cronbach's alpha value

K = number of items

s = variance of the total of respondents' scores.

Table 3. 3: The results of the reliability test using Cronbach's Alpha

Objectives	Cronbach's Alpha value	Number of Items
Investigate the level of awareness of some current available IBM used for sustainable construction in the Nigerian construction industry.	0.869	6
	0.908	6
	0.756	6
Assess the drivers for the adoption of IBM for sustainable construction	0.894	14
Assess the barriers affecting the adoption of IBM for sustainable construction in the Nigerian construction industry	0.951	31
Assess the benefits of the adoption of IBM for sustainable construction	0.948	18
Recommend strategies for the adoption of IBM for sustainable construction in the Nigerian construction industry	0.964	14

The data collected in the study were analysed using IBM Statistical Package for Social Sciences version 29.0 (SPSS). The results showed Cronbach's alpha correlation coefficient values ranging from 0.756 to 0.964, as presented in Table 3.3.

Straub, Boudreau and Gefen (2004) suggest a reliability score of 0.60 or higher is recommended for an exploratory or pilot study. Table 3.4 shows the four reliability cut-off points.

Table 3. 4: Four reliability cut-off points. Proposed by (Hinton *et al.* 2004)

Four reliability	**Cut-off points**
Good reliability	0.90 and above
High reliability	0.70-0.90
Moderate reliability	0.50-0.70
Low reliability	0.50 and below

While reliability is a necessary component of research, it is insufficient in and of itself, and validity must also be considered. For a test to be considered reliable, it must also demonstrate validity (Wilson 2010).

3.17. Method of Data Presentation and Analysis

Using the appropriate data analysis methods, data is always collected and analysed using computer-based statistical software called Statistical Package for Social Science (SPSS) and Microsoft Excel (MS Excel), and then presented using the Microsoft Word (MS Word) platform. The collected data was analysed using both descriptive and inferential statistics. This method includes compiling all the data collected and the findings based on the data analysis.

Table 3. 5: Method of data analysis

Objectives	**Data analysis method**	
	Descriptive statistics	**Inferential statistics**
To assess the level of awareness of some current available IBM	* Mean Item Score (MIS) * Relative Important Index (RII)	* Chi-square test
To investigate the drivers for the adoption of IBM	* Mean Item Score (MIS) * Relative Important Index (RII)	* ANOVA

Objectives	Data analysis method	
	Descriptive statistics	**Inferential statistics**
To assess the barriers affecting the adoption of IBM	* Mean Item Score (MIS) * Relative Important Index (RII)	* KMO & Bartlett's test * Factor analysis
To examine the benefits of the adoption of IBM	* Mean Item Score (MIS)	
To determine strategies for the successful adoption of IBM	* Mean Item Score (MIS)	* Chi-square test

Analysis tools employed are as follows:

1. **Mean item score (MIS)**

The method helps determine the rank of different elements (Fellows and Liu 2008). This technique makes it possible to compare and evaluate the relative importance of factors or elements that the respondents perceive. The mean item score was used to analyse objectives 1, 2, 3, 4 and 5 in connection with other data analysis tools.

The Mean Item Score is calculated using the expression:

$$MIS = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{N} = \Sigma W/AN$$

where: n = number of respondents based on their responses

N = total number of respondents

W = weighting given to each factor by respondents ranges from 1-5

A = highest weighting, i.e., 5

2. **Relative Importance Index (RII)**

The relative importance index (RII) method was defined by Hossen, Kang and Kim (2015) as a statistical technique employed to rank various factors. Aibinu and Jagboro (2002) also utilised the RII approach to assess the relative importance of specific causes and effects based on their probability of occurrence and impact on a project using a five-point Likert scale. The index of relative importance (RII) determines the critical cause or impact component, with a higher value indicating greater significance, as calculated by the equation below:

$$RII = \frac{\sum W}{(A*N)}$$

Where:

RII = relative importance index

W = the weight given to each factor by the respondents from 1, 2, and 3 for very low, low, moderate, high and very high, respectively,

A = the highest weight (i.e., 5 in this case), and

N = the total number of respondents.

The Relative Importance Index was used to analyse objectives 1, 2, 3, 4 and 5 in connection with other data analysis tools. The rating scale employed for RII is shown in Table 3.6.

Table 3. 6: Relative Important Index (RII) rating

RII values	**Usage level**
0.81 to 1.0	Very high
0.61 to 0.8	High
0.41 to 0.6	Average
0.21 to 0.4	Low
0.00 to 0.20	Never

3. Chi-square test

According to Onchiri (2013), the chi-square test is versatile and can be applied to various problems, including testing frequencies (such as testing the goodness of fit, testing the homogeneity of several frequency distributions, and testing independence) and testing population variance (such as testing single sample variance). The goodness-of-fit test employs the chi-square test to investigate the similarity of proportions or frequencies across different groupings or classifications of categorical data (Onchiri 2013). As stated by Kothari (2007), this test helps us determine how well the observed data distribution fits the theoretical distribution, such as a normal distribution, binomial distribution, or Poisson distribution. A good fit is indicated by a calculated chi-square value lower than the table value at a particular significance level, implying that the difference between the expected and observed frequencies is due to sampling fluctuations (Onchiri 2013). Conversely, if the calculated chi-square value exceeds the table value, the fit is deemed unsatisfactory (Onchiri 2013).

4. **Analysis of variance (ANOVA)**

ANOVA is a widely used and effective statistical method for testing experiments that involve multiple groups (Smalheiser 2017). Despite its simplicity in concept, ANOVA is a powerful tool for analysing data. Pallant (2013) states that ANOVA, a parametric test, is frequently employed to compare mean scores across three or more groups, provided that the sample follows a normal distribution. ANOVA was used to analyse objective 2.

5. **Kaiser-Meyer-Olkin (KMO) and Bartlett test**

a). Kaiser-Meyer-Olkin’s (KMO’s) Measure of Sampling Adequacy

According to Shrestha (2021), the KMO test is specifically designed to assess the appropriateness of data for factor analysis by examining whether the sample size is sufficient. This test evaluates the adequacy of the sample size for each variable in the model and the entire model. The KMO’s measure of sampling adequacy is computed using a specific formula:

$$KMO_j = \frac{\sum_{i \neq j} R_{ij}^2}{\sum_{i \neq j} R_{ij}^2 + \sum_{i \neq j} U_{ij}^2}$$

where,

Rij = correlation matrix

Uij = partial covariance matrix.

KMO value varies from 0 to 1.

Values ranging from 0.80 to 1.0 indicate adequate sampling; 0.70 to 0.79 indicate middling sampling; 0.60 to 0.69 indicate mediocre sampling; and less than 0.6 indicate inadequate sampling, which would require remedial action. If the KMO value is less than 0.5, it is unlikely that the factor analysis results would be suitable for data analysis. For sample sizes below 300, it is essential to check the average communality of the retained items, where an average value higher than 0.6 is acceptable for sample sizes below 100, and an average value between 0.5 and 0.6 is acceptable for sample sizes between 100 and 200, according to Tabachnick and Fidell (2013).

b). Bartlett's test of Sphericity

According to Shrestha (2021), Bartlett's test of sphericity is a statistical test used to evaluate whether the variables in a dataset are unrelated or orthogonal, with the correlation matrix being an identity matrix. The null hypothesis assumes no structure in the correlation matrix. In contrast, the alternative hypothesis assumes that the variables are sufficiently correlated to cause the correlation matrix to diverge significantly from the identity matrix. A significant value of less than 0.05 suggests that factor analysis may be appropriate for the dataset.

The determinant of the correlation matrix, |R|, is calculated to determine the overall relationship between the variables. Under the null hypothesis, |R| equals 1, whereas highly correlated variables result in |R| approaching 0. The formula for Bartlett's test of sphericity is also provided.

$$\chi^2 = -\left(n - 1 - \frac{2p+5}{6}\right) \times \ln|R|$$

Where:

p = number of variables,

n = total sample size and

R = correlation matrix

6. Factor Analysis

Factor analysis proves to be particularly valuable in determining the underlying factors of variables by grouping related variables within the same factor (Verma and Abdel-Salam 2019). Factor analysis can be approached through two main methods: exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). EPA is employed to assess dimensionality and is commonly used in the initial stages of research to explore the interrelationships among a group of variables (Pituch and Stevens 2016). In contrast, confirmatory factor analysis involves more advanced and intricate techniques utilised in the research process to test specific hypotheses or theories regarding the underlying structure of a variable set (Hair *et al.* 2010; Pallant 2013).

The study employed CFA to assess the compatibility of the measured variables with the nature of the connected component. Principal components analysis (PCA) was utilised as the method of extraction. Tables 4.10 outline the minimum criteria utilised in the analysis, including factors such as factor loading, eigenvalue, correlation coefficient, KMO's value, Bartlett's test results, and total variance explained (TVE). The CFA findings from this study were then used to confirm the validity and reliability of the measured variables. The analysis was conducted using SPSS IBM (version 29). Factor analysis was utilised to examine objective 3.

3.18. Delimitations

This study is limited to assessing the level of adoption of IBM for sustainable construction among the relevant registered built environment professionals, primarily involved in the construction and facilities management of building projects in Lagos, Nigeria.

CHAPTER FOUR

DATA ANALYSIS, INTERPRETATION RESULTS AND DISCUSSIONS

4.1. Introduction

This chapter analyses data from a field survey in line with the study's objectives. The respondents' demographic attributes and professional qualifications, areas of specialisation and operation, and years of experience were analysed. Results on awareness, drivers, barriers, benefits, and strategies for adopting IBM in sustainable construction were presented. 282 out of 363 questionnaires distributed to architects, builders, engineers, and quantity surveyors in Nigeria were suitable for analysis. The study achieved an overall response rate of 77.6%, which is considered high and adequate, according to (Wu, Zhao and Fils-Aime 2022).

4.2. Background Information of Respondents

The first section of the questionnaire presented the respondent's background information. The respondents' information includes gender, profession, educational qualification, years of experience in construction, professional qualification, membership status, area of specialisation, area of operation, and organisation years of operation in the construction industry. Among the sample size of 363, 282 respondents provided clear information about their gender distribution. Of these, 217 (77%) respondents identified as male, while 65 (23%) identified as female. However, this does not necessarily significantly impact the project's outcomes since the focus is on adopting IBM for sustainable construction in the Nigerian industry, which is not gender-specific. Figure 4.1 illustrates the gender distribution of the respondents.

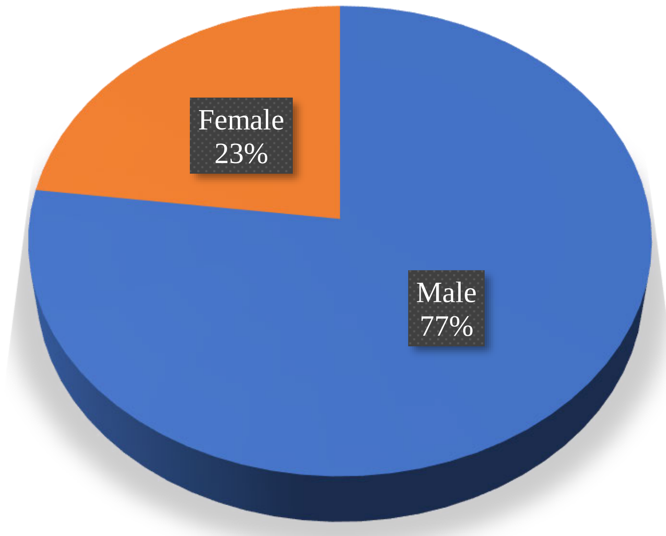

Figure 4. 1: Gender distribution of the respondents

Furthermore, the profession distribution of the respondents shows that 52 (18.4%) respondents are architects, 101 (35.8%) respondents are builders, 65 (23.0%) respondents are engineers, and 64 (22.7%) respondents are quantity surveyors. This shows an equitable contribution of over 18% from Nigeria's significant built environment professionals. Also, the results of the study conducted by Dahiru and Bashir (2015) indicate that the major built environment professionals in Nigeria, namely architects, builders, engineers, and quantity surveyors, provided balanced inputs, with each profession contributing more than 18%. However, this diverse range of professions allows for a broader perspective on adopting IBM for sustainable Nigerian construction. Figure 4.2 shows the distribution of the professions among the respondents.

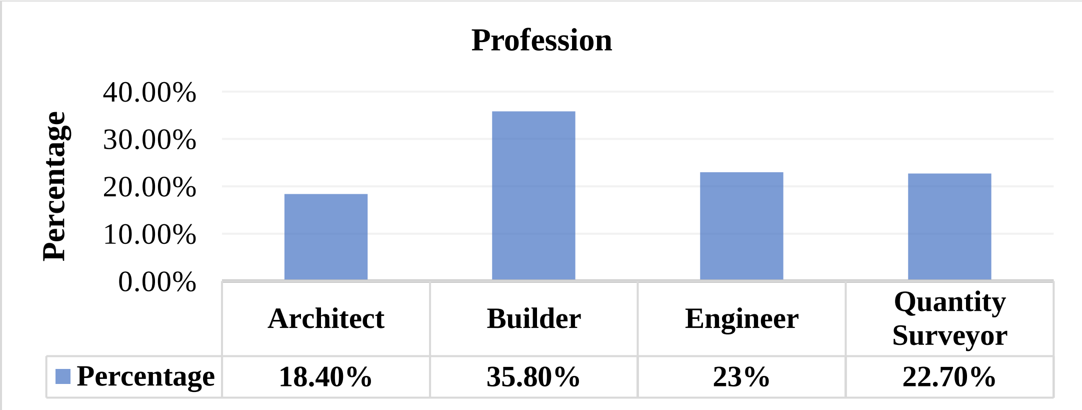

Figure 4. 2: The profession distribution of the respondents.

Also, as reported in Figure 4.3, based on the educational qualification responses, 3 (1.1%) respondents have a National Diploma qualification, 27 (9.6%) respondents have a Higher National Diploma qualification, 130 (46.1%) respondents have a B.Sc./B. Tech qualification, 84 (29.9%) respondents have a M.Sc./M. Tech qualification, and 38 (13.5%) respondents have a PhD qualification. The respondents' educational qualifications indicate that they possess academic knowledge, which makes them well-suited to provide relevant information for the study.

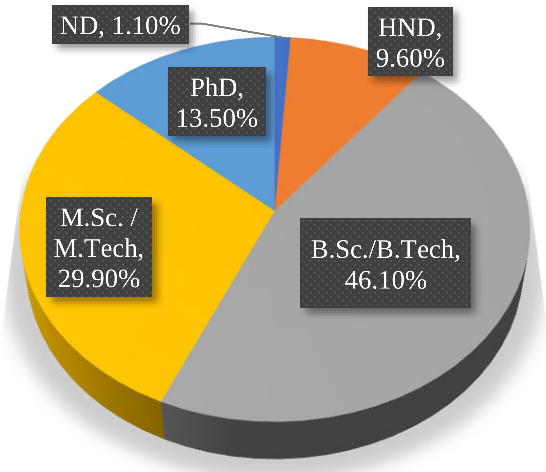

Figure 4. 3: The distribution of the respondent's educational qualifications.

For the years of experience of the respondents, 37 (13.2%) respondents have 1—5 years of work experience, 81 (28.8%) respondents have 6—10 years of work experience, 94 (33.4%) respondents have 11—15 years of work experience, 52 (18.3%) respondents have 16—20 years of work experience, 18 (6.3%) respondents have over 20 years of work experience. The respondents, on average, possess 12.9 years of work experience. Aghimien *et al.* (2018) also conducted a research study that found that the respondents had an average working experience of over 12 years. This information suggests that they are not only academically qualified but also have significant practical experience in their respective professional fields. Consequently, they can provide significant responses to effectively address the study's objectives. Figure 4.4 shows the distribution of the years of experience of the respondents.

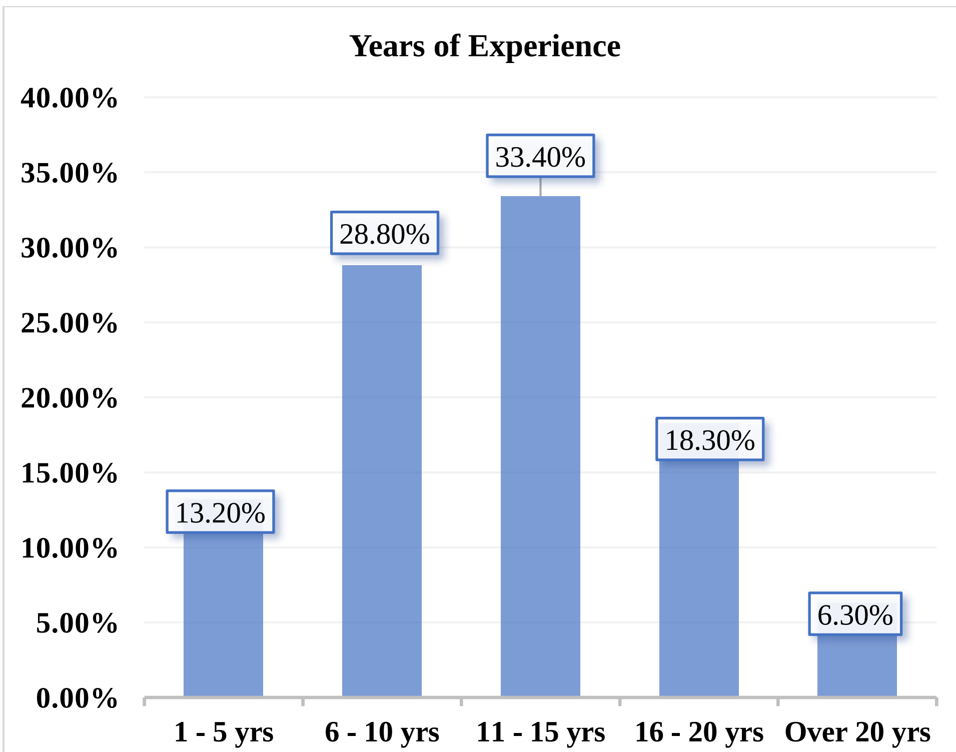

Figure 4. 4: The distribution of the respondent's years of experience

Furthermore, the professional qualification distribution of the respondents shows that 52 (18.4%) respondents were affiliated with NIA professionally, 101 (35.8%) respondents were affiliated with NIOB professionally, 65 (23.0%) respondents were affiliated with NSE professionally, 64 (22.7%) respondents were affiliated with NIQS professionally. Most importantly, this indicates that 100%

of the respondents were affiliated with their respective professional bodies. Also, this diverse range of professional bodies allows for a broader perspective on adopting IBM for sustainable Nigerian construction. Figure 4.5 shows the professional qualification distribution of the respondents.

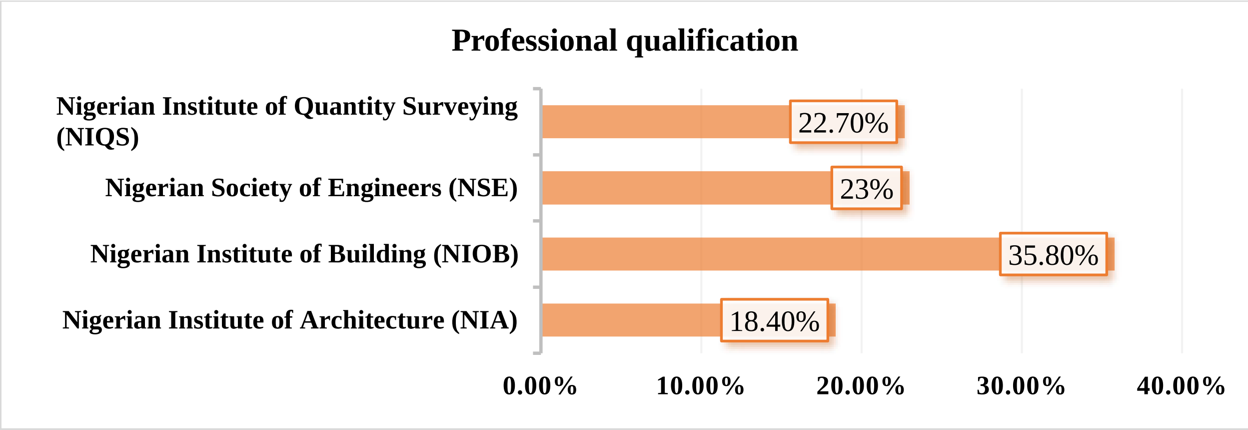

Figure 4. 5: The professional qualification distribution of the respondents

Figure 4.6 shows the distribution of the membership status of the respondents in professional bodies: 49 (17.4%) respondents have student membership, 103 (36.5%) respondents have graduate membership, 11 (3.9%) respondents are at the technologist membership level, 26 (9.2%) respondents have associate membership, eight (2.8%) respondents are at the technician membership level, 67 (23.8%) respondents have corporate membership, 17 (6.0%) respondents have fellow membership, and one (0.4%) respondent has licentiate membership. This implies that every respondent in the study holds a professional membership status, which indicates that they can provide adequate responses that meet the research objectives. According to Owolabi and Olatunji (2014), the significance of professional membership in the construction industry lies in its ability to offer individuals diverse membership levels along with opportunities for networking, professional growth, and training.

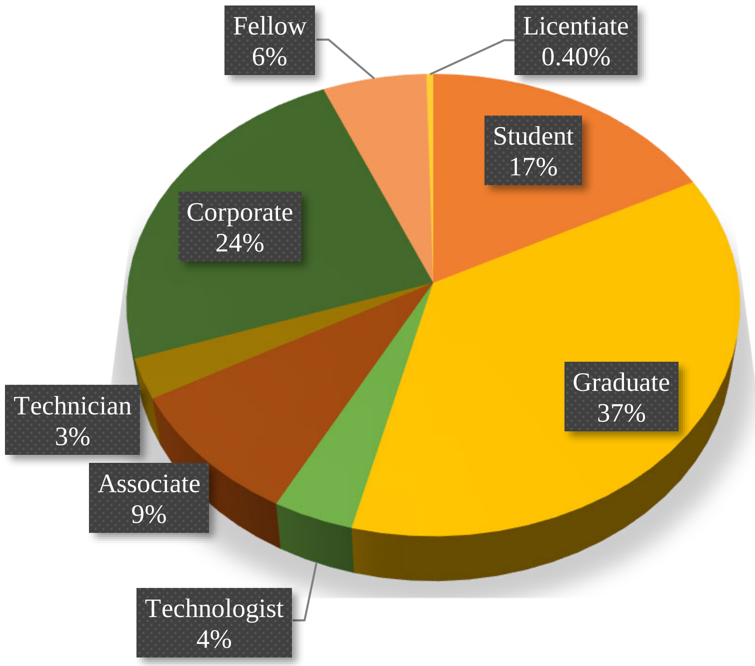

Figure 4. 6: The distribution of the membership status of the respondents

For the respondents' area of specialisation in the construction industry, 27 (13.1%) respondents are contractors, 59 (20.9%) respondents are consultants in the industry, 21 (7.4%) respondents are clients in the industry, 97 (34.4%) respondents are educational institution researchers, 41 (14.5%) respondents are site engineers/supervisors in the industry, 14 (5.0%) respondents are subcontractors, and 13 (4.6%) respondents were professional bodies representatives in the industry. The result implies that the respondents have a diverse range of specialisations and roles in the Nigerian construction industry, which could provide a more comprehensive perspective on the issues and challenges faced in the industry. Figure 4.7 shows the distribution of the area of specialisation of the respondents.

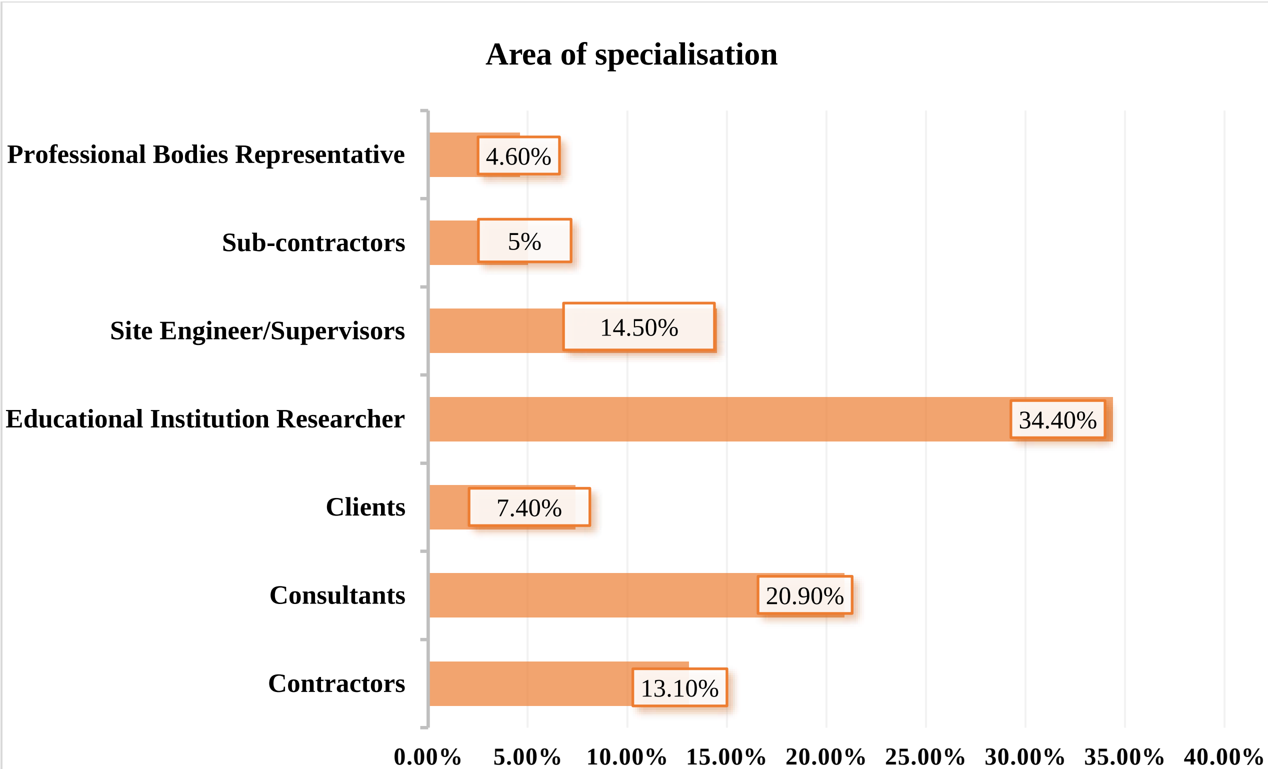

Figure 4. 7: The distribution of the area of specialisation of the respondents

According to Figure 4.8, the respondents' area of operation is diverse. Of the entire population, 106 (37.6%) respondents' function in government establishments, 67 (23.8%) respondents' function in client organisations, 58 (20.6%) respondents' function in contracting, and 51 (18.1%) respondents' function in consulting. The large percentage of respondents working in government establishments 106 (37.6%) suggests that the government plays a significant role in the construction industry, and their perspectives can provide valuable insights. The diverse areas of operation of the respondents also suggest that the study can collect feedback from different perspectives, which can help improve the adoption of IBM for sustainable construction.

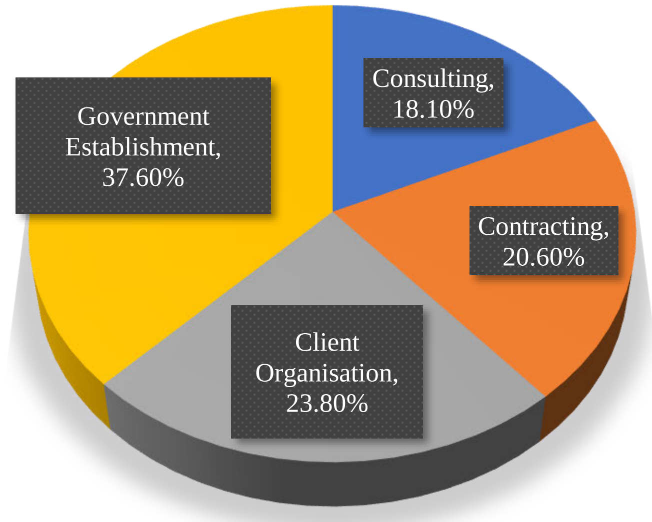

Figure 4. 8: The distribution of the area of operation of the respondents

For the respondents' organisation's years of operation, 23 (8.2%) respondents have been in operation between 1—5 years, 23 (8.2%) respondents have been in operation between 6—10 years, 40 (14.2%) respondents have been in operation between 11—15 years, 51 (18.1%) respondents have been in operation between 16—20 years, and 145 (51.4%) respondents have been in operation for over 20 years. This implies that a significant number of respondents' organisations have been in operation for over 20 years, which suggests that they have accumulated a vast amount of experience and knowledge in the construction industry in Nigeria. Based on the results, the average number of years organisations have been operating is around 23.3 years. Figure 4.9 shows the distribution of the organisation years of operation of the respondents.

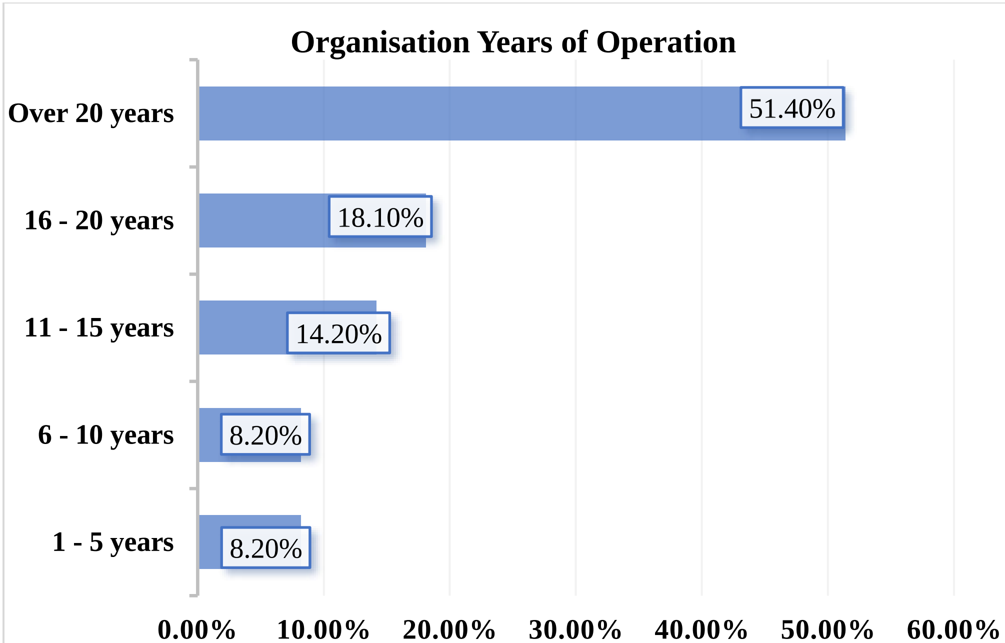

Figure 4. 9: The distribution of the respondents' organisation years of operation

The respondents' demographic information supports the assumption that they are knowledgeable enough to exercise sound judgement, and their responses can be trusted as reliable for the research. This is because they possess sufficient professional qualifications, significant years of experience, and knowledge to offer a valuable opinion on the study's objective. Therefore, this section establishes that the participants are academically and professionally qualified, experienced, and possess the requisite knowledge to contribute meaningfully to the study's objective.

4.3. Level of awareness of some current available IBM used for sustainable construction

4.3.1. Descriptive analysis (Level of awareness of IBM)

This section presents the awareness, relevance, and application level of six IBMs used for sustainable construction in the Nigerian construction industry. The findings from this study provide essential insights into the current state of awareness and adoption of IBM in the Nigerian construction industry. The most significant IBM were determined by ranking based on mean, RII, and standard deviation; the rating levels are shown in Table 4.1.

Table 4. 1: RII Decision rules. Adopted from Toyin and Mewomo (2022)

RII values	Significance level	Codes
0.81 ≤ RII ≤ 1	Strongly significant	SS
0.61 ≤ RII ≤ 0.80	Significant	S
0.41 ≤ RII ≤ 0.60	Neutral	N
0.21 ≤ RII ≤ 0.40	Less significant	LS
0 ≤ RII ≤ 0.20	Not significant	NS

Table 4.2 clearly shows the level of awareness of six (6) IBM in terms of awareness, relevance, and application. In terms of awareness, the table shows that "Smart Glass Windows" ranked first (RII = 0.7943), "Cross Laminated Timber (CLT)" ranked second (RII = 0.6667), "Pigmented/Coloured Concrete" ranked third (RII = 0.6475), "3D-Printed Graphene" ranked fourth (RII = 0.6312), "Timbercrete" ranked fifth (RII = 0.5752), and "Light-Generating Concrete" ranked sixth (RII = 0.5496). The RII result ranges from 0.54 to 0.79. It could be concluded that most are familiar with smart glass windows, cross-laminated timber, pigmented/ coloured concrete and 3D-printed graphene, according to the viewpoint of the respondents. This also revealed that most professionals in this study know about these innovative building materials. According to this result, there has been a notable improvement in the awareness of IBMs among professionals. This positive shift contrasts the findings of Umar, Lembi and Emechebe (2021) research study, which highlighted a low level of awareness and knowledge specifically regarding sustainable building materials among architects.

Table 4. 2: Awareness, relevance and application of some selected IBM

Level	Innovative building materials	Mean	Std. Dev.	RII	Significance level	Rank
Awareness	Smart Glass Windows	3.97	.928	0.7943	S	1st
	Cross Laminated Timber (CLT)	3.33	.925	0.6667	S	2nd
	Pigmented/ Coloured Concrete	3.24	.875	0.6475	S	3rd
	3D-Printed Graphene	3.16	1.018	0.6312	S	4th
	Timbercrete	2.88	.989	0.5752	N	5th
	Light-Generating Concrete	2.75	.979	0.5496	N	6th
Relevance	Smart Glass Windows	3.89	.918	0.7787	S	1st
	Cross Laminated Timber (CLT)	3.51	.788	0.7028	S	2nd
	3D-Printed Graphene	3.32	.752	0.6957	S	3rd
	Pigmented/ Coloured Concrete	3.48	.823	0.6631	S	4th
	Timbercrete	3.31	.764	0.6617	S	5th
	Light-Generating Concrete	3.18	.771	0.6355	S	6th
Application	Smart Glass Windows	3.41	1.310	0.6816	S	1st
	Cross Laminated Timber (CLT)	2.39	1.015	0.4787	N	2nd
	Pigmented/ Coloured Concrete	2.15	.994	0.4298	N	3rd
	3D-Printed Graphene	1.58	.765	0.2681	LS	4th
	Timbercrete	1.36	.713	0.3163	LS	5th
	Light-Generating Concrete	1.34	.719	0.2716	LS	6th

In terms of relevance, the RII result ranging from 0.63 to 0.77 indicates that the respondents agreed that all six IBM (smart glass windows, cross-laminated timber, 3D-printed graphene, pigmented/ coloured concrete, timbercrete and light-generating concrete) under study are relevant. Considering that smart glass windows are very relevant and light-generating concrete is least relevant in the construction industry, according to this result, all the professionals are well aware of the relevance/benefits of IBM.

In terms of application, the RII result ranges from 0.27 to 0.68. Furthermore, the results indicate that the respondents consider “smart glass windows (RII = .6816)” the most applicable among the six innovative building materials. This aligns with Wang and Narayan (2021) assertion that smart windows hold promise due to their ease of implementation and simplicity in industrial production. In summary, the findings revealed that most respondents know about innovative building materials. However, very few professionals adopt IBM in construction, indicating the low level of adoption of IBM in the Nigerian construction industry.

4.3.2. Chi-square test of association between the level of awareness and level of application of IBM

The analysis result from Table 4.3 concluded that there is enough evidence to suggest an association between the level of awareness of IBM and the level of application of IBM. Since the p-value (0.000) is less than the chosen significance level ($\alpha = 0.05$). This means that there needs to be an increase in the level of awareness for an increase in the application level. In other words, there is a need for increased awareness and promotion of IBMs for sustainable construction in Nigeria. Therefore, a strong association exists between IBM's awareness level and application level in the Nigerian construction industry. Higher awareness levels tend to facilitate increased application and adoption of IBM, while lower awareness levels may hinder their utilisation. Based on Okoye, Odesola and Okolie (2021) findings, it has been established that the recognition and understanding of the advantages of sustainable construction practices are crucial foundations for successfully implementing such practices as IBM adoption, which is also a sustainable practice. Also, the findings presented by Otali and Ujene (2020) suggested a direct relationship between the level of awareness and the adoption of sustainability practices within the Nigerian construction industry. However, to promote the widespread adoption of IBM for sustainable construction in Nigeria, efforts should be made to raise awareness among stakeholders through education, training programs, knowledge-sharing platforms, and highlighting successful case studies demonstrating the benefits and feasibility of using IBM.

Table 4. 3: Chi-square test of association between the level of awareness and level of application

Chi-Square Tests			
	Value	**df.**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	136.728[a]	12	0.000
Likelihood Ratio	103.825	12	0.000
Linear-by-Linear Association	65.544	1	0.000
N of Valid Cases	282		
a. 8 cells (40.0%) have an expected count of less than 5. The minimum expected count is .17.			

Key values; The Pearson chi-square = 136.728

The p-value of the test statistic = 0.000

4.4. The drivers for adopting IBM for sustainable construction

4.4.1. Descriptive analysis (Drivers of IBM)

The results of the 14 identified IBM drivers subjected to a survey among Nigerian built environment professionals were processed using RII analysis and ANOVA. A reliability check was conducted to validate the 5-point Likert scale using SPSS. As shown in Table 3.3, the Cronbach alpha result was computed at 0.894, indicating that the 5-point Likert scale used is statistically reliable and can be subjected to further analysis. The result of the descriptive analysis in Table 4.4 indicated that the respondents strongly agreed with all 14 identified drivers as the drivers of IBM for sustainable construction. The MIS ranges from 4.12 to 4.46, and the RII value ranges from 0.82 to 0.89. The most significant drivers were determined by ranking based on mean, standard deviation and RII; the rating levels are shown in Table 4.1.

Table 4. 4: Drivers for the adoption of innovative building materials

Code	Drivers	Mean	Std. Dev.	RII	Significance level	Rank
D1	Client's requirement	4.46	0.620	0.8922	VS	1st
D13	Government regulations	4.41	0.626	0.8816	VS	2nd

Code	Drivers	Mean	Std. Dev.	RII	Significance level	Rank
D9	Availability of IBM suppliers	4.36	0.634	0.8716	VS	3rd
D5	Developments in ICT/ Technology-push	4.34	0.618	0.8681	VS	4th
D11	Improved efficiency of the firm	4.30	0.631	0.8609	VS	5th
D7	Increase performance and productivity (cost saving, desired duration, improved quality)	4.29	0.608	0.8574	VS	6th
D12	Environmental sustainability	4.26	0.577	0.8512	VS	7th
D4	Availability of manufacturing firms	4.26	0.558	0.8511	VS	8th
D3	Demand-pull (client) vs Capability-push (contractor)	4.22	0.664	0.8433	VS	9th
D6	Design/Aesthetics trends	4.22	0.572	0.8432	VS	10th
D10	Procurement system for IBM	4.21	0.574	0.8418	VS	11th
D2	End-user requirement	4.20	0.593	0.8397	VS	12th
D8	Reduction in cost	4.18	0.561	0.8369	VS	13th
D14	Competitive advantage	4.12	0.553	0.8241	VS	14th

4.4.2. Discussion of findings (Drivers of IBM)

Based on Table 4.5, the 14 drivers of adopting IBM are discussed below in order of significance determined by the respondents.

The respondents ranked “clients’ requirements (D1)” as the most significant driver of adopting IBM for sustainable construction. Brandon and Lu (2008) and Eze *et al.* (2021) noted that clients play an essential role in driving innovation. Clients can drive the stakeholders and construction team to adopt IBM and sustainable construction to get value for their money. With clients and stakeholders increasingly looking for ways to improve the sustainability and efficiency of their buildings, this can drive demand for IBM, which offers improved performance and reduced environmental impact. Also, “government regulations (D13)” on IBM can drive IBM adoption. It was the second-most significant driver for IBM. Governments worldwide are implementing policies and regulations aimed at reducing the environmental impact of construction, including requirements for energy-efficient buildings, the use of renewable materials, and the reduction of greenhouse gas emissions (Nikyema and Blouin 2020). However, by imposing these requirements, governments can create a market for IBM and incentivise clients and stakeholders to adopt these materials (Eze, Sofolahan and Omoboye 2023).

"Availability of IBM suppliers (D9)", which is the third-ranked driver, can also drive the adoption of IBM mainly, when IBM suppliers are widely available (Kulatunga *et al.* 2011). A well-established, reliable and competitive IBM supply chain will help to ensure that the materials are available and accessible, reducing the time and costs associated with procurement. Thereby making IBM more appealing and accessible to building professionals, encouraging wider adoption of these materials. "Developments in ICT/technology-push (D5)" was IBM's fourth most significant driver. This is driving force of innovation in technology (Abadi 2014). Developments in ICT and technology-push help increase the availability of tools and solutions that enable building professionals to optimise their use of IBM, making it easier to choose and integrate these materials into their projects. "Improved efficiency of the firm (D11)" was identified as IBM's fifth most significant driver. According to (Ozorhon *et al.* 2010; Gambatese and Hallowell 2011), improved organisation efficiency was noted as a strong driver of construction innovation. This refers to the benefits building owners and contractors can achieve by using IBM, such as lower costs, improved quality, and reduced project duration. By incorporating IBM into their projects, building professionals can improve their performance and overall productivity, resulting in more efficient and cost-effective building processes.

According to the respondents, the sixth most significant driver of IBM was an "increase in performance and productivity (cost saving, desired duration, improved quality) (D7)", which is a direct result of the improved efficiency of the firm. By using IBM, building professionals can reduce costs, complete projects faster, and improve the overall quality of their work, resulting in increased performance and productivity. “Environmental sustainability (D12)” refers to the growing awareness and concern for the impact of building and construction on the environment. This has increased the demand for environmentally sustainable building materials, including IBM, making it an attractive option for building professionals. According to Kibert (2016), one crucial area of environmental sustainability is sustainable construction, which is extensively pursued after by governments, environmentalists, and other interested parties for its numerous benefits. “Availability of manufacturing firms (D4)” refers to the presence of companies that produce and supply IBM, making it easier for building professionals to access and use these materials in their projects. “Demand-pull (client) vs capability-push (contractor) (D3)” indicates the influence of clients and contractors (Ozorhon *et al.* 2010) in the adoption of IBM. If clients demand environmentally sustainable building materials, contractors may be more likely to use IBM as a sustainable building material. On the other hand, if contractors can use IBM and promote its benefits to clients, it can also drive its adoption.

“Design/aesthetics trends (D6)” indicate the growing emphasis on design and aesthetics in building and construction (Ozorhon *et al.* 2010; Owolabi and Faleye 2019). As building professionals aim to create attractive and visually appealing structures, they may be more likely to adopt IBM as it can offer unique design features and benefits. The “procurement system for IBM (D10)” indicates acquiring and incorporating these materials into building projects (Kulatunga *et al.* 2011). If the procurement system is efficient and streamlined, it can make it easier and more attractive for building professionals to use IBM, driving its adoption. “End-user requirement (D2)” indicates the increasing demand for more sustainable, energy-efficient, and environmentally friendly building materials. End-users such as building owners, occupants, and tenants are becoming more aware of the environmental impact of buildings. They are increasingly looking for materials that can help reduce their carbon footprint. “Reduction in cost (D8)” indicates the potential cost savings that can be achieved using innovative building materials. These materials often provide the same performance benefits as traditional materials while being less expensive in the long run due to lower maintenance costs and improved energy efficiency. Also, as discussed by Bingham in 2003, innovation, particularly in the public sector, often prioritises cost reduction as the primary driver and sometimes the sole criterion for selection.

According to the respondents, “competitive advantage (D14)” was the least significant driver of innovation. This may be because there needs to be a competitive advantage that supports or encourages IBM in the study area. (Magretta 2012) defines competitive advantage as the capability of a company to outperform others in its industry or market, which can be attained through innovation. Many researchers and practitioners believe that innovation is the starting point for gaining a competitive advantage (Xue *et al.* 2014). By using more sustainable, energy-efficient materials with a lower environmental impact, manufacturers can differentiate themselves in a crowded marketplace and attract more customers looking for environmentally responsible products and services.

4.4.3. ANOVA Application of materials against drivers for the adoption

In this study, Table 4.5 shows that the calculated p-value is 0.003, which is significantly lower than the chosen significance level of 0.05. This means that the observed relationship between the application of IBM and the drivers of adoption is considered statistically significant.

Table 4. 5: ANOVA Application of materials against drivers for the adoption

ANOVA					
Awareness based on Application					
	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	9.347	4	2.337	4.168	0.003
Within Groups	155.278	277	0.561		
Total	**164.624**	**281**			

Therefore, the findings suggest a strong and significant relationship between the application of IBM and the drivers of adoption. The term "drivers of adoption" refers to the factors or influences that lead to the acceptance and implementation of these materials. The results indicate that these drivers are closely linked to the application of IBM.

Furthermore, the findings suggest that applying these materials plays a crucial role in determining whether IBM will be adopted. In other words, the successful implementation and use of IBM depend on various drivers related to their application. This implies that factors such as clients' requirements, government regulations, availability of IBM suppliers, developments in ICT/technology push, and improved efficiency of the firm, among others, can influence the adoption of these materials in construction projects.

4.5. The barriers affecting the adoption of IBM for sustainable construction in the NCL

This section presents the findings on the barriers affecting the adoption of IBM for sustainable construction. The barriers to IBM were examined in this section. They were analysed using the mean item score (MIS), relative importance index (RII), KMO's test of sphericity, Bartlett's test of sphericity, and factor analysis.

4.5.1. Descriptive Analysis of IBM Barriers

This study identified 31 barriers to IBM adoption in developing countries' construction industries. Though the most critical barriers were determined by ranking based on mean, RII, and standard deviation, the rating levels are shown in Table 4.6.

Table 4. 6: Criticality levels based on RII rating

RII values	Criticality level	Codes
0.81 to 1	Very Critical	VC
0.61 to 0.8	Critical	C
0.41 to 0.6	Average	A
0.21 to 0.4	Less Critical	LC
0 to 0.2	Not Critical	NC

Table 4.7 revealed that thirty (30) barriers are considered highly critical, with the remaining barrier, BA22, categorised as critical. This data implies that all the barriers are associated with the Nigerian construction industry. Thus, exploring alternative methods, like factor analysis, is imperative to enhance the efficiency of examining these variables.

Table 4. 7: Barriers to IBM

Code	Barriers	Mean	Std. Dev.	RII	Criticality level	Rank
BA1	Lack of awareness and knowledge	4.53	0.591	0.9057	VC	1st
BA13	Learning/training period	4.43	0.699	0.8865	VC	2nd
BA3	Cost and economic viability	4.42	0.581	0.8844	VC	3rd
BA23	Lack of qualified staff	4.41	0.621	0.8829	VC	4th
BA19	Lack of end-user involvement	4.38	0.622	0.8766	VC	5th
BA11	Status quo in rules and regulations	4.37	0.583	0.8730	VC	6th
BA9	Lack of public interest and buyers' demand	4.36	0.544	0.8723	VC	7th
BA18	Poor funding for research and development, training, and education	4.35	0.568	0.8709	VC	8th
BA28	Lack of clear benefits	4.35	0.591	0.8702	VC	9th

Code	Barriers	Mean	Std. Dev.	RII	Criticality level	Rank
BA12	Availability of green/sustainable building materials	4.34	0.605	0.8674	VC	10th
BA27	Poor coordination and communication among project participants	4.34	0.594	0.8674	VC	11th
BA17	The perception that the industry is doing well without it	4.33	0.591	0.8652	VC	12th
BA29	Lack of sustainability measurement tools	4.32	0.581	0.8631	VC	13th
BA25	Poor innovation motivators in an organisation	4.32	0.628	0.8631	VC	14th
BA24	Lack of government policy	4.31	0.573	0.8617	VC	15th
BA20	Poor technical knowhow	4.28	0.588	0.8567	VC	16th
BA5	Characteristics of the construction industry: Project-based nature and Price-based competition	4.27	0.613	0.8539	VC	17th
BA15	Cultural aversion to change	4.25	0.655	0.8496	VC	18th
BA4	Industry regulations and codes	4.24	0.557	0.8475	VC	19th
BA8	Lack of local authority and government involvement	4.23	0.571	0.8454	VC	20th
BA30	Lack of exemplar demonstration projects	4.23	0.571	0.8454	VC	2st
BA21	Temporary nature of construction (one-off construction industry)	4.22	0.695	0.8433	VC	22nd
BA14	Associating sustainable concept with luxury living	4.21	0.560	0.8411	VC	23rd
BA26	Excessive subcontracting of construction works	4.18	0.526	0.8361	VC	24th
BA10	Employees resistance	4.18	0.557	0.8355	VC	25th
BA7	Passive culture	4.17	0.688	0.8333	VC	26th
B31	Unwillingness to change	4.16	0.498	0.8319	VC	27th
BA16	Project delivery method	4.13	0.523	0.8269	VC	28th
BA2	Lack of top management commitment	4.11	0.552	0.8219	VC	29th
BA6	Risk of failure	4.07	0.578	0.8135	VC	30th
BA22	Fragmented nature of construction	4.05	0.592	0.8092	C	31st

4.5.2. Suitability and adequacy check for factor analysis (FA)

Before conducting factor analysis (FA), several analyses were performed on the collected data to assess their suitability and adequacy for factor analysis. Initially, the sample size and number of variables were examined. The sample size of 282 was found to be sufficient, as suggested by previous studies (Hair *et al.* 2010; Pallant 2013). As for the number of variables, Hair *et al.* (1998) suggest that a range of 20—50 variables is commonly regarded as the most suitable for conducting factor analysis (FA). However, research has indicated that fewer variables can be utilised (Kim *et al.* 2016). Nonetheless, the 31 variables employed in this study were deemed sufficient for factor analysis. Eze, Idiake and Ganiyu (2018) suggest that variables with communalities figures of ≥ 0.5 align well with the construct and other variables. The findings presented in Table 4.8 reveal that out of the 31 barriers assessed, thirty (30) possess communality figures above 0.50. The communality value in the study ranged from a maximum of 0.842 to a minimum of 0.414, with an average communality value of 0.694. Based on these results, it can be concluded that the collected data is suitable and adequate for factor analysis, considering the number of barriers, sample size, and obtained communality figures.

Table 4. 8: Communalities figures

	Communalities	
Codes	**Initial**	**Extraction**
BA1	1.000	.692
BA 2	1.000	.615
BA 3	1.000	.704
BA4	1.000	.568
BA5	1.000	.719
BA6	1.000	.776
BA7	1.000	.693
BA8	1.000	.609
BA9	1.000	.685
BA10	1.000	.588

Communalities		
Codes	Initial	Extraction
BA11	1.000	.666
BA12	1.000	.799
BA13	1.000	.747
BA14	1.000	.630
BA15	1.000	.671
BA16	1.000	.554
BA17	1.000	.708
BA18	1.000	.761
BA19	1.000	.687
BA20	1.000	.715
BA21	1.000	.842
BA22	1.000	.690
BA23	1.000	.797
BA24	1.000	.776
BA25	1.000	.752
BA26	1.000	.675
BA27	1.000	.739
BA28	1.000	.738
BA29	1.000	.706
BA30	1.000	.636
BA31	1.000	.414
Extraction Method: Principal Component Analysis.		

4.5.3. Kaiser–Meyer–Olkin's Measure of Sampling Adequacy (KMO) and Bartlett's Test

The collected data's factorisability was assessed by applying KMO's measure of sampling adequacy and Bartlett's test of sphericity. For this study, Table 4.9 displays a KMO value of 0.908 and a significant level of 0.000 for Bartlett's test. Previous studies by Stern (2010) have recommended a KMO value greater than 0.7 to indicate an adequate sample size. Additionally, Pallant (2005) proposed that Bartlett's test of sphericity should yield a significant result ($p < 0.05$) for factor analysis to be considered appropriate. The KMO and Bartlett's test results for this study affirm that the gathered data is suitable for factor analysis.

Table 4. 9: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin's measure of sampling adequacy.		.908
Bartlett's test of sphericity	**Approx. Chi-Square**	6863.311
	df	465
	Sig.	.000

4.5.4. Factor analysis (Barriers of IBM)

The principal component analysis (PCA) extraction method was used to analyse the data, including 31 identified barriers, obtained from Lagos State, Nigeria. The data obtained from Lagos, Nigeria, which includes 31 identified barriers, underwent factor analysis using the principal component analysis (PCA) extraction method. The factor loading cutoff point of 0.50 was applied based on a valid response rate of 282. Table 4.10 also displays the criteria used for conducting PCA on the 31 variables and the calculated parameters for conducting PCA in the Nigeria column. The PCA focused on data reliability and adequacy verification.

Table 4. 10: Criteria for conducting PCA for IBM barriers

S/N	Criteria	Parameter	
		Minimum Required	**Lagos, Nigeria N = 282**
1	Factor loading value	0.30	≥ 0.50
2	Eigen factor value	> 1	
3	Kaiser-Meyer-Olkin (KMO) test	0.5	0.908
4	Bartlett's test of sphericity		6863.311
5	p-value		0.000
6	df		465
7	Sig.		0.000
8	Variable to the respondent ratio	1:5	1:9.10
9	Percentage of Variance	50%	68.879
10	Variable Communality Value ≥ 0.5	≥ 0.5	0.554 to 0.842
11	Reliability Statistics (Cronbach α)	0.60	0.951

4.5.4.1. Total variance explained

Having met the necessary conditions for factor analysis, PCA was performed using the extraction method. Table 4.11 presents the results, revealing that five (5) components were extracted with eigenvalues greater than 1. The extracted components accounted for 40.995% for Component 1, 13.217% for Component 2, 7.751% for Component 3, 3.621% for Component 4, and 3.295% for Component 5. Overall, the PCA and extracted components explained approximately 68.879% of the total cumulative variance, satisfying the criterion of factors explaining at least 50% of the variation as suggested by (Stern 2010; Papandrea *et al.* 2020).

Table 4. 11: Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	12.709	40.995	40.995	12.709	40.995	40.995	5.507	17.763	17.763
2	4.097	13.217	54.213	4.097	13.217	54.213	4.233	13.653	31.417
3	2.403	7.751	61.964	2.403	7.751	61.964	4.075	13.146	44.563
4	1.122	3.621	65.584	1.122	3.621	65.584	3.848	12.412	56.974
5	1.022	3.295	68.880	1.022	3.295	68.880	3.691	11.905	68.880
6	.888	2.864	71.744						
7	.753	2.428	74.172						
8	.718	2.318	76.490						
9	.640	2.063	78.553						
10	.585	1.888	80.441						
11	.561	1.809	82.250						
12	.524	1.691	83.941						
13	.465	1.499	85.440						
14	.448	1.445	86.884						
15	.409	1.319	88.204						
16	.363	1.172	89.376						
17	.349	1.125	90.500						
18	.343	1.106	91.606						
19	.329	1.060	92.666						
20	.296	.955	93.622						
21	.289	.932	94.554						
22	.257	.828	95.382						
23	.221	.713	96.094						
24	.211	.679	96.773						
25	.204	.657	97.431						
26	.185	.596	98.026						
27	.148	.479	98.505						
28	.140	.451	98.956						
29	.124	.399	99.356						
30	.109	.353	99.709						
31	.090	.291	100.000						

Extraction Method: Principal Component Analysis.

4.5.4.2. Scree plot graph

According to Pallant (2013), evaluating the scree plot when determining the specific components is advised. By examining the scree plot, the researcher looks for a noticeable change, or "elbow" in its shape, and only components beyond this point are considered for retention. By observing the scree plot depicted in Figure 4.10, it is evident that the slope of the curve gradually decreases, indicating a flattening of the explained variance as each eigenvalue diminishes. The information conveyed in Figure 4.10 reveals that five factors were derived from the extracted loadings, as also demonstrated in the scree plot. Consequently, the number of factors obtained corresponds to the count of data points ≥ 1, disregarding those directly below the value of 1. For the same purpose, this study also adopted the conventional approach proposed by Aghimien, Aigbavboa and Thwala (2019) of selecting an eigenvalue of 1 for factor extraction.

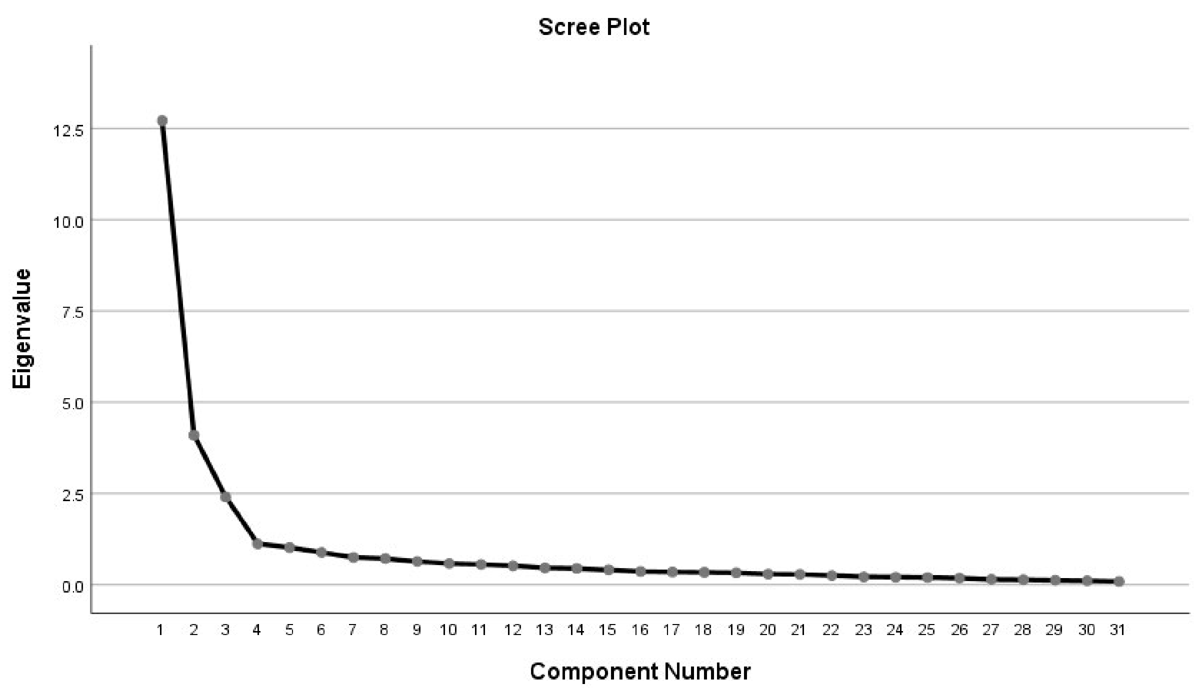

Figure 4. 10: Scree plot of the barriers affecting the adoption of IBM

4.5.4.3. Rotated Component Matrix

The findings in Table 4.12 display the five extracted components and the corresponding variables that load onto them. According to Spector (1992), a distinct component structure is evident when a variable exhibits a substantial factor loading (loading > 0.50) on a single component exclusively. Therefore, only factors with a loading of 0.50 or higher are considered significant and are included in the discussion for each principal component.

Table 4.10 demonstrates that the appropriate significance level from the PCA rotated component matrix is ≥ 0.50. Table 4.12 shows the rotated component matrix.

Table 4. 12: Rotated Component Matrix

Barriers of IBM	Component				
	1	2	3	4	5
Availability of green/ sustainable building materials	.788				
Lack of clear benefits	.785				
Poor funding for research and development, training and education	.783				
Lack of government policy	.757				
Poor technical knowhow	.739				
Lack of industry regulations and codes	.623				
Lack of exemplar demonstration projects	.616				
Associating sustainable concepts with luxury living		.813			
Temporary nature of construction (one-off construction industry)		.782			
Lack of sustainability measurement tools		.704			
Poor innovation motivators in an organisation		.702			
The perception that the industry is doing well without it		.690			
Cultural aversion to change		.504			
Risk of failure			.859		
Lack of top management commitment			.690		
Employees’ resistance			.668		
Fragmented nature of construction			.622		
Project delivery method			.583		
Excessive subcontracting of construction works			.553		
Lack of awareness and knowledge				.719	

Barriers of IBM	Component				
	1	2	3	4	5
Lack of public interest and buyers' demand				.695	
Cost & economic viability				.655	
Characteristics of the construction industry: Project-based nature and Price-based competition				.596	
Passive culture				.570	
Learning/training period				.538	
Unwillingness to change	x	x	x	x	x
Lack of qualified staff					.706
Status quo in rules and regulations					.675
Poor coordination and communication among project participants					.644
Lack of end-user involvement					.535
Lack of local authority and government involvement					.475
Extraction Method: Principal Component Analysis. ***Rotation Method: Equamax with Kaiser Normalisation.***					
a. Rotation converged in 17 iterations.					

4.5.4.4. Component naming

Table 4.13 shows the five-component naming. Component 1 is named Resource and Policy-related barriers and has seven variables. Component 2 is named Perception and Cultural related barriers and has six variables. Component 3 is named Organisational-related barriers and has six variables. Component 4 is named Awareness and Market-related barriers and has six variables. Component 5 is named Resistance and Stakeholder Engagement related barriers and has six variables.

Table 4. 13: Component naming

Component naming	Code	Barriers of IBM	Factor Loading
Component 1			
Resource and Policy related barriers	BA12	Availability of green/ sustainable building materials	.788
	BA28	Lack of clear benefits	.785
	BA18	Poor funding for research and development, training and education	.783
	BA24	Lack of government policy	.757
	BA20	Poor technical knowhow	.739

Component naming	Code	Barriers of IBM	Factor Loading
	BA4	Lack of industry regulations and codes	.623
	BA30	Lack of exemplar demonstration projects	.616
Component 2			
Perception and Cultural related barriers	BA14	Associating sustainable concepts with luxury living	.813
	BA21	Temporary nature of construction (one-off construction industry)	.782
	BA29	Lack of sustainability measurement tools	.704
	BA25	Poor innovation motivators in an organisation	.702
	BA17	The perception that the industry is doing well without it	.690
	BA15	Cultural aversion to change	.504
Component 3			
Organisational related barriers	BA6	Risk of failure	.859
	BA2	Lack of top management commitment	.690
	BA10	Employees' resistance	.668
	BA22	Fragmented nature of construction	.622
	BA16	Project delivery method	.583
	BA26	Excessive subcontracting of construction works	.553
Component 4			
Awareness and Market-related barriers	BA1	Lack of awareness and knowledge	.719
	BA9	Lack of public interest and buyers' demand	.695
	BA3	Cost & economic viability	.655
	BA5	Characteristics of the construction industry: Project-based nature and Price-based competition	.596
	BA7	Passive culture	.570
	BA13	Learning/training period	.538
Component 5			
Resistance and Stakeholder Engagement related barriers	BA31	Unwillingness to change	X
	BA23	Lack of qualified staff	.706
	BA11	Status quo in rules and regulations	.675
	BA27	Poor coordination and communication among project participants	.644
	BA19	Lack of end-user involvement	.535
	BA8	Lack of local authority and government involvement	.475
Extraction Method: Principal Component Analysis. Rotation Method: Equamax with Kaiser Normalisation.			
a. Rotation converged in 17 iterations.			

4.5.4.5. Component discussion

1. **Component 1: Resource and Policy related barriers**

The first principal component has the highest factor loading of the seven barriers, accounting for 40.9% of the total variance explained. These barriers are availability of green/sustainable building materials (BA12), lack of clear benefits (BA28), poor funding for research and development, training and education (BA18), lack of government policy (BA24), poor technical know-how (BA20), lack of industry regulations and codes (BA4), and lack of exemplar demonstration projects (BA30). The component is named "resource and policy-related" because it encompasses barriers that are directly linked to resources (such as the availability of sustainable building materials, funding, and technical expertise) and policies (including government policy, industry regulations, and a lack of exemplar demonstration projects). These factors highlight the key barriers arising from resource-related limitations and the absence, or inadequacy of supportive policies in adopting innovative building materials for sustainable construction in the Nigerian construction industry.

Resource-related barriers impede the effective deployment of IBMs due to challenges such as the limited availability of environmentally sustainable materials (Nikyema and Blouin 2020), a lack of demonstrative projects (Dzokoto and Dadzie 2013), shortages in skills and labour (Eze *et al.* 2019), and insufficient technical guidance (Owolabi and Faleye 2019). For policy-related barriers, these findings support the notion presented by Mohammed and Abbakyari (2016) that there currently needs to be a clear policy in Nigeria to promote sustainable building design and construction practices. This assertion is further supported by the findings of Dahiru, Abdulazeez and Abubakar (2012), who highlight that the National Building Code of 2006 does not adequately address the issue of sustainability.

2. **Component 2: Perception and Cultural related barriers**

The second principal component has a factor loading of six variables, accounting for 13.2% of the total variance explained. Variables loading on this component include: the association of sustainable concepts with luxury living (BA14), the temporary nature of construction projects (BA21), the lack of sustainability measurement tools (BA29), the absence of innovation motivators within organisations (BA25), the perception that the industry is doing well without sustainable practices (BA17), and cultural aversion to change (BA15). Based on the latent properties of these barriers, this component was subsequently named "perception and cultural related barriers" because the barriers within this group revolve around perceptions, cultural attitudes, and related barriers that hinder the adoption of IBM for sustainable construction. These factors shed light on the role of perception and cultural barriers in shaping attitudes and behaviours within the construction industry. According to research conducted by Ozorhon *et al.* (2010) and Owolabi and Faleye (2019), there is a perception within the industry that it is thriving without the incorporation of construction innovations such as IBM. This perception suggests that certain construction professionals and clients believe that conventional building materials and construction methods are satisfactory on their own, rendering IBM unnecessary. As a result, this perception can limit the willingness of building owners and design teams to select innovative materials, even when these materials offer significant advantages over traditional alternatives.

3. **Component 3: Organisational-related barriers**

The third principal component also has a factor loading of six variables, accounting for 7.8% of the total variance explained. The factors loading on this component are risk of failure (BA6), lack of top management commitment (BA2), employees' resistance (BA10), the fragmented nature of the construction industry (BA22), project delivery methods (BA16), and excessive subcontracting of construction works (BA26). These barriers are organisational-related; hence, the component was named “organisational related barriers” because the factors within this group pertain to barriers specifically related to organisational aspects. These factors highlight challenges and obstacles within the organisational structure, culture, and practices that hinder the adoption of innovative building materials for sustainable construction.

Issues regarding organisation have been observed as a significant challenge to achieving SC in Nigeria; barriers like lack of top management commitment (Abisuga and Oyekanmi 2014), employees' resistance (Ozorhon *et al.* 2010), the fragmented nature of the construction industry (Owolabi and Faleye 2019), project delivery methods, risk of failure (Gambatese and Hallowell 2011), and excessive subcontracting of construction works (Eze *et al.* 2019).

4. **Component 4: Awareness and Market-related barriers**

The fourth principal component has six factors loading significantly on it, accounting for 3.6% of the total variance explained. These barriers include lack of awareness and knowledge (BA1), lack of public interest and buyers' demand (BA9), cost and economic viability (BA3), characteristics of the construction industry such as its project-based nature and price-based competition (BA5), passive culture (BA7), and the learning/training period required for adopting innovative materials (BA13). This component was subsequently named “awareness and market-related barriers” because the factors within this group pertain to barriers directly related to awareness, knowledge, and market conditions. These factors highlight challenges and obstacles regarding awareness and market dynamics, which can hinder the adoption of innovative building materials for sustainable construction. This finding is in tandem with Addy *et al.* (2021) and Nikyema and Blouin (2020) assertion that in sub-Saharan Africa, barriers to sustainable development include a lack of knowledge and awareness, and an overemphasis on capital costs rather than operating costs. Also, market-related barriers impact the adoption and incorporation of IBM by stakeholders. The high cost of capital is identified as one of these barriers (Abisuga and Oyekanmi 2014).

Additionally, low market demand and a lack of client interest are significant issues, as highlighted in the literature by Hwang and Tan (2012) and Hwang and Ng (2013). Challenges related to extra costs and financial factors are reported to hinder the achievement of sustainable construction in building projects in Nigeria (Akadiri 2015; Aghimien *et al.* 2018). Financial aspects contribute to the low adoption of IBMs and the under-utilisation of sustainable construction markets in Nigeria and other developing nations (Eze *et al.* 2021).

5. Component 5: Resistance and Stakeholder Engagement related barriers

The last extracted principal component has six factors loading significantly, accounting for 3.3% of the total variance explained. These six barriers are: unwillingness to change (BA31), lack of qualified staff (BA23), status quo in rules and regulations (BA11), poor coordination and communication among project participants (BA27), lack of end-user involvement (BA19), and lack of local authority and government involvement (BA8). This component was subsequently named "resistance and stakeholder engagement related barriers" because the factors within this group pertain to barriers primarily associated with resistance to change and challenges related to stakeholder engagement. These factors highlight the obstacles and difficulties faced in overcoming resistance, engaging stakeholders effectively, and fostering collaboration in adopting innovative building materials for sustainable construction.

Resistance from critical stakeholders regarding innovative approaches, techniques, and materials in the construction industry is a prominent barrier to adopting innovative/green/sustainable building materials (Aghimien, Aigbavboa and Thwala 2019; Marsh, Brent and De Kock 2020; Umar, Lembi and Emechebe 2021). This resistance, coupled with an overreliance on existing methods and materials, hinders the achievement of sustainable construction (Eze, Sofolahan and Omoboye 2023). Consequently, adopting IBMs in Nigeria and other developing nations faces significant challenges (Akadiri 2015). To foster sustainability in the built environment and upgrade current structures, it is essential for construction stakeholders, including clients and experts, to embrace change and accept new approaches and materials for project delivery. Raising awareness and disseminating information about the benefits of incorporating IBMs can help overcome resistance, as knowledge of the advantages tends to generate interest and support for their use (Eze *et al.* 2021). Figure 4.11 shows the five components of barriers to IBM.

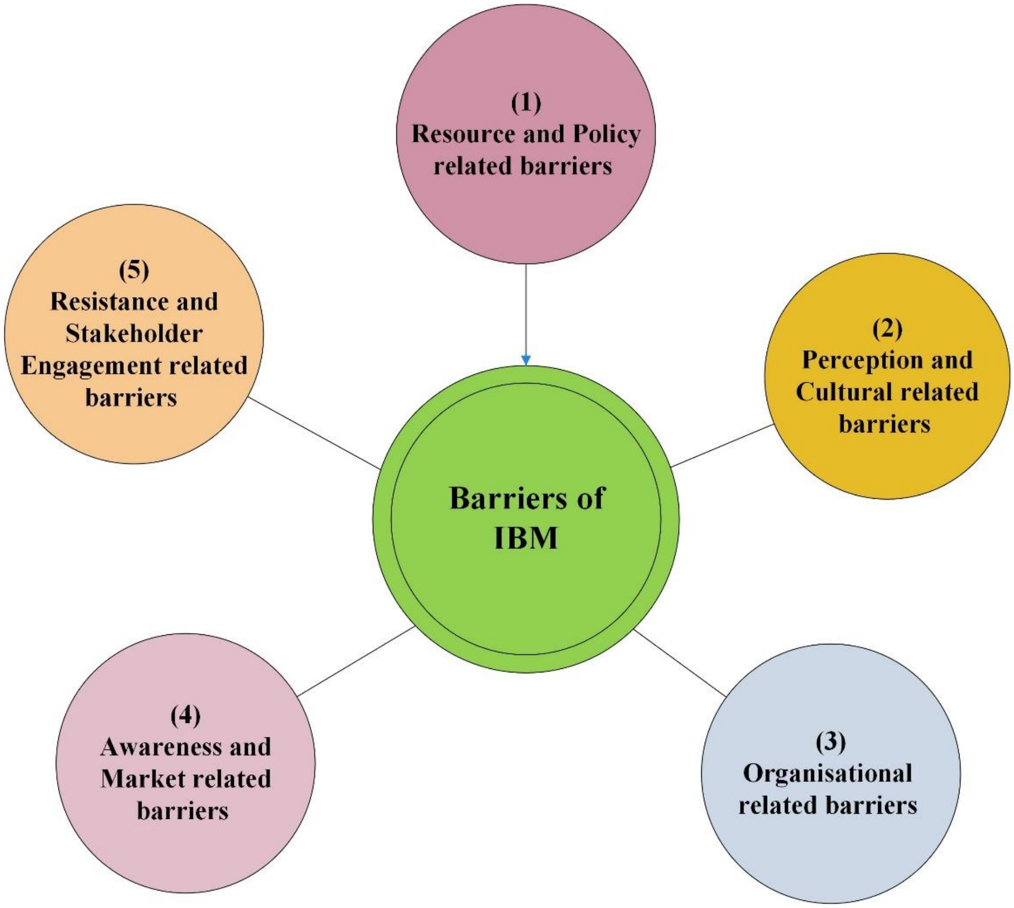

Figure 4. 11: Five components of barriers to IBM

4.6. The Benefits of the Adoption of IBM for sustainable construction

4.6.1. Descriptive analysis (Benefits of IBM)

In this study, a total of eighteen (18) benefits of adopting IBM were identified. To ensure the credibility of the research instrument, a reliability check using SPSS was carried out to validate the 5-point Likert scale. The resulting Cronbach alpha value, depicted in Table 3.3, was computed as 0.948 for IBM benefits, indicating that the scale is statistically reliable and suitable for further examination. By evaluating the mean values presented in Table 4.14, the 18 benefits were ranked, with scores ranging from 4.51 to 3.85. This data implies that all the benefits are associated with the Nigerian construction industry.

Table 4. 14: Benefits affecting the adoption of IBM

Code	Benefits	Mean	Std. Dev.	Rank
BE1	Sustainable and environmentally friendly	4.51	0.567	1st
BE9	Efficient use of energy	4.43	0.588	2nd
BE13	Environmental protection	4.43	0.557	3rd
BE5	Increasing the use of recycled waste as building materials	4.41	0.585	4th
BE11	Water conservation	4.38	0.597	5th
BE17	Partnering with countries with a better green rating and exchange of know-how	4.37	0.571	6th
BE15	Improved construction project outcomes	4.37	0.558	7th
BE7	Lower life-cycle costs	4.32	0.651	8th
BE10	Efficient use of materials	4.30	0.565	9th
BE14	Protection of the ecosystem and biodiversity	4.30	0.539	10th
BE16	Preventing global warming	4.29	0.555	11th
BE8	Improves the quality of life	4.29	0.541	12th
BE12	Waste minimisation	4.27	0.557	13th
BE3	Increase employees' productivity and reduce absenteeism	4.25	0.712	14th
BE4	Reduction of building material wastage	4.23	0.555	15th
BE18	Allows for integration of technology into construction	4.22	0.543	16th
BE6	Improved quality of air	4.21	0.612	17th
BE2	Low operating and maintenance cost	3.85	0.768	18th

4.6.2. Discussion of findings (Benefits of IBM)

People pursue innovation because it offers benefits (Akintoye, Goulding and Zawdie 2012). From Table 4.14, the eighteen (18) benefits of IBM, in order of significance according to the respondents, are discussed below:

"Sustainable and environmentally friendly (BE1)" was ranked first with a very high mean value of 4.51, indicating that IBM is designed to have a lower environmental impact throughout its life cycle. This can include using recycled materials, reducing energy consumption in production and during use, minimising waste, and reducing greenhouse gas emissions. These materials can also have a longer lifespan, which helps reduce the need for frequent replacement and the associated environmental impacts. Research of multiple sustainability studies highlights the emphasis placed on environmental impact, as it acts as the basis for the other components of sustainability (Obringer and Nateghi 2021). “Efficient use of energy (BE9)” was ranked second, indicating that IBM is often designed to improve building energy efficiency. This can be achieved by reducing the energy needed to produce the materials, improving insulation properties to reduce heating and cooling demands, and incorporating renewable energy sources into the building design (Darko *et al.* 2018). Additionally, energy-efficient buildings can provide occupants with a more comfortable indoor environment and help reduce dependence on non-renewable energy sources (Darko *et al.* 2018; Eze *et al.* 2021).

“Environmental protection (BE13)” was ranked third, indicating that IBM is designed to reduce the environmental impact of construction projects. IBM can also reduce water and air pollution and conserve natural resources (Darko *et al.* 2018; Eze *et al.* 2021). “Increasing the use of recycled waste as building materials (BE5)” was ranked fourth, indicating that it helps to reduce waste and conserve natural resources. By incorporating recycled materials into building projects, it is possible to divert waste from landfills and repurpose it for use in construction. This not only helps to reduce waste but also conserves natural resources that would have been required to produce new building materials. Also, using recycled materials can reduce the environmental impact of producing new materials, such as greenhouse gas emissions, water and air pollution, and deforestation (Du Plessis 2002; Bamigboye *et al.* 2019). “Water conservation (BE11)” was ranked fifth, indicating that IBM can reduce the water demand of buildings by using drought-resistant plants and water-efficient fixtures (Whole Building Design Guide 2021). “Partnering with countries with a better green rating and exchange of know-how (BE17)”, ranked sixth, can help spread sustainable construction practices and technologies to other countries, positively impacting the global environment. “Improved construction project outcomes (BE15)” was ranked seventh, indicating that IBM can lead to more efficient and effective construction processes, better building performance, and higher quality outcomes. “Lower life-cycle costs (BE7)” was ranked eighth, indicating that IBM can have a longer lifespan and lower maintenance costs, resulting in cost savings over the long term.

“Efficient use of materials (BE10)” was ranked ninth, indicating that IBM can reduce the number of materials needed for construction, which can reduce waste and conserve resources. “Protection of the ecosystem and biodiversity (BE14)” was ranked tenth, indicating that IBM is for sustainable construction because it can reduce the environmental impact of construction projects and help preserve natural habitats and ecosystems. “Preventing global warming (BE16)” was ranked eleventh, indicating that IBM can reduce the greenhouse gas emissions associated with the production and use of building materials, helping mitigate climate change's effects. “Improves the quality of life (BE8)” was ranked twelfth, indicating that sustainable buildings can provide better indoor air quality, natural lighting, and access to green spaces, improving occupants' health and well-being (Darko *et al.* 2018; Simpeh and Smallwood 2018). “Waste minimisation (BE12)” was ranked thirteenth, indicating that IBM can reduce waste generated during construction, helping to conserve resources. “Increase employees’ productivity and reduced absenteeism (BE3)” was ranked fourteenth, indicating that sustainable buildings can provide healthier indoor environments, leading to improved health and productivity among employees (Simpeh and Smallwood 2018). “Reduction of building material wastage (BE4)” was ranked fifteenth, indicating that IBM can reduce waste generated during construction and over the building's lifespan, helping to conserve resources and minimise environmental impact (Abolore 2013). “Allows for integration of technology into construction (BE18)" was ranked sixteenth, indicating that IBM can facilitate technology integration, such as building automation systems and smart materials, improving building performance and reducing environmental impact (Eze *et al.* 2021). "Improved quality of air (BE6)" was ranked seventeenth, indicating that sustainable buildings can provide better indoor air quality, improving the health and well-being of occupants (Eze *et al.* 2021).

"Low operating and maintenance cost (BE2)" was ranked eighteenth, indicating that IBM can have a longer lifespan and lower maintenance costs, resulting in cost savings over the long term and helping reduce the environmental impact associated with frequent replacement of building components. However, most respondents considered this benefit the least beneficial because they believed IBM has a high operating cost. Using sustainable building materials is generally estimated to cost more than traditional building materials, with research suggesting an increase in cost ranging from 1—25% (Dwaikat and Ali 2016). The cost difference between sustainable and traditional building materials is around 3—4% higher, as reported by (Zhang, Platten and Shen 2011).

4.7. Strategies for adopting IBM for sustainable construction in the NCI.

4.7.1. Descriptive analysis (Strategies of IBM)

This section presents the findings on the strategies for adopting IBM for sustainable construction. The strategies of IBM were examined in this section and analysed using the mean item score (MIS). Table 4.15 presents a report of respondents' views as analysed using mean scores and standard deviation. The table revealed that all strategies are essential and highly important; however, the most important strategy for adopting IBM based on mean rank is "owner/client support". The least important strategy for adopting innovative building materials based on mean rank is "using resources from more sustainable sources"**.**

Table 4. 15: Strategies for the adoption of IBM

Code	Strategies	Mean	Std. Dev.	Rank
S1	Owner/client support	4.64	.594	1st
S5	Appraisal of building code and establishment of sustainable building code	4.60	.559	2nd
S13	Provision of sustainable materials selection criteria	4.57	.582	3rd
S3	Mandatory governmental policies and regulations encouraging the use of IBM	4.56	.595	4th
S11	Regular inspections and monitoring of works with set rules and legislation	4.55	.596	5th
S7	Availability of institutional framework for effective implementation of IBM	4.54	.602	6th
S9	Supportive work environment	4.52	.660	7th
S2	Public awareness creation through workshops, seminars, and conferences	4.50	.592	8th
S8	Adequate training centres with adequate funding for research and development	4.47	.591	9th
S10	Establishment of enticements to inspire invention in sustainable construction	4.45	.584	10th
S6	Reducing resistance due to fear of changing traditional building materials	4.44	.607	11th
S14	Reducing costs through improving the supply of IBM	4.42	.610	12th
S4	Promotion of sustainable construction by the construction industry	4.40	.590	13th
S12	Use of resources from a more sustainable source	4.39	.605	14th

4.7.2. Discussion of findings (Strategies of IBM)

These fourteen (14) promotion strategies for adopting IBM, according to the order of significance given by the respondents, are discussed below.

“Owner/client support (S1)” was ranked first with a very high mean value of 4.64, indicating that it can be difficult to implement sustainable construction practices without the support of the building owners or clients. By engaging clients and stakeholders and educating them about the benefits of IBM, it is possible to build support for sustainable construction practices and encourage the broader adoption of IBM (Gambatese and Hallowell 2011). “Appraisal of building code and establishment of sustainable building code (S5)” was ranked second, indicating that building codes and regulations play an essential role in shaping construction practices. By reviewing existing building codes and establishing sustainable building codes, it is possible to create a regulatory framework that supports the use of IBM and promotes sustainable construction practices. This can include requirements for using sustainable materials, energy-efficient building designs, and incorporating renewable energy sources into building projects. This strategy was identified in various research papers (Mairami, Sanni and Jibrin 2020; Sagini 2020; Shittu 2021).

“Provision of sustainable materials selection criteria (S13)” was ranked third, indicating that it helps ensure that suitable materials are selected for construction projects. Providing clear criteria for sustainable materials selection (Abolore 2013) makes it possible to ensure that IBM is chosen based on its environmental and social impacts and performance characteristics. This can help ensure that the most appropriate materials are used and that sustainable construction practices are promoted (Shittu 2021). “Mandatory governmental policies and regulations encouraging the use of IBM (S3)” was ranked fourth, indicating that government policies and regulations can significantly shape construction practices. As a result, imposing the required laws and regulations for green building construction on stakeholders is critical to promoting adoption (Chan, Darko and Ameyaw 2017). By mandating the use of IBM, it is possible to create a regulatory framework that encourages sustainable construction and helps promote the broader adoption of IBM. Wong, Chan and Wadu (2016) discovered that the government's obligatory environmental restrictions were essential for the effectiveness of green acquisition in Hong Kong.

“Regular inspections and monitoring of works with set rules and legislations (S11)” was ranked fifth, indicating that it helps ensure that established standards and regulations carry out construction projects. By conducting regular inspections and monitoring work, it is possible to identify deviations from established rules and regulations and ensure that the work is being carried out in a safe and sustainable manner (Shittu 2021). “Availability of institutional framework for effective implementation of IBM (S7)” was ranked sixth, indicating that infrastructure and support systems must be put in place for the effective implementation of IBM. This can include establishing institutions such as research centres and testing facilities and creating regulatory and policy frameworks that support the use of IBM. Slaughter (1998) noted that research and development organisations like universities had become excellent sources of innovation. However, an adequate institutional framework can help ensure that IBM is developed, tested, and implemented safely and sustainably. This strategy was identified by Chan, Darko and Ameyaw (2017).

“Supportive work environment (S9)” was ranked seventh, indicating that it helps ensure that workers can effectively implement sustainable construction practices. By creating a supportive work environment, it is possible to encourage the broader adoption of IBM and ensure that workers have the necessary resources and support systems to carry out their work safely and sustainably. This strategy was identified by Ozorhon *et al.* (2010). “Public awareness creation through workshops, seminars, and conferences (S2)” was ranked eighth, indicating that it helps raise public awareness about the benefits of sustainable construction practices. Educating the public about the benefits of IBM can encourage the broader adoption of these materials and promote sustainable construction practices. “Adequate training centres with adequate funding for research and development (S8)” was ranked ninth, indicating that it helps ensure that workers are trained in the latest techniques and technologies for sustainable construction. By providing training and funding for research and development, it is possible to ensure that workers have the necessary skills and knowledge to implement sustainable construction practices effectively (Sagini 2020).

"Establishment of enticements to inspire invention in sustainable construction (S10)" was ranked tenth, indicating that it helps encourage innovation in developing and implementing sustainable building practices. This can include creating incentives such as grants, tax credits, subsidies for research and development of sustainable construction practices, and recognition and rewards for companies and individuals who lead the way in sustainable construction (Shittu 2021). "Reducing resistance due to fear of changing traditional building materials (S6)" was ranked eleventh. This indicates that it helps address any resistance to change that may be present in the construction industry (Mairami, Sanni and Jibrin 2020). This can include education and training programs that help workers understand the benefits of sustainable construction practices and dispel any misconceptions about the safety and durability of IBM. "Reducing cost through improving the supply of IBM (S14)" was ranked twelfth. This indicates that it helps reduce the cost of sustainable construction by improving the supply of these materials (Darko *et al.* 2018; Mairami, Sanni and Jibrin 2020). This can include the creation of partnerships with suppliers and manufacturers of IBM to improve the quality, availability, and affordability of these materials, as well as develop more efficient and cost-effective production methods.

"Promotion of sustainable construction by the construction industry (S4)" was ranked thirteenth, indicating that it helps raise awareness about the importance of sustainable construction practices. This can include the creation of industry-led initiatives and programs that promote sustainable construction and the participation of industry leaders in conferences, workshops, and other events that raise awareness about the benefits of sustainable construction practices (Shittu 2021). "Use of resources from more sustainable sources (S12)" was ranked fourteenth. This indicates that it helps ensure that the materials and resources used in construction are sourced from more sustainable sources (Shittu 2021). This can include the use of recycled materials, the implementation of more efficient resource management practices, and the development of supply chains that prioritise sustainable sourcing.

4.7.3. Chi-square test of association between the barriers and strategies for IBM adoption

This study investigated the relationship between barriers affecting the adoption of IBM and the strategies, shown in Table 4.16. The findings indicate that the statistical significance level chosen for the study ($\alpha = 0.05$) was surpassed by the calculated p-value. The p-value is a statistical measure used to determine the strength of evidence against the null hypothesis. In this case, the null hypothesis assumes no association or relationship between the barriers and the strategies. When the p-value is less than the significance level (α), it implies that the observed data is unlikely to have occurred by chance alone under the assumption of no association.

By rejecting the null hypothesis, the findings suggest that there is enough evidence to support the presence of an association between the barriers affecting the adoption of IBM and the strategies for adoption. This implies that the barriers are indeed related to the strategies, meaning that specific barriers to adopting IBM are influencing the strategies for adoption.

This finding implies that the study has identified a significant link between the barriers and the strategies, which can be valuable for various stakeholders involved in adopting IBM. It suggests that to enhance the adoption process, efforts should focus on addressing the identified barriers. Additionally, the strategies can serve as guidelines or solutions to overcome the barriers and facilitate the successful adoption of IBM.

Finally, the finding emphasises the importance of understanding and addressing the barriers to innovative building materials adoption. By recognising the association between these barriers and the strategies, stakeholders can make informed decisions and take appropriate actions to promote the adoption of innovative building materials within the industry.

Table 4. 16: Chi-square test of association between the barriers and strategies for IBM adoption

Chi-Square Tests			
	Value	**df**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	342.582[a]	12	.000
Likelihood Ratio	96.402	12	.000
Linear-by-Linear Association	84.182	1	.000
N of Valid Cases	282		
a. 16 cells (80.0%) have an expected count of less than 5. The minimum expected count is .01.			

Key values; The Pearson chi-square = 342.582

The p-value of the test statistic = 0.000

4.7.4. IBM Acceptance and IBM Adoption

In assessing the adoption of innovative building materials for sustainable construction within the Nigerian construction industry, two pertinent concepts come into play: IBM Acceptance and IBM Adoption. These concepts can be comprehensively elucidated through established theories, shedding light on the intricate dynamics of material adoption in this context.

a). IBM Acceptance

IBM Acceptance refers to individuals or organisations' initial perceptions and attitudes toward incorporating innovative building materials in construction practices. The Theory of Planned Behavior (TPB) and the Technology Acceptance Model (TAM) can be employed to understand this aspect. According to TPB, an individual's intention to adopt new technology, such as IBM, is influenced by their attitude towards the innovation, the subjective norm and perceived behavioural control (Faisal Shehzad *et al.* 2022). In the context of IBM Acceptance, this implies that positive attitudes towards the sustainability benefits of these materials, coupled with social encouragement and a sense of feasibility, can foster a favourable inclination towards their adoption. Similarly, TAM posits that perceived usefulness and ease of use significantly impact an individual's intention to adopt a technology (Chan *et al.* 2022; Faisal Shehzad *et al.* 2022). In the case of IBM Acceptance, this implies that if these materials are perceived as advantageous and uncomplicated to integrate, their acceptance is more likely.

b). IBM Adoption

On the other hand, IBM Adoption pertains to integrating and utilising IBM in construction projects. The Diffusion of Innovations Theory (DOI) and the Unified Theory of Acceptance and Use of Technology (UTAUT) can be applied to comprehend this phase. The Diffusion of Innovations Theory categorises adopters into groups based on their propensity to embrace new technologies, ranging from early adopters to laggards. This notion gains support from the research conducted by Eze, Sofolahan and Omoboye (2023), who noted that due to a pronounced resistance and a prevalent dependence on conventional materials and traditional project delivery methods, the construction sector is often perceived as laggards or late adopters in embracing environmentally friendly materials and technologies.

Within the framework of IBM Adoption, this theory suggests that the construction industry's willingness to adopt these materials may follow a similar trajectory. UTAUT, on the other hand, amalgamates various constructs from different technology acceptance models, highlighting the role of performance expectancy, effort expectancy, social influence, and facilitating conditions in shaping technology adoption (Faisal Shehzad *et al.* 2022). In the context of IBM Adoption, this implies that if these materials are perceived as enhancing construction outcomes, requiring manageable effort, endorsed by influential peers, and supported by accessible resources, their integration into construction projects becomes more feasible.

Comprehending the challenges of utilising sustainable or innovative building materials can facilitate more informed and effective decision-making among industry stakeholders (Eze, Sofolahan and Omoboye 2023). Consequently, this understanding could foster an enhanced adoption and integration of these environmentally sustainable materials in construction projects within Nigeria and on a broader scale.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

The study was conducted to assess the adoption of IBM for sustainable construction in the Nigerian construction industry. This chapter summarises the key findings of each research objectives and presents conclusion and recommendations related to the set objectives evaluated in this study.

5.2. Summary of Key Findings

The research objectives were designed to fulfil the purpose of the study, as outlined in the research plan. The first objective aimed to assess awareness of some current available IBM used for sustainable construction in the Nigerian construction industry. Objective two sought to examine the drivers that can improve the adoption of IBM for sustainable construction. The third objective aimed to assess the barriers that affect the adoption of IBM for sustainable construction in the Nigerian construction industry. Objective four focused on investigating the benefits of adopting IBM for sustainable construction in Nigeria. Lastly, objective five aimed to identify and recommend strategies for successfully adopting IBM for sustainable construction in the Nigerian construction industry.

5.2.1. Objective 1: Level of Awareness of some current IBM

Six of IBM's awareness levels are divided into awareness, relevance, and application. For awareness of the six selected IBM, the research has shown that "smart glass windows" had the highest awareness ranking, followed by "cross laminated timber (CLT)," "pigmented/coloured concrete," and "3D-printed graphene." This indicates that professionals in the study are most familiar with these materials. The findings also suggest a notable improvement in awareness compared to a previous study, which reported low awareness and knowledge of sustainable building materials.

The relevance of the IBM was assessed, and the results indicated that all of them were considered relevant by the respondents, with smart glass windows being perceived as highly relevant and light-generating concrete as the least relevant. This suggests that professionals in the industry are well aware of the benefits and relevance of IBM.

The application of the six IBM was assessed, with smart glass windows identified as the most applicable among them. However, despite IBM's awareness and perceived relevance, the findings reveal a low level of adoption among professionals in the Nigerian construction industry.

Also, the chi-square test analysis indicates a strong association between the level of awareness and the application of IBM in the Nigerian construction industry. Implying that higher levels of awareness are linked to increased adoption of IBM, while lower awareness levels hinder utilisation.

5.2.2. Objective 2: Drivers of IBM

The study shows that the respondents strongly agreed with all 14 identified drivers for IBM in sustainable construction. The most significant driver, as identified by the respondents, was “clients' requirements,” followed by “government regulations,” “availability of IBM suppliers,” “developments in ICT/technology-push,” and “improved efficiency of the firm.” These drivers also highlight the importance of client demand, regulatory policies, access to suppliers, technological advancements, and improved operational efficiency in driving the adoption of IBM. Other drivers included increase in performance and productivity, environmental sustainability, availability of manufacturing firms, demand-pull vs capability-push, design/aesthetics trends, procurement system for IBM, end-user requirements, reduction in cost, competitive advantage, and competitive advantage.

Also, the ANOVA analysis shows a significant relationship between the application of IBM and the drivers for their adoption. This implies that the application of these IBM is influenced by the drivers identified, and their successful implementation determines their adoption.

5.2.3. Objective 3: Barriers to IBM

The study shows 30 highly critical barriers and one critical barrier, indicating that all the barriers are relevant to the Nigerian construction industry. The first five highly critical barriers are: lack of awareness and knowledge (BA1), learning/training period (BA13), cost and economic viability (BA3), lack of qualified staff (BA23), and lack of end-user involvement (BA19). The 31 barriers were divided into five (5) components using factor analysis, namely, “resource and policy related barriers” with seven variables; “perception and cultural related barriers” with six variables; “organisational related barriers” with six variables; “awareness and market-related barriers’ with six variables; and “resistance and stakeholder engagement related barriers” with six variables. These findings suggest that addressing these barriers is essential for overcoming challenges and promoting the adoption of IBM in the construction industry.

5.2.4. Objective 4: Benefits of IBM Adoption

In this research, 18 benefits were identified. From the perspective of Nigerian construction professionals, 17 benefits were seen as very important, with a mean score greater than 4. In contrast, BE2 (low operating and maintenance cost) was considered significant, with a mean score of 3.85. The first five significant benefits are: sustainable and environmentally friendly (BE1), efficient use of energy (BE9), environmental protection (BE13), increasing the use of recycled waste as building materials (BE5), and water conservation (BE11). This data implies that all the benefits are associated with the Nigerian construction industry.

5.2.5. Objective 5: Strategies to Promote IBM Adoption

Regarding the strategies needed to promote the successful adoption of IBM for sustainable construction in the Nigerian construction industry, this study's findings pointed that all 14 strategies identified are crucial and highly important. This study has shown that Nigerian construction professionals are more concerned with the wide adoption of IBM in Nigeria. The first five highly important strategies are: owner/client support (S1), appraisal of building code and establishment of sustainable building code (S5), provision of sustainable materials selection criteria (S13), mandatory governmental policies and regulations encouraging the use of IBM (S3), and regular inspections and monitoring of works with set rules and legislation (S11).

5.3. Conclusion

Based on the findings of this study, there is an adequate awareness level of IBM for sustainable construction among Nigerian construction professionals and based on the findings, there is a need for increased awareness and promotion of IBM for sustainable construction in Nigeria. All six innovative building materials under study may be the most promising materials to invest in and adopt in construction projects. The results identified that 14 drivers of IBM revealed significant agreement among the professionals on all of the identified benefits. It was noted that they are all vital and already have an insight into the capabilities of IBM.

Still, much more effort has to be made to increase understanding and adoption of IBM in the building construction industry. This study established that there are still IBM-related barriers peculiar to Nigeria; these barriers could be responsible for their low adoption and application in the Nigerian construction industry. The contributions of built environment professionals, professional bodies, and policymakers (the government) will go a long way in limiting or eradicating these barriers and promoting their adoption and application. In addition, building and construction professionals also need to be willing to learn and adopt IBM for sustainable construction to remain relevant and compete with professionals in the construction industry globally.

The results of the benefits derived from using IBM revealed that all of the 18 identified benefits are very significant among professionals. This means they already have an insight into the importance of IBM. Their ability to have sufficient working experience, engagement in building production, and usage of building materials during building design and construction stages aids their understanding of its importance. The result drawn from these research findings based on the impact of successful BIM applications reveals that BIM has significantly improved building products through its contribution to performing tasks from building design to post-construction stages.

The findings on the strategies needed and recommended to promote the successful adoption of IBM in the construction industry are: the need for foundational knowledge in an educational institution about IBM for sustainable construction, with an emphasis on government and professional bodies' support in the actualisation of IBM adoption and the readiness of the professionals to take charge of the innovation.

Finally, this study affirms that the extent to which IBM is used for sustainable construction in Nigeria still needs to be improved. There is a need to advocate for sufficient training for built environment professionals and to encourage educational institutions to incorporate sustainable practices into their curricula. This will improve the utilisation of IBM adoption. By promoting the use of IBM, the construction industry in Nigeria has the potential to contribute to the country's sustainable development. Note that this study is limited to Lagos State's construction industry. Therefore, further study can be conducted in other construction-oriented states in Nigeria.

5.4. Recommendation

Based on the conclusion drawn from the study, the following recommendations are proposed:

1. Building material manufacturers and suppliers should engage with clients and building professionals and educate them about IBM's benefits and performance characteristics. This can help build knowledge and awareness about these materials and promote their wider adoption in the building and construction industry.
2. Building code organisations and policy regulators should keep pace with technological advancements and update their codes and standards to allow for the use of IBM. This can help ensure these materials are used safely and efficiently, promoting wider adoption.
3. Governments, construction firms, building material manufacturers, and suppliers should invest in research and development, training, and education programs to support the growth and development of IBM.
4. There should be clear communication of the benefits of IBM and demonstrations of their performances through real-world projects in Nigeria. This can build trust and increase the willingness of end-users and stakeholders to choose these materials, promoting wider adoption and driving industry growth.
5. Collaboration with government agencies and the construction industry to develop policies and regulations promoting innovative building materials.
6. Provision of sustainability measurement tools, promotion of the benefits of innovative building materials and working with building owners and stakeholders to create incentives for sustainability.
7. Senior sustainability leaders or stakeholders in the construction industry demonstrate their commitment to sustainability and innovation by investing in developing and adopting

innovative building materials.

8. The resource and policy-related barriers can be addressed by developing and implementing a clear and comprehensive policy that promotes the use of innovative and sustainable building materials in construction projects by the Nigerian government.

9. Addressing these perceptions and cultural-related barriers is crucial for fostering a positive perception of sustainable concepts, promoting innovation and change, and overcoming cultural aversions. By recognising and addressing these barriers, stakeholders can work towards creating a more conducive environment for adopting innovative building materials for sustainable construction.

10. Addressing these organisational-related barriers is crucial for creating a supportive organisational culture, fostering stakeholder buy-in, and successfully adopting innovative building materials for sustainable construction. By recognising and addressing these barriers, organisations can overcome internal challenges and promote a more conducive environment for adopting sustainable practices.

11. Addressing these awareness and market-related barriers is crucial for creating market demand, generating interest among buyers, addressing economic viability concerns, and fostering a supportive market environment for adopting innovative building materials for sustainable construction. By recognising and addressing these barriers, stakeholders can work towards creating a more informed and receptive market, facilitating the wider adoption of sustainable construction practices.

12. Addressing this resistance and stakeholder engagement-related barriers is crucial for overcoming resistance, fostering stakeholder support and involvement, enhancing

collaboration and communication, and ensuring the successful adoption of innovative building materials for sustainable construction. By recognising and addressing these barriers, stakeholders can work towards creating a more engaged and cooperative environment, facilitating the wider adoption of sustainable construction practices.

5.5. Potential Outputs

The research study aims to identify and analyse the adoption of innovative building materials (IBM) for sustainable construction in the Nigerian construction industry. The potential outputs of this research include the following:

1. Identification of the IBM currently available in the Nigerian construction industry and their potential benefits towards sustainable construction.
2. Assessment of the level of adoption of IBM in the Nigerian construction industry.
3. Recommendation of strategies for successfully adopting IBM for sustainable construction in the Nigerian construction industry.
4. Identification of the barriers affecting the successful adoption of IBM in the Nigerian construction industry and recommendations for mitigating these barriers.
5. Contribution of empirical data to the body of knowledge on adopting IBM for sustainable construction in developing countries.
6. Dissemination of the research findings through academic publications and conference presentations, contributing to the advancement of sustainable construction practices in Nigeria and beyond.

5.6. Recommendation for further research

1. An in-depth analysis of Nigeria's regulatory framework for adopting innovative building materials, including assessing the current policies and regulations affecting their use.

2. A case study approach that analyses specific examples of successful adoption of innovative building materials in the Nigerian construction industry.
3. A comparative study that evaluates the adoption of innovative building materials in other countries focuses on best practices and lessons learned.
4. An examination of government and private sector stakeholders' roles in promoting the adoption of innovative building materials in Nigeria, including an assessment of the current partnerships and collaborations.
5. An investigation into the availability of funding and support mechanisms for adopting innovative building materials in Nigeria, including an assessment of the current financing and investment options available.

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APPENDIX 1: LETTER OF INFORMATION

DUT DURBAN UNIVERSITY OF TECHNOLOGY INSTITUTIONAL RESEARCH ETHICS COMMITTEE

LETTER OF INFORMATION

Title of the Research Study: Assessment of the Adoption of Innovative Building Materials (IBM) for Sustainable Construction in Nigerian Construction Industry.

Principal Investigator/s/researcher: Mogaji, Iseoluwa Joanna **-** B. Tech Building

Co-Investigator/s/supervisor/s: Dr. M.C. Mewomo

Top of the day to you, I am Mogaji, Iseoluwa Joanna, a Master student in the Department of Construction Management and Quantity Surveying, Durban University of Technology, Steve Biko Campus, Durban, South Africa.

I would like to invite you to participate in this research. Research is a systematic investigation or enquiry for generalized new knowledge or the use of existing knowledge in a new and creative way so as to generate new concepts.

I am currently conducting research on **"*Assessment of the Adoption of Innovative Building Materials (IBM) for Sustainable Construction in Nigerian Construction Industry*"**. This study aims to investigate the adoption of innovative building materials for sustainable construction in the Nigerian construction industry to promote the adoption of Innovative Building Materials among construction professionals for sustainable construction in Nigeria. The questionnaire, therefore, seeks to:

1. assess the level of awareness of some current available innovative building materials used for sustainable construction in the Nigerian construction industry.
2. investigate the drivers for the adoption of innovative building materials for sustainable construction.
3. assess the barriers to the adoption of innovative building materials for sustainable

construction in the Nigerian construction industry.

4. examine the benefits of the adoption of innovative building materials for sustainable construction.
5. determine strategies for the successful adoption of innovative building materials for sustainable construction in the Nigerian construction industry.

A description of the procedures to be followed in administering Questionnaire

Section A: Demographic information of respondent and organisation.

Section B: The level of awareness of some current available innovative building materials used for sustainable construction.

Section C: The drivers to the adoption of innovative building materials for construction projects.

Section D: The barriers to the adoption of innovative building materials for construction projects.

Section E: The benefits of the adoption of innovative building materials for construction projects.

Section F: The strategies for the successful adoption of innovative building materials for sustainable construction.

You are kindly requested to complete the questionnaire. There are no names required in this survey. Participation is voluntary and you are free to withdraw at any time with no negative consequences to you. The questionnaire will take between 20 and 25 minutes to complete. The data collected will be treated anonymously and the findings of the survey will be used for the research purposes only. Please note that there are no risks, current or anticipated, to you as a participant in this research. The researcher will take the responsibility to protect the participants as an ethical commitment that considers the participant's rights. Confidentiality and anonymity of the research participants will be of a high degree to the researcher. This will be achieved by not asking for personal details of the participant e.g., names, ID number, cell phone number, etc. All data acquired from the survey questionnaires will be analysed by the researcher and sent in as part of the dissertation which will be stored in the DUT premises for five (5) years, and thereafter destroyed. The participant is entitled to withdraw from the study at any time should they wish to do so and will still continue to receive the appropriate standard of care. Your co-operation will be greatly appreciated.

In the event of any problems or concerns/questions, you may contact the researcher at 22176047@dut4life.ac.za, cell: (+234)8038047313, my supervisor at modupem@dut.ac.za, Cell: 0744870101, or the Institutional Research Ethics Administrator on 031 373 2375.

Complaints can be reported to the Acting Director: Research and Postgraduate Support Prof K Motaung on TtiDirector@dut.ac.za.

Thank you.

APPENDIX 2: LETTER OF INFORMED CONSENT

DUT DURBAN UNIVERSITY OF TECHNOLOGY — INSTITUTIONAL RESEARCH ETHICS COMMITTEE

CONSENT

Full Title of the Study: Assessment of the Adoption of Innovative Building Materials (IBM) for Sustainable Construction in Nigerian Construction Industry

Names of Researcher/s: Mogaji, Iseoluwa Joanna

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, ___**Mogaji, Iseoluwa Joanna**__, about the nature, conduct, benefits, and risks of this study - Research Ethics Clearance Number: ______**IREC 204/22**_______,
- I have also received, read, and understood the above written information (Participant Letter of Information) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerised system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

Sincerely,

Mogaji J. Iseoluwa

APPENDIX 3: QUESTIONNAIRE

DUT DURBAN UNIVERSITY OF TECHNOLOGY

QUESTIONNAIRE SURVEY ON ASSESSMENT OF THE ADOPTION OF INNOVATIVE BUILDING MATERIALS (IBM) FOR SUSTAINABLE CONSTRUCTION IN THE NIGERIAN CONSTRUCTION INDUSTRY

I am Mogaji, Iseoluwa Joanna, a Master's student in the Department of Construction Management and Quantity Surveying, Durban University of Technology, Steve Biko Campus, Durban, South Africa. I am currently conducting research on "**Assessment of the Adoption of Innovative Building Materials (IBM) for Sustainable Construction in the Nigerian Construction Industry**."

This study aims to investigate the adoption of innovative building materials for sustainable construction in the Nigerian construction industry to promote the adoption of Innovative Building Materials among construction professionals for sustainable construction in Nigeria. The questionnaire, therefore, seeks to:

1. assess the level of awareness of some current available innovative building materials used for sustainable construction in the Nigerian construction industry.
2. investigate the drivers for the adoption of innovative building materials for sustainable construction.
3. assess the barriers to the adoption of innovative building materials for sustainable construction in the Nigerian construction industry.
4. examine the benefits of the adoption of innovative building materials for sustainable construction.

5. determine strategies for the successful adoption of innovative building materials for sustainable construction in the Nigerian construction industry.

You are kindly requested to complete the questionnaire. There are no names required in this survey. Participation is voluntary, and you can withdraw without negative consequences. The questionnaire will take about 20 to 25 minutes to complete. The data collected will be treated anonymously, and the survey findings will be used for research purposes only. Please note that there are no current or anticipated risks to you as a participant in this research. Your co-operation will be greatly appreciated. For any queries or comments regarding the survey, please contact 22176047@dut4life.ac.za cell: (+234)8038047313, or modupem@dut.ac.za cell: +27744870101. Your completion of the survey will be understood to meet the requirements of informed consent according to the following:

"I have been invited to participate in the study named above and have also been informed about my involvement in the research and what is required of me. I understand that:

- My participation in this research is voluntary;
- I may withdraw from the research at any time with no negative consequences for myself;
- This study has been described to me in a language that I understand;
- My answers will be kept confidential;
- I agree that my responses from the questionnaire can be used for the research.

With full knowledge of all preceding, I agree to participate in this study."

Thank you in anticipation of your positive response to this request.

QUESTIONNAIRE SURVEY ON ASSESSMENT OF THE ADOPTION OF INNOVATIVE BUILDING MATERIALS (IBM) FOR SUSTAINABLE CONSTRUCTION IN THE NIGERIAN CONSTRUCTION INDUSTRY

Instruction: Please tick "√" in boxes with the most appropriate.

SECTION A: DEMOGRAPHIC INFORMATION OF RESPONDENT AND ORGANISATION

1). Gender of the respondent

(a) Female [ ]

(b) Male [ ]

2). Profession of respondent

(a) Architect [ ]

(b) Builder [ ]

(c) Engineer [ ]

(d) Quantity Surveyor [ ]

3). Highest Academic Qualification.

(a) National Diploma (ND) [ ]

(b) Higher National Diploma (HND) [ ]

(c) B. Tech /B. Sc [ ]

(d) M. Tech / M. Sc [ ]

(e) Ph. D [ ]

4). Years of experience as a respondent in the construction industry

(a) 1 - 5 years [ ]

(b) 6 - 10 years [ ]

(c) 11 - 15years [ ]

(d) 16 - 20 years [ ]

(e) Over 20 years [ ]

5). Professional qualification of respondents

(a) NIA [ ]

(b) NIOB [ ]

(c) NSE [ ]

(d) NIQS [   ]

6). Membership status

(a) Fellow [   ]

(b) Corporate [   ]

(c) Graduate [   ]

(d) Technologist [   ]

(e) Licentiate [   ]

(f) Technician [   ]

(g) Craftsmen [   ]

(h) Student [   ]

7). **Area of specialisation** (Tick only one).

(a) Clients [   ]

(b) Contractors [   ]

(c) Subcontractors [   ]

(d) Consultants [   ]

(e) Site engineers/supervisors [   ]

(f) Professional bodies representative [   ]

(g) Educational Institution representative/Researcher [   ]

8). Area of operation

(a) Consulting [   ]

(b) Contracting [   ]

(c) Client organisation [   ]

(d) Government establishment [   ]

9). Number of years of organisation operation

(a) 1 - 5 years [   ]
(b) 6 - 10 years [   ]
(c) 11 - 15 years [   ]
(d) 16 - 20 years [   ]
(e) Over 20 years [   ]

SECTION B: THE LEVEL OF AWARENESS OF SOME CURRENT AVAILABLE INNOVATIVE BUILDING MATERIALS (IBM) USED FOR SUSTAINABLE CONSTRUCTION IN THE NIGERIAN CONSTRUCTION INDUSTRY

10. Kindly use the ratings below to answer the following questions.

(a). What is your level of awareness of the following innovative building materials?

Level of Awareness: 1- Not Aware, **2-** Slightly Aware, **3-** Aware, **4-** Very Aware, **5-** Very much Aware

(b). To what extent do you agree with the relevance of the various innovative building materials?

Relevance: **1-** Not Relevant, **2-** Fairly Relevant, **3-** Relevant, **4-** Very Relevant, **5-** Highly Relevant

(c). How often do you use these innovative building materials in your construction site?

Application: 1- Not Applicable, **2-** Fairly Applicable, **3-** Applicable, **4-** Very Applicable, **5-** Highly Applicable

S/N	Some current Innovative Building Materials used for sustainable construction	Level of awareness					Relevance to the construction industry					Application to your construction site				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	Pigmented/coloured concrete															
2	Light-generating concrete															
3	Cross Laminated Timber (CLT)															
4	Timbercrete															
5	Smart glass windows															
6	3D-printed graphene															

SECTION C: DRIVERS FOR THE ADOPTION OF INNOVATIVE BUILDING MATERIALS (IBM) FOR SUSTAINABLE CONSTRUCTION.

11. To what extent do you agree with the following drivers for adopting innovative building materials for sustainable construction?

Below are some of the selected drivers or motivators for adopting innovative building materials for sustainable construction in the construction industry.

Kindly use the ratings below to answer the following questions

Tick as appropriate: **1-** Strongly disagree, **2-** Disagree, **3-** Undecided, **4-** Agree, **5-** Strongly Agree

S/N	Drivers for the Adoption of Innovative Building Materials	1	2	3	4	5
1	Client's requirement					
2	End-user requirement					
3	Demand-pull (client) vs capability-push (contractor)					
4	Availability of manufacturing firms					
5	Developments in ICT/Technology-push					
6	Design/Aesthetics trends					
7	Increase performance and productivity (cost saving, desired duration, improved quality)					
8	Reduction in cost					
9	Availability of IBM suppliers					
10	Procurement system for IBM					
11	Improved efficiency of the firm					
12	Environmental sustainability					
13	Government regulations					
14	Competitive advantage					

SECTION D: THE BARRIERS AFFECTING THE ADOPTION OF INNOVATIVE BUILDING MATERIALS (IBM) FOR SUSTAINABLE CONSTRUCTION IN THE NIGERIAN CONSTRUCTION INDUSTRY

12. What is your level of agreement with the following barriers affecting the adoption of innovative building materials for sustainable construction in the Nigerian construction industry?

Below are some barriers hindering the adoption of innovative building materials in the construction industry.

Kindly use the ratings below to answer the following questions

Tick as appropriate: **1-** Strongly disagree, **2-** Disagree, **3-** Undecided, **4-** Agree, **5-** Strongly Agree.

S/N	Barriers Affecting the Adoption of Innovative Building Materials	1	2	3	4	5
1	Lack of awareness and knowledge					
2	Lack of top management commitment					
3	Cost & economic viability					
4	Lack of industry regulations and codes					
5	Characteristics of the construction industry: Project-based nature and Price-based competition					
6	Risk of failure					
7	Passive culture					
8	Local authority's and government's involvement					
9	Lack of public interest and buyers' demand.					
10	Employees' resistance					
11	Status quo in rules and regulations					
12	Availability of green/sustainable building materials.					
13	Learning/training period.					
14	Associating sustainable concepts with luxury living.					
15	Cultural aversion to change					
16	Project delivery method					
17	The perception that the industry is doing well without it					
18	Poor funding for research and development, training, and education.					
19	Lack of end-user involvement					
20	Poor technical knowhow					
21	Temporary nature of construction (one-off construction industry)					
22	Fragmented nature of construction					
23	Lack of qualified staff					
24	Lack of government policy					
25	Poor innovation motivators in an organisation					
26	Excessive subcontracting of construction works					
27	Poor coordination and communication among project participants					
28	Lack of clear benefits					
29	Lack of sustainability measurement tools					
30	Lack of exemplar demonstration projects					
31	Unwillingness to change					

SECTION E: THE BENEFITS OF THE ADOPTION OF INNOVATIVE BUILDING MATERIALS (IBM) FOR SUSTAINABLE CONSTRUCTION.

13. What is your level of agreement with the following benefits of adopting innovative buildings for sustainable construction?

Below are the benefits or advantages of adopting innovative building materials in the construction industry.

Kindly use the ratings below to answer the following questions

Tick as appropriate: 1- Strongly disagree, **2-** Disagree, **3-** Undecided, **4-** Agree, **5-** Strongly Agree.

S/N	Benefits of the Adoption of Innovative Building Materials	1	2	3	4	5
1	Sustainable and environmentally friendly					
2	Low operating and maintenance cost					
3	Increase employees' productivity and reduce absenteeism.					
4	Reduction of building material wastage					
5	Increasing the use of recycled waste as building materials					
6	Improved quality of air					
7	Lower life-cycle costs					
8	Improves the quality of life					
9	Efficient use of energy					
10	Efficient use of materials					
11	Water conservation					
12	Waste minimisation					
13	Environmental protection					
14	Protection of the ecosystem and biodiversity					
15	Improved construction project outcomes					
16	Preventing global warming					
17	Partnering with countries with better green ratings and exchange of know-how					
18	Allows for integration of technology into construction					

SECTION F: THE STRATEGIES FOR THE SUCCESSFUL ADOPTION OF INNOVATIVE BUILDING MATERIALS (IBM) FOR SUSTAINABLE CONSTRUCTION IN THE NIGERIAN CONSTRUCTION INDUSTRY.

14. What is your level of agreement with the following strategies for the successful adoption of innovative building materials for sustainable construction in the Nigerian construction industry?

Below are the strategies or remedies for successfully adopting innovative building materials for sustainable construction in the Nigerian construction industry.

Kindly use the ratings below to answer the following questions

Tick as appropriate: 1- Strongly disagree, **2-** Disagree, **3-** Undecided, **4-** Agree, **5-** Strongly Agree.

S/N	Strategies for the Successful Adoption of Innovative Building Materials for Sustainable Construction	1	2	3	4	5
1	Owner/client support					
2	Public awareness creation through workshops, seminars, and conferences					
3	Mandatory governmental policies and regulations encouraging the use of IBM					
4	Promotion of sustainable construction by the construction industry					
5	Appraisal of building code and establishment of sustainable building code					
6	Reducing resistance due to fear of changing traditional building materials					
7	Availability of institutional framework for effective implementation of IBM					
8	Adequate training centres with adequate funding for research and development					
9	Supportive work environment					
10	Establishment of enticements to inspire invention in sustainable construction					
11	Regular inspections and monitoring of works with set rules and legislations.					
12	Use of resources from more sustainable source					
13	Provision of sustainable materials selection criteria					
14	Reducing costs through improving the supply of IBM					

Thank You for Your Participation.

APPENDIX 4: PILOT STUDY LETTER REQUEST

PILOT STUDY LETTER REQUEST

Dear Sir,

Good day. I trust this email finds you well.

Kindly permit me to introduce myself. I am Ms. MOGAJI Iseoluwa Joanna, a master student at the Durban University of Technology (DUT). I am currently conducting research on "**Assessment of the Adoption of Innovative Building Materials (IBM) for Sustainable Construction in Nigerian Construction Industry".** This study aims to investigate the adoption of innovative building materials for sustainable construction in the Nigerian construction industry to promote the adoption of innovative building materials among construction professionals for sustainable construction in Nigeria.

My research study has just received a provisional ethical clearance from my university and I am required to conduct a pilot test on the research instrument (questionnaire) to determine its ability to collect the required information in order to achieve the objectives of the research.

As one of the registered built professionals in Nigeria, you are recognised as one of the knowledgeable professionals in the field of building construction and management.

I request your kind assistance to take a few minutes of your time and go through the attached survey questionnaire that I wish to use as a tool to gather information for the research study. Kindly advice on the questionnaire's rationality, appropriateness, and ability to do the job which it is designed to perform.

Your comments on the following will be highly appreciated:

- The covering letter.
- Rationality and appropriateness of the questions.
- Overall appearance of the questionnaire (please click on the link to view the appearance).
- Time taken to complete.
- The layout of the questions.
- Any additional comments.

Your assistance will be highly appreciated.

Kind regards,
Iseoluwa J. MOGAJI

APPENDIX 5: DUT-IREC APPROVAL LETTER

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

Tel: 031 373 2375
Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics

www.dut.ac.za

4 November 2022

Ms I J Mogaji
Block F2 Plot 17
Alaba layout
Off FUTA South Gate
Akure
Ondo State
Nigeria

Dear Ms Mogaji

Assessment of the Adoption of Innovative Building Materials for Sustainable Construction in Nigerian Construction Industry
Ethical Clearance number IREC 204/22

The Institutional Research Ethics Committee acknowledges receipt of your final data collection toolfor review.

We are pleased to inform you that the data collection tool has been approved. Kindly ensure thatparticipants used for the pilot study are not part of the main study.

In addition, the DUT-IREC acknowledges receipt of your gatekeeper permission letters.

Please note that FULL APPROVAL is granted to your research proposal. You may proceed withdata collection.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the DUT-IREC according to the DUT-IREC Standard Operating Procedures (SOP's).

Please note that any deviations from the approved proposal require the approval of the DUT-IRECas outlined in the DUT-IREC SOP's.

Yours Sincerely

[redacted]

Prof J K Adam Chairperson:
DUT-IREC