

**THE USE OF ARTIFICIAL INTELLIGENCE IN DESIGNING SUSTAINABLE AND
ENERGY-EFFICIENT BUILDINGS**

BY

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**A RESEARCH DISSERTATION SUBMITTED TO THE DEPARTMENT OF
ARCHITECTURE, FACULTY OF ENVIRONMENTAL SCIENCE, UNIVERSITY OF
BENIN, BENIN CITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE AWARD OF BACHELOR OF SCIENCE(B.SC) DEGREE IN ARCHITECTURE OF
THE UNIVERSITY OF BENIN.**

APRIL, 2025

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DECLARATION

I, AIZENOSA AIBI-WOGHIREN, with matriculation number ENV2002714, of the
DEPARTMENT OF ARCHITECTURE, FACULTY OF ENVIRONMENTAL SCIENCES
UNIVERSITY OF BENIN CITY, hereby declare that this research submitted by me for the
award of the degree of BACHELOR OF SCIENCE(B.SC) in ARCHITECTURE is a record of
genuine work executed by me under the supervision of ARC (Mr) TIMMY.O. IKHISEMOJIE
(FNIA).

AIZENOSA AIBI-WOGHIREN _____

NAME	SIGNATURE	DATE
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CERTIFICATION

I, AIZENOSA AIBI-WOGHIREN with matriculation number ENV2002714, of the DEPARTMENT OF ARCHITECTURE, FACULTY OF ENVIRONMENTAL SCIENCES UNIVERSITY OF BENIN CITY, BENIN CITY, EDO STATE, hereby certify that this research was carried out and complied by me in fulfilment of the requirements for the award of Bachelor of science(B.SC) degree in Architecture of the University of Benin.

Sign: _____

ARC. TIMMY IKHISEMOJIE, (FNIA)

Project supervisor

Date: _____

Sign: _____

ARC. HENRY OMOREGBE

Head of Department

Date: _____

DEDICATION

This study is dedicated to my beloved parents, who have been my source of inspiration and guide throughout my academic journey.

To my friends who have supported me throughout my research until its completion.

To my **Project supervisor ARC TIMMY.O. IKHISEMOJIE (FNIA)**, who believed that I would be able to finish my research in time.

Lastly, I dedicate this research to Jehovah God, who guided me and gave me strength in order to carry out my research.

ACKNOWLEDGEMENT

As I reflect on my academic journey, reaching this stage would not have been possible without the divine guidance and unwavering support of Jehovah God. I am deeply grateful to Him for granting me the strength, wisdom, and perseverance to accomplish this milestone.

I wish to extend my sincere appreciation to my project supervisor, Arc. Timmy O. Ikhisemojie (FNIA), whose mentorship, encouragement, and constructive feedback have been instrumental throughout the course of this research.

I am profoundly grateful to my beloved parents, Mr. and Mrs. Aibi-Woghiren, as well as my siblings, family and friends, for their constant support, encouragement, and invaluable advice during various phases of this academic endeavor.

Special thanks go to Ma Constance, my Pastor, and the wonderful church family I have come to cherish. Their prayers, guidance, and steadfast support have played a significant role in sustaining me throughout my time at the University of Benin.

ABSTRACT

The growing demand for sustainable and energy-efficient buildings has created opportunities for technological innovations such as Artificial Intelligence (AI) to reshape the construction industry. This research examined the role of AI in promoting sustainable building design in Benin City, Edo State, with particular emphasis on energy efficiency, smart technologies, and environmentally responsible construction practices. The study was guided by objectives which sought to assess awareness of AI applications, evaluate the effectiveness of AI-driven tools such as Building Information Modeling (BIM), Smart Metering, and Building Management Systems (BMS), and analyze the impact of AI on material selection, waste reduction, and overall building performance.

A survey research design was adopted, and data were collected through structured questionnaires administered to construction professionals including architects, engineers, and facility managers. The responses were analyzed using descriptive and inferential statistical tools, and hypotheses were tested to establish relationships between AI adoption and sustainable building outcomes.

The findings revealed that although awareness of AI in the local construction sector is steadily increasing, practical application remains limited. Respondents strongly agreed that AI-driven tools can significantly enhance sustainability by optimizing energy consumption, improving

design efficiency, and supporting predictive maintenance. Nevertheless, challenges such as high implementation costs, inadequate local expertise, poor awareness among stakeholders, and insufficient government policies were identified as major obstacles to widespread adoption.

The study concludes that AI has transformative potential in addressing sustainability and energy efficiency challenges in Nigeria's construction sector. However, its successful adoption requires deliberate interventions including government incentives, targeted training, policy reforms, and collaborative innovation. Recommendations were made to promote awareness, strengthen local expertise, implement supportive regulations, and encourage pilot projects in public infrastructure.

This study contributes to knowledge by highlighting both the opportunities and limitations of AI integration in the Nigerian building industry. While the scope was limited to Benin City, the findings provide a foundation for further research across other urban centers, as well as for longitudinal studies tracking the long-term impacts of AI adoption in construction.

CHAPTER ONE

INTRODUCTION

1.1 General Introduction of the Research

The global construction industry is undergoing a transformation driven by sustainability concerns and the need for energy-efficient buildings. Buildings contribute significantly to global energy consumption and greenhouse gas emissions, necessitating innovative approaches to mitigate their environmental impact (Yüceses & Selçuk, 2024). Artificial Intelligence (AI) is increasingly being recognized as a powerful tool in optimizing energy efficiency in buildings. AI can enhance the sustainability in building by predicting energy performance during the early design phase, facilitating decision-making that ensures minimal energy consumption and maximum sustainability (Ekici, Turkcan, Turrin, & Sariyildiz, 2022).

Developing countries like Nigeria face unique challenges in adopting AI-driven sustainable design due to limited technological infrastructure and awareness (Anabaraonye, Nzemeka, & Nzewi, 2024). However, integrating AI into Nigeria's Building designs process, can yield significant benefits, including optimizing energy consumption, managing renewable energy resources, and enhancing predictive maintenance in smart buildings (Evareh, Effiom, Effiom, &

Odu, 2023). This also further enhances the potential of AI in sustainable building practices by improving project efficiency and reducing resource wastage (Li, Liu, Han, & Demian, 2024).

As AI continues to gain traction in the construction industry, it is imperative to explore its role in building designs to maximize energy efficiency, particularly in regions where sustainable building practices are still evolving. Understanding this interplay, can provide valuable insights for policymakers, architects, and engineers striving to achieve energy efficiency in the built environment (Oboti, Anabaraonye, & Orji, 2024).

1.2 Problem Statement

Despite the recognized potential of AI in enhancing energy-efficient building design, its adoption remains slow, particularly in Nigeria (Anabaraonye, Nzemeka, & Nzewi, 2024). The Nigerian construction sector faces numerous challenges, including a lack of awareness of AI applications, limited access to technological infrastructure, and inadequate integration of sustainable practices (Evareh, Effiom, Effiom, & Otubu Odu, 2023). These barriers hinder the country's ability to leverage AI for optimizing energy performance during the building design phase.

Existing studies have demonstrated AI's effectiveness in predicting and managing energy consumption in high-rise buildings (Ekici, Turkcan, Turrin, & Sariyildiz, 2022) AI-driven approaches in smart building systems have been shown to enhance efficiency, improve occupant

comfort, and lower energy costs (Li, Liu, Han, & Demian, 2024). However, the application of these technologies in Nigeria remains underdeveloped due to financial constraints, insufficient expertise, and the absence of a structured policy framework supporting AI Integration in construction (Oboti, Anabaraonye, & Orji, 2024).

This study aims to bridge the gap by investigating AI's role in predicting building energy performance during the early design phase and assessing its feasibility in Nigeria's construction industry. The findings will provide insights into how AI-driven sustainable design practices can be effectively implemented in Nigeria, paving the way for enhanced energy efficiency and environmental sustainability.

1.3 Aim and Objectives of the Study

The aim of this study is to examine the role of Artificial Intelligence (AI) in designing sustainable and energy-efficient buildings, focusing on how AI-driven technologies optimize energy consumption, enhance sustainability, and improve overall building performance.

To achieve this, the study will focus on the following objectives:

1. To assess the level of awareness and application of Artificial Intelligence (AI) technologies in designing sustainable and energy-efficient buildings in Benin City.

2. To evaluate the role of AI smart technologies, such as Building Information Modeling (BIM), Smart Metering, and Building Management Systems (BMS), in enhancing sustainable and energy-efficient buildings in Benin City.
3. To assess the effectiveness of AI in sustainable construction practices and the use of eco-friendly building materials for sustainable and energy-efficient buildings in Benin City.

1.4 Research Hypotheses

The study will test the following hypotheses to determine whether AI-driven solutions significantly impact the process of designing sustainable and energy-efficient buildings:

1. There is no significant awareness or application of Artificial Intelligence (AI) technologies in designing sustainable and energy-efficient buildings in Benin City.
2. AI smart technologies such as Building Information Modeling (BIM), Smart Metering, and Building Management Systems (BMS) have no significant role in designing sustainable and energy-efficient buildings in Benin City.
3. Artificial Intelligence (AI) has no significant effect on sustainable construction practices and materials in designing sustainable and energy-efficient buildings in Benin City.

1.5 Scope of Study

This study is limited to assessing the role of Artificial Intelligence (AI) in designing sustainable and energy-efficient buildings within Benin City, Edo State. Specifically, it focuses on three key areas: the level of awareness and application of AI technologies in sustainable building design; the role of AI smart technologies such as Building Information Modeling (BIM), Smart Metering, and Building Management Systems (BMS); and the effectiveness of AI in sustainable construction practices and material selection.

The research will draw insights from professionals in architecture, engineering, and construction within Benin City, providing context-specific findings rather than a generalized global perspective. Emphasis will be placed on identifying current gaps in practice, evaluating the potential of AI integration, and exploring challenges hindering adoption.

The outcomes of this study will be relevant to architects, builders, urban planners, policymakers, and facility managers seeking practical strategies for applying AI in sustainable and energy-efficient building design in Nigeria.

1.6 Limitations of the Research

Despite the significance of this study in exploring the use of Artificial Intelligence (AI) in designing sustainable and energy-efficient buildings, certain limitations may impact the research process and findings.

1. **Limited Access to AI-Driven Building Data** – In Nigeria, AI adoption in building design and energy management is still in its early stages. As a result, access to real-world case studies, performance metrics, or comprehensive datasets on AI-driven sustainable buildings may be limited. This could affect the depth of empirical analysis.
2. **Technological and Infrastructure Constraints** – Many buildings in Benin City still rely on traditional energy management systems, with minimal integration of AI-driven solutions. The lack of existing infrastructure could limit the ability to assess AI's full impact on energy efficiency within the local context.
3. **Awareness and Expertise Gaps** – AI-driven solutions for sustainable building design require specialized knowledge. However, many stakeholders, including architects, engineers, and facility managers, may have limited awareness or understanding of AI applications in building energy efficiency. This could influence the quality and depth of survey responses.
4. **Financial and Policy Barriers** – AI implementation in building design requires substantial investment and supportive government policies. The absence of clear regulatory frameworks

or financial incentives for AI-driven sustainability solutions in Nigeria may present a limitation in assessing the feasibility of widespread adoption.

5. Time and Resource Constraints – Given the scope of the research and the reliance on primary data collection, time constraints may limit the number of surveyed stakeholders. Additionally, conducting in-depth technical assessments of AI's impact on building energy efficiency would require extensive computational modeling and simulations, which may be beyond the scope of this study.

Despite these limitations, the research will provide valuable insights into AI's potential in sustainable building design, highlight existing challenges, and propose strategies for overcoming these barriers.

1.7 Justification of the Study

Benin City, like many growing urban centers in Nigeria, faces significant energy management challenges in building infrastructure, leading to high energy consumption, operational inefficiencies, and increased environmental impact. With the rapid expansion of the city's commercial and public infrastructure, there is an urgent need for sustainable, energy-efficient building designs that minimize energy waste and optimize resource utilization.

Artificial Intelligence (AI) presents a transformative opportunity to address these challenges. AI-powered smart grids, automated energy systems, and predictive maintenance solutions can

significantly enhance the efficiency of buildings by reducing energy consumption, lowering operational costs, and improving overall sustainability. Research indicates that AI-driven building automation can reduce energy consumption by up to 30%, making it a viable strategy for enhancing energy efficiency in urban areas like Benin City.

This study is particularly significant as it will assess the current state of energy management in Benin City's building sector, explore the feasibility of AI integration, and identify the key challenges preventing its adoption. By providing data-driven insights and strategic recommendations, this research will contribute to the development of energy-efficient policies, improved urban planning frameworks, and more sustainable public infrastructure.

Moreover, as global cities increasingly prioritize smart and sustainable urban development, Benin City must embrace AI-driven innovations to remain competitive and environmentally responsible. This research will serve as a practical guide for policymakers, architects, and facility managers seeking to leverage AI for sustainable and energy-efficient building designs in Edo State.

1.8 Research Methodology

This research outlines the methodology employed in conducting the study on "The Use of Artificial Intelligence in Designing Sustainable and Energy-Efficient Buildings." This study uses

an exploratory and descriptive research design. This design was adopted to obtain a comprehensive understanding of AI-driven energy efficiency strategies in buildings. While the descriptive component includes analyzing the current state of energy consumption and sustainability practices in building design, the exploratory component examines how AI technologies can be integrated to enhance energy efficiency in buildings.

The method of data collection employed for this research is quantitative data analysis, which will be gathered through structured surveys and questionnaires distributed among architects, engineers, facility managers, real estate developers, and policymakers. The survey will cover aspects such as current building energy management practices, awareness and adoption of AI-driven solutions, challenges in implementing AI for sustainability, and potential benefits of AI-driven energy optimization.

The target population for this research study includes professionals and decision-makers in the building industry within Benin City, Edo State. The research will prioritize ethical considerations, ensuring informed consent, confidentiality, and anonymity of participants. Ethical guidelines will be strictly followed throughout the research process.

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Framework

2.1.1 Artificial Intelligence (AI) in Building Designs

Artificial Intelligence (AI) refers to the simulation of human intelligence in machines, enabling them to perform tasks such as learning, reasoning, and problem-solving (Yüceses & Selçuk, 2024). In building design, AI integrates machine learning algorithms, predictive analytics, and automation to enhance architectural planning, energy efficiency, and structural integrity. AI-powered systems can analyze large datasets to optimize building performance, improve material selection, and enhance occupant comfort (Ekici, Turkcan, Turrin, & Sariyildiz, 2022)

Several studies have highlighted the growing role of AI in sustainable building management. For example, Yüceses and Selçuk (2024) explored how AI can predict building energy performance during the early design phase, allowing architects to make data-driven decisions. Similarly, Li, Liu, Han, and Demian (2024) examined the intersection of AI and Building Information Modeling (BIM), emphasizing its potential in smart city infrastructure. These studies indicate

that AI is becoming a fundamental tool for designing buildings that are more energy-efficient and environmentally sustainable.

2.1.2 Sustainable and Energy-Efficient Buildings

Sustainable and energy-efficient buildings are structures designed to minimize environmental impact, reduce energy consumption, and promote resource efficiency. Such buildings incorporate renewable energy sources, smart grid technologies, and advanced materials to enhance their ecological footprint (Jane, 2024). The use of AI in sustainable building systems allows for predictive maintenance, automated energy adjustments, and optimized HVAC (Heating, Ventilation, and Air Conditioning) systems, significantly reducing energy waste (Ekici, Turkcan, Turrin, & Sariyildiz, 2022)

According to Anabaraonye et al. (2024), AI has played a transformative role in advancing green building projects in Nigeria. Their research highlights the integration of AI-driven energy monitoring systems to regulate power usage in public buildings. Additionally, Jane (2024) emphasizes that AI can automate the design of sustainable buildings by analyzing past energy consumption patterns and recommending modifications to enhance efficiency.

2.1.3 The Role of AI in Optimizing Energy Consumption in Buildings

AI-driven technologies are revolutionizing energy management in buildings by enabling real-time energy monitoring, demand forecasting, and automated system adjustments. Machine learning algorithms can predict peak energy demand and adjust consumption accordingly, thereby reducing operational costs and improving sustainability (Bachina, Kanagala, Korapu, & Ratnaraju, 2025)

A study by Ekici, Turkcan, Turrin, and Sariyildiz (2022) examined AI's role in optimizing energy use in high-rise buildings, demonstrating how AI-driven self-sufficiency models can balance energy consumption with on-site renewable energy generation. Similarly, Bai et al. (2024) explored how AI influences sustainable finance and investment decision-making in the green building sector. Their research suggests that AI-powered analytics can help investors assess the energy efficiency of buildings and make data-driven financial decisions.

Anabaraonye et al. (2024) also noted that AI applications in Nigeria's green building sector face several challenges, including inadequate infrastructure, high implementation costs, and limited expertise. However, with proper policy frameworks and technological advancements, AI has the potential to drive substantial improvements in energy efficiency across public buildings.

2.2 Smart Building Technology

2.2.1 Machine Learning and AI Models in Energy-Efficient Building Design

Machine learning and artificial intelligence (AI) have emerged as transformative tools in energy-efficient building design, enabling architects and engineers to develop predictive models that optimize energy consumption and sustainability metrics. AI-driven models analyze large datasets related to building materials, climate conditions, and energy demand, allowing for the simulation of various design scenarios to identify the most efficient solutions (Yüceses & Selçuk, 2024). These models enhance decision-making in the early design phase, reducing long-term operational costs and environmental impact.

Supervised and unsupervised machine learning algorithms are frequently used in predictive energy modeling. Supervised learning methods, such as regression models and neural networks, enable precise energy demand forecasting based on historical data. Unsupervised techniques, like clustering algorithms, identify patterns in building performance, facilitating data-driven adjustments to energy usage. Reinforcement learning, an advanced AI model, has also been employed to optimize energy distribution by continuously learning from real-time feedback and adjusting control systems accordingly (Ekici, Turkcan, Turrin, & Sariyildiz, 2022)

One notable application of AI in building design involves generative adversarial networks (GANs), which simulate energy-efficient structures by iteratively refining architectural parameters. These AI models help architects design buildings that minimize thermal losses while maximizing natural ventilation and lighting. The integration of AI with computational fluid dynamics (CFD) further enhances the efficiency of HVAC (Heating, Ventilation, and Air Conditioning) systems, ensuring optimal airflow distribution and temperature regulation within buildings (Li, Liu, Han, & Demian, 2024).

Despite these advancements, challenges remain in implementing AI-driven building models, particularly concerning data availability and computational complexity. The accuracy of predictive models depends on the quality of training datasets, which are often limited in developing regions. Additionally, AI systems require substantial computational power, which can be costly for large-scale implementation in commercial and residential buildings (Bachina, Kanagala, Korapu, & Ratnaraju, 2025)

2.2.2 AI and Building Information Modeling (BIM) for Smart Cities

Building Information Modeling (BIM) has revolutionized urban development by creating digital representations of buildings that encompass architectural, structural, and energy-related data. The integration of AI with BIM enhances the efficiency of smart city infrastructure by enabling real-time monitoring, predictive maintenance, and automated decision-making (Li, Liu, Han, &

Demian, 2024). AI-powered BIM systems utilize deep learning algorithms to analyze construction plans, identify potential structural weaknesses, and recommend modifications that improve sustainability.

The relationship between AI and BIM extends to material selection and lifecycle assessment. AI-driven analysis tools evaluate the environmental impact of construction materials, recommending sustainable alternatives that minimize carbon footprints. In smart cities, this capability is crucial for meeting green building certification standards and reducing overall emissions from the construction sector (Anabaraonye, Nzemeka, & Nzewi, 2024).

One of the most promising developments in AI-BIM integration is the use of autonomous construction robots. These robots utilize AI algorithms to interpret BIM models, enabling them to perform precise construction tasks such as bricklaying, welding, and concrete pouring. By reducing human intervention in labor-intensive processes, AI-powered robotics enhance construction speed and accuracy while ensuring compliance with sustainability guidelines (Li, Liu, Han, & Demian, 2024).

AI-enhanced BIM facilitates urban planning by simulating the interaction between buildings and surrounding environments. AI models can predict traffic congestion patterns, assess the impact of new developments on existing infrastructure, and optimize land use allocation. This predictive capability is particularly beneficial for developing nations, where rapid urbanization often leads

to poorly planned cities with inadequate energy infrastructure (Oboti, Anabaraonye, & Orji, 2024).

In Nigeria, the application of AI-BIM technology is gradually gaining traction, particularly through pilot initiatives such as smart housing prototypes in Lagos and Abuja, where BIM platforms are being combined with AI-driven energy modeling to optimize building performance. For instance, projects spearheaded by private developers in Lekki have begun experimenting with AI-integrated BIM systems to monitor energy use and streamline design efficiency. Similarly, some government-backed urban renewal schemes in Abuja are incorporating BIM tools for planning resilient infrastructure. Despite these encouraging efforts, challenges such as inadequate digital infrastructure, high implementation costs, and limited technical expertise remain significant barriers to widespread adoption. Nevertheless, with continuous technological advancements and growing interest in sustainable urban development, AI-BIM integration is expected to play a pivotal role in shaping energy-efficient and resilient Nigerian cities (Anabaraonye, Nzemeka, & Nzewi, 2024).

2.2.3 AI in Automated Building Management Systems

AI-integrated Building Management Systems (BMS) enhance energy efficiency through intelligent automation. These systems optimize lighting, ventilation, temperature control, and security to minimize energy waste while ensuring occupant comfort. By continuously learning

from user preferences, environmental conditions, and occupancy trends, AI-powered BMS makes real-time adjustments to maximize operational efficiency (Jane, 2024).

One of the most impactful applications of AI in BMS is the use of reinforcement learning algorithms for adaptive energy control. These algorithms analyze multiple factors, including weather conditions, energy prices, and occupancy schedules, to dynamically adjust building operations. Over time, they refine their strategies, ensuring optimal energy efficiency with minimal waste (Bachina, Kanagala, Korapu, & Ratnaraju, 2025). AI-driven BMS facilitates seamless integration with renewable energy sources such as solar and wind power. By predicting energy generation patterns and aligning them with consumption needs, AI ensures buildings make the most of renewable energy, reducing dependency on conventional power grids. Smart grid compatibility further enhances efficiency, enabling buildings to store excess energy and redistribute it during peak demand periods (Li, Liu, Han, & Demian, 2024).

2.3 AI and Sustainable Building Materials

Artificial intelligence (AI) is increasingly applied to promote sustainability in construction by improving material selection, optimizing energy efficiency, and supporting lifecycle assessments. AI-driven algorithms analyze large datasets on material durability, thermal performance, recyclability, and embodied carbon, enabling architects and engineers to identify energy-efficient and low-impact alternatives (Bai, Jeena, & Shanavas, 2024). Generative design and predictive

models further enhance this process by simulating configurations that balance structural stability with minimal environmental cost, such as recommending insulation materials that reduce cooling and heating loads (Bai, Jeena, & Shanavas, 2024).

AI also facilitates the adoption of bio-based and recycled materials, including bamboo, recycled steel, and bio-concrete, by assessing their performance in diverse construction contexts (Li, Liu, Han, & Demian, 2024). In parallel, its integration into construction practices, such as prefabrication, modular systems, and robotics, helps reduce waste, optimize resource management, and minimize carbon emissions (Jane, 2024; Ekici et al., 2022). For instance, AI-enabled predictive models improve procurement accuracy, while robotics enhance precision in material use and real-time quality control (Ekici, Turkcan, Turrin, & Sariyildiz, 2022)

AI furthermore strengthens lifecycle assessment (LCA) methodologies by automating data collection and predicting long-term material performance under varying conditions. Through advanced analytics, it estimates embodied energy, degradation rates, and recyclability, supporting the design of buildings with deconstructable components for reuse and circularity (Bachina et al., 2025; Li et al., 2024). These insights also enable compliance with global sustainability standards such as LEED and BREEAM, making AI a critical tool for embedding accountability in green construction (Jane, 2024).

Each research highlights AI's capacity to reduce environmental impact through smarter material choices, optimized construction practices, and data-driven lifecycle assessments, though widespread adoption is still limited in developing contexts due to infrastructural and skill-related barriers (Bachina et al., 2025; Li et al., 2024).

2.4 AI and Policy Frameworks for Sustainable Buildings

The integration of Artificial Intelligence (AI) in sustainable building policies is rapidly evolving, influencing regulatory frameworks, urban development strategies, and green financing models. AI is being leveraged to enhance decision-making in sustainable infrastructure planning, allowing governments and urban planners to optimize energy use, reduce environmental impact, and improve the resilience of smart cities (Li, Liu, Han, & Demian, 2024). AI-powered predictive models are now integral to evaluating the energy efficiency of new construction projects in real time, enabling more informed regulatory measures for sustainable urban development (Yüceses & Selçuk, 2024). These advancements align with global decarbonization goals, where AI contributes to enforcing policies such as net-zero emissions mandates and green building certifications.

Government policies supporting AI adoption in building design vary across regions. In developed nations, regulatory frameworks have evolved to integrate AI in construction, with policies mandating AI-driven energy audits and smart building codes (Ekici, Turkcan, Turrin, &

Sariyildiz, 2022) For example, European cities are implementing AI-assisted urban planning models that optimize energy distribution while ensuring compliance with carbon reduction targets (Buitrago et al., 2024). However, in Nigeria and other developing economies, policy frameworks remain fragmented. Research highlights that while AI has the potential to transform Nigeria's construction sector, inadequate policy backing, lack of digital infrastructure, and limited government incentives hinder its large-scale adoption (Anabaraonye, Nzemeka, & Nzewi, 2024). Addressing these gaps requires comprehensive AI-driven policies that prioritize energy-efficient building design, enforce sustainability standards, and incentivize smart building technologies.

Sustainable finance is another critical policy area influenced by AI in green construction. AI-powered financial models are revolutionizing investment decision-making by automating risk assessment, optimizing credit allocation for sustainable projects, and improving energy performance tracking in buildings (Bai, Jeena, & Shanavas, 2024). Research suggests that AI-driven investment tools are being deployed to monitor environmental, social, and governance (ESG) metrics, ensuring that sustainable building projects align with global standards (Oboti, Anabaraonye, & Orji, 2024). In Nigeria, AI has the potential to enhance green financing by improving data transparency and making sustainability-linked loans more accessible to developers (Evareh, Effiom, Effiom, & Otubu Odu, 2023). However, the absence of structured

policies regulating AI-driven finance in Nigeria limits its adoption in large-scale infrastructure projects.

Additionally, AI is contributing to climate resilience strategies through policy-driven applications in sustainable construction. Advanced machine learning models now predict climate-related risks in urban areas, enabling policymakers to design AI-assisted resilience plans for extreme weather conditions (Oboti, Anabaraonye, & Orji, 2024). Studies indicate that integrating AI with Building Information Modeling (BIM) facilitates more accurate environmental impact assessments, helping cities develop regulatory frameworks for adaptive infrastructure (Li, Liu, Han, & Demian, 2024). Despite these advancements, challenges such as ethical concerns, data privacy regulations, and cybersecurity risks need to be addressed for AI-driven policies to be widely implemented in sustainable building projects.

2.5 Challenges and Limitations of AI Adoption in Building Design

Despite the transformative potential of AI in sustainable building design, several challenges hinder its widespread adoption. These challenges range from financial constraints to technical barriers and ethical considerations.

High Cost of AI Implementation in Building Projects

The deployment of AI-driven solutions in building design requires significant financial investment, particularly in infrastructure, software, and skilled labor. Ekici, Turkcan, Turrin, and Sariyildiz (2022) emphasizes that AI-powered energy optimization models demand high-performance computing resources, making them expensive to implement in large-scale projects. Similarly, Bai et al. (2024) note that while sustainable finance mechanisms can support AI adoption, the lack of financial incentives and funding opportunities in developing nations, including Nigeria, remains a major barrier. Additionally, Oboti, Anabaraonye, and Orji (2024) highlight that the costs of integrating AI with existing smart infrastructure further increase the financial burden on project developers.

Technical Limitations and Data Requirements for AI Systems

AI models require vast amounts of high-quality data for accurate predictions and optimization. However, Li, Liu, Han, and Demian (2024) point out that many developing countries face issues related to data scarcity, inconsistencies, and poor interoperability between AI systems and traditional construction frameworks. Furthermore, the lack of standardized AI protocols in the building sector, as noted by Jane (2024), limits the effectiveness of AI-driven solutions. In high-rise buildings, where energy efficiency is a key concern, Ekici, Turkcan, Turrin, and Sariyildiz (2022) report that inadequate real-time data from smart meters reduces the predictive accuracy of AI algorithms, leading to suboptimal energy-saving strategies.

Ethical Concerns and Data Privacy in AI-Driven Building Management

The increasing reliance on AI in smart buildings raises concerns regarding data privacy and ethical considerations. AI-based building management systems collect extensive occupant data, including energy usage patterns, movement tracking, and behavioral analytics. Evareh, Effiom, Effiom, and Otubu Odu (2023) caution that inadequate data protection frameworks may expose users to cybersecurity risks and unauthorized surveillance. Moreover, the potential for algorithmic bias in AI-driven decision-making is a growing concern. Li, Liu, Han, and Demian (2024) explain that biases in training datasets can lead to energy optimization models that disproportionately benefit certain building users while neglecting others. This ethical dilemma underscores the need for regulatory policies that ensure fair and transparent AI implementation in the construction sector.

While AI presents numerous opportunities for enhancing building energy efficiency and sustainability, challenges related to cost, data availability, technical limitations, and ethical concerns must be addressed to enable widespread adoption. Addressing these challenges requires collaborative efforts from policymakers, financial institutions, and technology developers to create regulatory frameworks, improve data accessibility, and enhance cybersecurity measures.

2.6 Empirical Review

Several Nigerian scholars and practitioners have explored the application of Artificial Intelligence (AI) in promoting sustainable and energy-efficient building designs, providing empirical insights into its relevance within the local context. For example, Anabaraonye et al. (2024) examined the integration of AI with Building Information Modeling (BIM) in Nigeria's construction industry and highlighted its potential in reducing material waste, optimizing energy use, and enhancing the durability of public buildings. Their findings suggest that, while pilot projects have shown promising outcomes, widespread adoption is hindered by inadequate infrastructure and the high cost of AI-enabled systems.

Similarly, Afolabi, Oyeyipo, Ojelabi, and Mosaku (2023) investigated the role of AI in construction management and revealed how predictive algorithms could support sustainable material selection and reduce project delays. Their study emphasized that AI applications can complement traditional green construction practices by enabling real-time monitoring of energy usage and forecasting long-term environmental impacts. However, they cautioned that the lack of skilled professionals in AI technologies remains a critical barrier in the Nigerian context.

In another related study, Ujene, Okolie, and Onoh (2022) focused on AI's role in climate-responsive building designs, particularly in rapidly urbanizing areas such as Lagos and Abuja. Their work demonstrated how AI-powered simulations could model passive cooling techniques and optimize building orientation, significantly reducing reliance on non-renewable energy

sources. The study further recommended that public institutions adopt AI in school and hospital building projects to demonstrate its practicality and scalability.

Beyond Nigeria, comparative studies across developing countries also provide useful lessons. For instance, Li, Liu, Han, and Demian (2024) documented how AI-driven smart systems were used in East Asian urban centers to retrofit existing buildings for improved efficiency, while Bachina et al. (2025) highlighted India's experience with AI in lifecycle assessments of materials for affordable housing. These studies are particularly relevant to Nigeria, as they reveal how resource-constrained environments can adapt AI technologies incrementally rather than through wholesale transformation.

Taken together, the empirical evidence underscores both the opportunities and limitations of AI adoption in Nigeria's sustainable building sector. While AI has been shown to enhance energy performance, promote sustainable material use, and support climate-adaptive designs, its local application remains in early stages. Lessons from other developing countries suggest that incremental integration, government-backed pilot projects, and capacity building among professionals are essential steps for Nigeria to unlock the full potential of AI in sustainable building practices.

2.7 Gap in Existing Studies

Although existing studies have demonstrated the potential of Artificial Intelligence (AI) in advancing sustainable and energy-efficient building design, most of these works remain either conceptual or limited to developed countries with advanced digital infrastructure. The empirical evidence from Nigeria, particularly at the city level, is still scarce. For instance, while studies have explored AI-BIM integration in sustainable urban planning and AI applications in energy management, they often lack context-specific findings related to Nigerian cities where infrastructural, economic, and policy challenges significantly shape adoption outcomes. Moreover, the few Nigerian studies that exist tend to generalize AI's role in construction without specifically examining its contribution to sustainable and energy-efficient building design.

This research seeks to address these gaps by narrowing the focus to Benin City, a growing urban center with unique sustainability challenges. Unlike previous studies, it emphasizes three key dimensions: the level of awareness and application of AI in building design, the role of AI-powered smart technologies such as BIM, Smart Metering, and Building Management Systems (BMS), and the effectiveness of AI in promoting sustainable construction practices and materials. By focusing on these specific objectives, the study contributes empirical evidence that reflects the realities of AI adoption in Nigeria and provides actionable insights for policymakers, architects, and engineers working toward sustainable and energy-efficient buildings.

CHAPTER THREE

DATA COLLECTION

3.1 Research Design

This study adopted a descriptive survey research design. The descriptive survey design is appropriate because it enables the researcher to collect and analyze data from a sample of professionals whose perspectives reflect the broader population involved in building design and construction (Akuezuiilo & Agu, 2015). The design aligns with the objectives of this study, which seek to assess the awareness, application, and perceived effectiveness of Artificial Intelligence (AI) technologies in designing sustainable and energy-efficient buildings in Benin City. By employing this design, the study provides both quantitative and qualitative insights into current practices, challenges, and opportunities for AI integration.

3.2 Population of the Study

The population of this study comprised professionals directly engaged in the architecture, engineering, and construction (AEC) industry within Benin City. This includes registered architects, civil engineers, builders, quantity surveyors, and facility managers who are actively involved in building design, construction, and management. These professionals were considered

appropriate for this study because they possess the technical expertise and industry experience necessary to evaluate the role of AI in sustainable and energy-efficient building practices.

3.3 Sample and Sampling Techniques

A sample size of 80 professionals was selected from the target population in Benin City. The sample was drawn using a purposive sampling technique, ensuring that only individuals with direct involvement in building design and construction were included. To ensure representation across different professional groups, stratified sampling was applied, dividing the population into sub-groups such as architects, engineers, builders, and facility managers. This approach guaranteed that the views of key stakeholders were adequately captured, thus enhancing the validity of the study findings.

3.4 Research Instrument

The primary research instrument used in this study was a structured questionnaire developed by the researcher. The questionnaire was divided into three sections. Section A focused on the demographic information of respondents, including their profession, years of experience, and types of projects handled. Section B contained items designed to assess the level of awareness and application of Artificial Intelligence (AI) technologies in sustainable and energy-efficient building design. Section C included items that measured the perceived effectiveness of specific AI tools such as Building Information Modeling (BIM), Smart Metering, Building Management

Systems (BMS), and AI-driven material selection. Most of the items were structured using a five-point Likert scale, ranging from Strongly Agree (5) to Strongly Disagree (1), while some open-ended questions were incorporated to capture qualitative insights regarding challenges and recommendations for AI adoption in Benin City.

3.5 Validation of the Instrument

To ensure content validity, the questionnaire was reviewed by experts in architecture, construction management, and sustainable building design. Their feedback was used to refine the items for clarity, relevance, and alignment with the study objectives. In addition, face validity was established through a pilot test involving 10 professionals from the AEC industry in Benin City who were not included in the final study. Their responses helped identify ambiguous items, which were subsequently revised to improve the overall accuracy and usability of the instrument.

3.6 Reliability of the Instrument

The reliability of the instrument was determined using Cronbach's Alpha method to test internal consistency. A pilot study was conducted with responses from the 10 professionals, and the reliability coefficient obtained was 0.84, which is above the acceptable threshold of 0.70 for social science research (Nunnally & Bernstein, 1994). This confirmed that the instrument was reliable and capable of generating consistent results when administered to the main study population.

3.6 Data Management

To ensure that data was accurately collected and ensure data was properly organized and protected from corruption and loss, research data management was incorporated into this research. The data collected from surveys was properly backed up and can also be easily accessed when the need for information gathering occurs.

3.7 Data Collection Ethics

Ethical considerations were a critical component of this research to ensure that the study adhered to ethical standards and respected the rights of the participants. Before completing the survey, all participants were provided with detailed information about the research objectives, the intended use of the data, and the voluntary nature of their participation. Consent was explicitly obtained from each respondent to ensure that they were fully aware of their involvement in the study.

Additionally, confidentiality was strictly maintained throughout the research process. Respondents' identities and responses were kept anonymous, and data was stored securely to prevent unauthorized access. The research adhered to ethical guidelines by ensuring that participation was voluntary, that no participant felt coerced or pressured to respond, and that they were given the option to withdraw from the study at any time without facing any repercussions. The study also took steps to avoid bias in the design and implementation of the survey, ensuring

that the questions were neutral and relevant to all participants. The research process was designed to minimize harm and ensure that all participants were treated with respect and dignity.

3.8 Limitation of Data Collection

One of the limitations experienced was reaching out to individuals who would be willing and ready to respond to the surveys they were sent. Another limitation that was encountered was the lack of flexibility of the survey, as a result of having one questionnaire sent to all respondents as a result, there was the need to carefully evaluate the approach which was going to be favorable for the vast number of respondents.

CHAPTER FOUR

DATA ANALYSIS

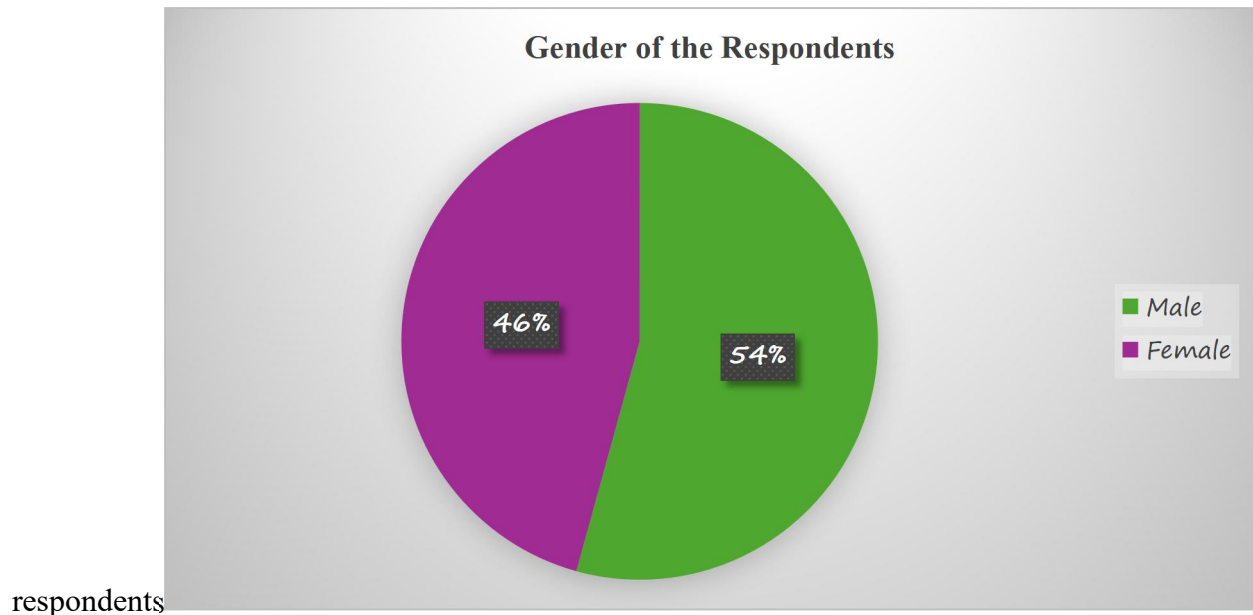
4.1 Introduction

This chapter presents the analysis of quantitative data gathered from the field through a structured questionnaire. The survey targeted professionals in the building industry within Benin City, including architects, engineers, developers, and facility managers. Out of the total questionnaires distributed, the response rate was satisfactory, yielding sufficient data for analysis. The responses provide insight into the current perception, usage, and awareness of Artificial Intelligence (AI) in the design of sustainable and energy-efficient buildings in Benin City.

4.2 Quantitative Analysis Demographic Characteristics of Data

Gender of Respondents

Figure 4.1: Pie chart showing the gender distribution of



respondents
Figure 1 Pie chart showing the gender distribution of respondents

The chart above illustrates the gender distribution of the respondents who participated in the study. Out of all respondents, 54% were male while 46% were female. This relatively balanced representation suggests inclusivity across genders, which is important for ensuring diverse perspectives in the study of artificial intelligence (AI) usage in building design and management in Benin City. The slight male majority reflects the typical gender dynamics observed in

technical and construction-related fields in Nigeria, potentially indicating a higher male engagement in roles where AI applications in design might be more visible.

Age distribution

Figure 4.2: Pie chart showing the age distribution of respondents

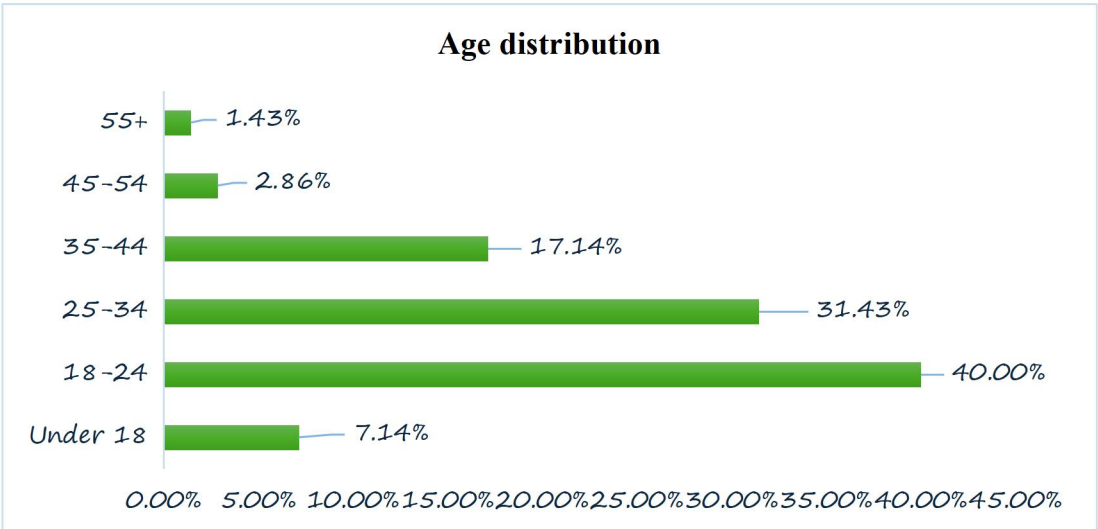


Figure 2 Pie chart showing the age distribution of respondents

The data reveals a predominantly youthful group of respondents, with 40% falling within the 18–24 age range and 31.43% between 25–34 years. Only 17.14% fall between ages 35–44, and minimal percentages are noted for those 45–54 (2.86%) and 55+ (1.43%). Additionally, 7.14% are under 18. This age structure implies that younger professionals and students are more actively involved or aware of AI and its application in building design and management. The

prominence of younger respondents suggests potential for innovation and a strong familiarity with technology trends, which aligns with the thrust of this study in exploring forward-thinking solutions for sustainable development.

Occupation

Figure 4.3: Pie chart showing the occupational background of respondents

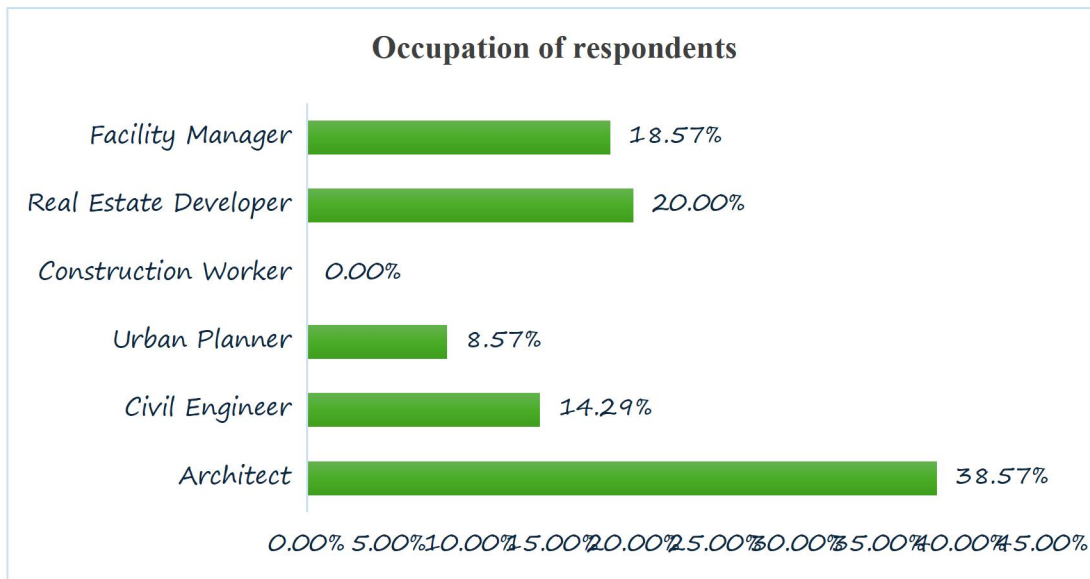


Figure 3 Pie chart showing the occupational background of respondents

This chart indicates that a significant proportion of respondents were Architects (38.57%), followed by Real Estate Developers (20%), Facility Managers (18.57%), and Civil Engineers (14.29%). Urban Planners accounted for 8.57%, while no respondents identified as

Construction Workers. The occupational spread reflects a strong representation from professionals directly involved in the planning, design, and execution of building projects, precisely the target population for this study. The dominance of architects is particularly noteworthy, as they are key stakeholders in the adoption of AI tools for sustainable and energy-efficient building designs.

4.3 Hypothesis Testing

Hypothesis One: The Level of Significant Awareness or Application of Artificial Intelligence (AI) Technologies in Designing Sustainable and Energy-Efficient Buildings

Table 1 Hypothesis One

S/N	Statements	SA	A	D	SD	MEAN	Decision
		4	3	2	1		
1	I am aware of the use of AI technologies in building design.	19	24	16	11	2.7	Agree
2	AI-driven technologies are currently being applied in sustainable building projects in Benin City.	18	45	5	2	3.1	Strongly Agree
3	I have personally used or participated in projects where AI technologies were applied in building design.	11	24	20	15	2.4	Agree

4	Awareness of AI applications in building design is generally low among professionals in Benin City.	16	45	7	2	3.1	Strongly Agree
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The first hypothesis stated that “There is no significant awareness or application of Artificial Intelligence (AI) technologies in designing sustainable and energy-efficient buildings in Benin City.” Data obtained from the questionnaire were analyzed, and the results revealed mean scores ranging between 2.4 and 3.1 across the four related items. Specifically, respondents agreed that they were aware of the use of AI technologies in building design (Mean = 2.7) and strongly agreed that AI-driven technologies are currently being applied in sustainable building projects within Benin City (Mean = 3.1). While personal participation in AI-driven projects recorded a lower mean of 2.4, the perception that awareness remains generally low among professionals also scored strongly (Mean = 3.1). These results demonstrate that, although full adoption may be limited, a significant level of awareness and application of AI in sustainable building design does exist in Benin City. Therefore, the null hypothesis is rejected, and it is concluded that there are significant awareness and application of AI technologies in designing sustainable and energy-efficient buildings in Benin City.

Hypothesis Two: AI Smart Technologies and Building Management Systems (BMS)

Table 2 Hypothesis Two

S/N	Statements	SA	A	D	SD	MEAN	Decision
1	Building Information Modeling (BIM) enhances sustainable and energy-efficient building design.	4	3	2	1		
		27	11	16	16	2.7	Agree
2	Smart metering systems help in monitoring and reducing building energy consumption.	17	28	23	2	2.9	Agree
3	Building Management Systems (BMS) contribute significantly to efficient energy management.	22	25	22	1	3.0	Agree
4	AI-based tools improve overall building performance compared to traditional methods.	17	34	17	2	2.9	Agree

The second hypothesis stated that “AI smart technologies such as Building Information Modeling (BIM), Smart Metering, and Building Management Systems (BMS) have no significant role in designing sustainable and energy-efficient buildings in Benin City.” The analysis showed that respondents generally agreed with the statements, with mean values ranging from 2.7 to 3.0. Specifically, respondents agreed that BIM enhances sustainable and energy-efficient building design (Mean = 2.7), while smart metering systems were recognized as useful in monitoring and reducing energy consumption (Mean = 2.9). Similarly, Building Management

Systems (BMS) were acknowledged as contributing significantly to energy management (Mean = 3.0), and AI-based tools were considered to improve overall building performance compared to traditional methods (Mean = 2.9). These results indicate that AI smart technologies play an important role in advancing energy-efficient and sustainable building practices in Benin City. Therefore, the null hypothesis is rejected, confirming that BIM, smart metering, and BMS significantly contribute to sustainable building design.

Hypothesis Three: Sustainable Construction Practices and Materials in Designing Sustainable and Energy-Efficient Buildings

Table 3 Hypothesis Three

S/N	Statements	SA (4)	A (3)	D (2)	SD (1)	MEAN	Decision
1	AI supports the selection of sustainable building materials.	22	25	22	1	3.0	Agree
2	AI improves waste reduction and resource management in building projects.	17	34	17	2	2.9	Agree
3	AI-based designs lower the environmental impact of construction projects.	15	33	21	1	2.9	Agree
4	AI significantly enhances the sustainability of building design compared to conventional approaches.	18	26	21	5	2.8	Agree

The third hypothesis stated that “Artificial Intelligence (AI) has no significant effect on sustainable construction practices and materials in designing sustainable and energy-efficient buildings in Benin City.” Findings from the data reveal mean scores between 2.8 and 3.0 across the four related items. Respondents agreed that AI supports the selection of sustainable building materials (Mean = 3.0), improves waste reduction and resource management (Mean = 2.9), and lowers the environmental impact of construction projects (Mean = 2.9). Furthermore, it was agreed that AI significantly enhances the sustainability of building designs compared to conventional approaches (Mean = 2.8). These findings suggest that AI has a clear effect on sustainable construction practices and materials, especially in promoting waste reduction and environmentally conscious designs. Based on these results, the null hypothesis is rejected, and it is concluded that AI significantly contributes to sustainable construction practices and materials in Benin City.

4.4 Qualitative Data Analysis

Types of Buildings Worked on or Interacted With

Figure 4.4: Bar chart showing types of buildings respondents have interacted with in Benin

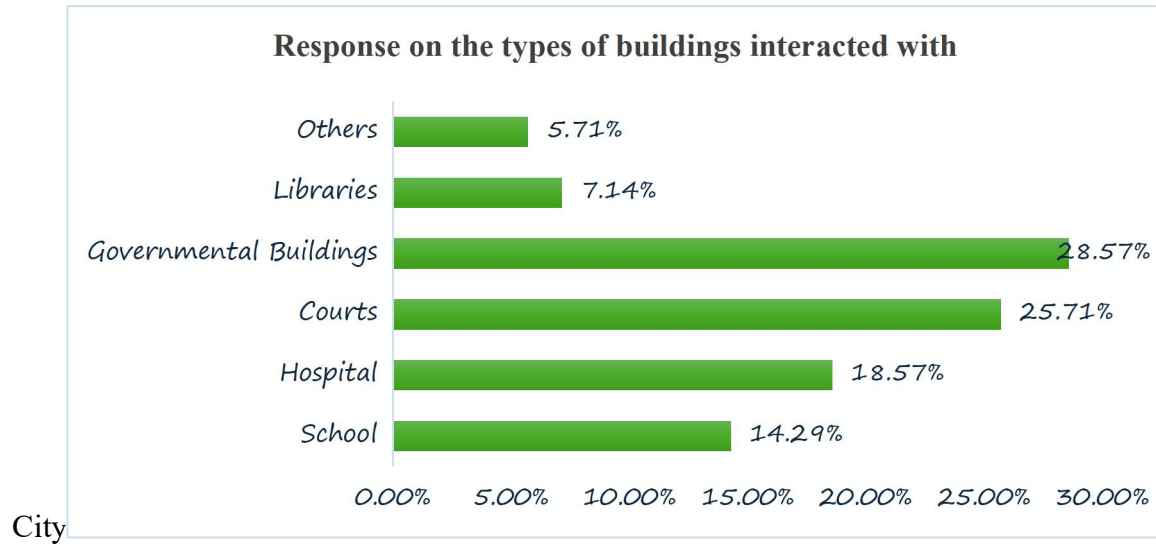


Figure 4 Bar chart showing types of buildings respondents have interacted with in Benin City

Respondents reported working with or interacting with various building types in Benin City. Governmental buildings accounted for the highest percentage (28.57%), followed by Courts (25.71%) and Hospitals (18.57%). Schools (14.29%), Libraries (7.14%), and others (5.71%) were less frequently mentioned. This indicates that a significant portion of AI-related building design or management practices, where present, may be concentrated in public and institutional infrastructure. The dominance of governmental buildings also highlights the role of public sector

investment in the built environment of Benin City, suggesting a valuable area for AI integration and policy focus.

Experience with AI in Building Design

Figure 4.5: Pie chart showing respondents' exposure to AI in building design

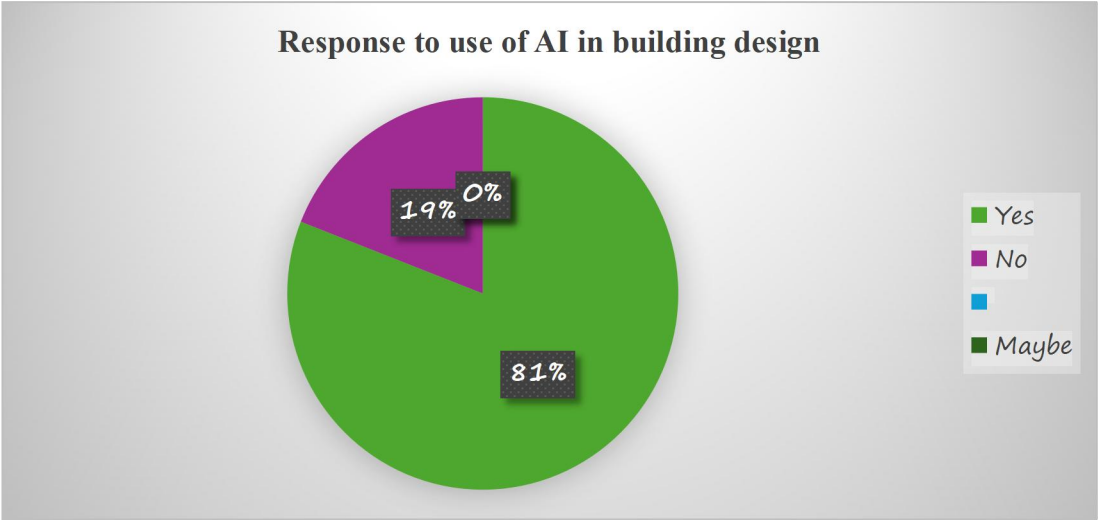


Figure 5 Pie chart showing respondents' exposure to AI in building design

As shown in the chart, 81% of respondents reported that they had encountered or been involved in the use of Artificial Intelligence in the context of building design or management. A smaller portion, 19%, had not experienced this, while none selected “Maybe.” This high level of exposure to AI reflects growing awareness and potential adoption of intelligent systems within the architectural and construction sectors in Benin City. This finding directly supports the study's

relevance, underscoring the need to further understand how AI can enhance sustainability and efficiency in the built environment.

Factors Hindering Sustainable Practices

Figure 4.11: Bar chart showing the challenges to implementing sustainable building design

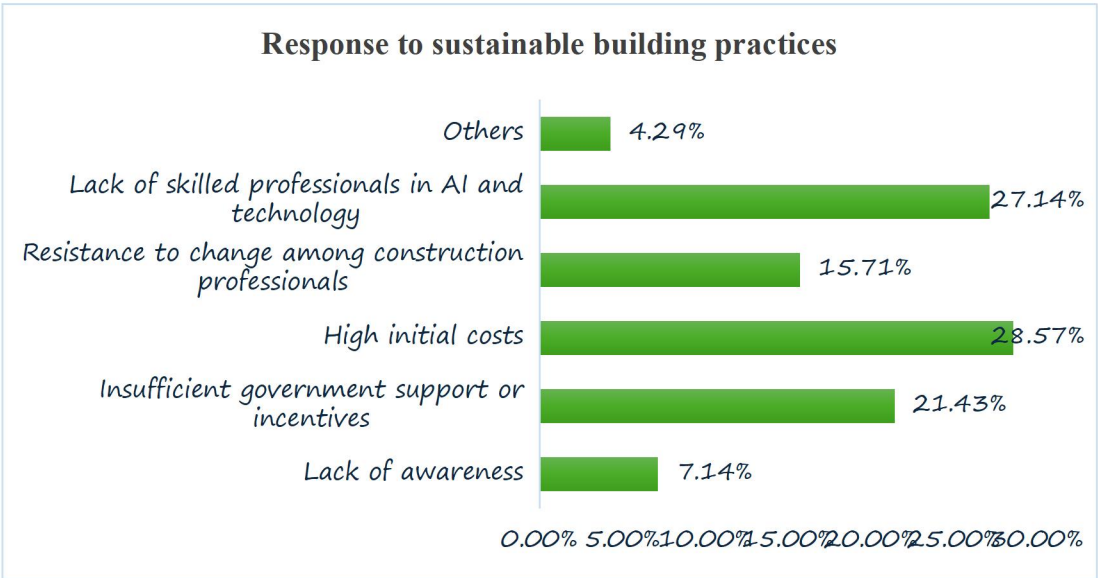


Figure 11 Bar chart showing the challenges to implementing sustainable building design

Respondents identified *high initial costs* (28.57%) and *lack of skilled professionals in AI and technology* (27.14%) as the top barriers. Other significant challenges include *insufficient government support* (21.49%), *resistance to change* (15.71%), and *lack of awareness* (7.14%). These results highlight systemic and capacity-related challenges to AI adoption and sustainable

practices. They suggest that while the technology is promising, structural and educational barriers must be addressed to unlock its full potential in Benin City's building industry.

Government’s Role in Promoting AI Adoption

Figure 4.14: Pie chart showing respondents’ views on government involvement

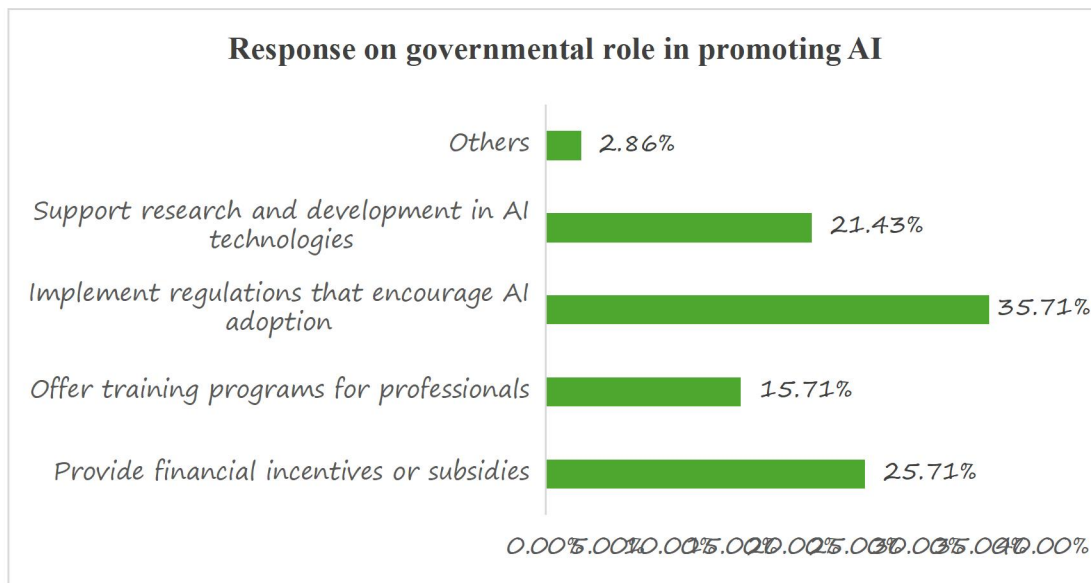


Figure 14 Pie chart showing respondents’ views on government involvement

When asked what the government should do to promote AI in sustainable building design, the most common response was to *implement regulations that encourage AI adoption* (35.71%), followed by *providing financial incentives or subsidies* (25.71%) and *supporting research and development* (21.43%). Fewer respondents chose *training programs for professionals* (15.71%),

and only 2.86% selected others. These findings emphasize the importance of policy-level engagement and financial backing in accelerating AI integration into the construction sector.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study investigated the role of Artificial Intelligence (AI) in designing sustainable and energy-efficient buildings within Benin City, Edo State. The objectives of the research were to assess the awareness and application of AI technologies, evaluate the role of smart tools such as Building Information Modeling (BIM), Smart Metering, and Building Management Systems (BMS), and examine the effectiveness of AI in sustainable construction practices and materials. Data were collected through structured questionnaires administered to professionals in the construction sector, including architects, engineers, and facility managers.

Findings from the study revealed that while awareness of AI in the building sector is growing, its actual application remains limited. Respondents strongly agreed that AI-driven tools such as BIM, Smart Metering, and BMS can significantly enhance energy efficiency and improve the performance of buildings. Similarly, AI was found to support sustainable construction through better material selection, waste reduction, and resource management. These outcomes show that AI can play a transformative role in addressing the challenges of energy inefficiency and unsustainable construction practices in Benin City.

Despite these promising results, several challenges hinder widespread adoption. High implementation costs, inadequate local expertise, limited infrastructure, and low levels of awareness among professionals were identified as major barriers. Furthermore, the absence of strong government incentives and policies has slowed the pace of adoption in Nigeria compared to more advanced economies.

In summary, this study concludes that AI holds immense potential in enhancing sustainability and energy efficiency in building design. However, for its benefits to be fully realized in Benin City and Nigeria at large, deliberate efforts are needed to overcome the barriers of cost, awareness, technical expertise, and policy support.

5.2 Recommendation

Based on the findings and analysis of this research, the following recommendations are proposed to foster the adoption of AI in sustainable and energy-efficient building design:

1. Promote Awareness and Capacity Building

Professional bodies, universities, and industry stakeholders should organize training workshops, seminars, and awareness campaigns to educate architects, engineers, builders, and policymakers on the benefits and applications of AI in building design.

2. Government Support and Incentives

Government agencies should introduce supportive policies such as tax breaks, grants, or subsidies for projects that integrate AI-based sustainable technologies. This will encourage private developers to invest in AI-powered solutions.

3. Pilot Projects in Public Infrastructure

The government should take the lead by adopting AI-driven sustainable solutions in the design and management of public buildings. These projects can serve as demonstration models and benchmarks for the private sector.

4. Strengthen Local Expertise through Education and Partnerships

Academic institutions should integrate AI and sustainability modules into architecture, engineering, and construction curricula. Collaborations with technology firms can also provide specialized training and certification programs to equip professionals with relevant skills.

5. Policy Frameworks for Sustainable Design

Policymakers should establish building codes and regulatory frameworks that mandate the use of AI-enabled energy efficiency and sustainability measures in new construction projects.

6. Encourage Research, Development, and Collaboration

Collaborative innovation between universities, professional associations, and the construction

industry should be encouraged. Pilot studies, joint research projects, and shared knowledge platforms will advance the adaptation of AI technologies to Nigeria's unique context.

7. Monitoring and Evaluation Systems

Mechanisms should be put in place to monitor energy use, operational efficiency, and user comfort in AI-powered buildings. Continuous evaluation will provide data-driven insights for improving performance and informing policy refinements.

Implementing these recommendations, Benin City, and by extension, Nigeria, can move closer to achieving sustainable urban development while embracing the benefits of Artificial Intelligence in the built environment.

5.3 Limitations of the Study

While this study achieved its objectives, certain limitations were encountered. The research focused only on Benin City, which may not fully represent other urban contexts in Nigeria. Additionally, the reliance on self-reported data from professionals introduces the possibility of bias or overestimation of awareness and application. Time and resource constraints also limited the sample size and the depth of case study analysis.

5.4 Suggestions for Further Research

Future studies should expand the geographical scope to include other Nigerian cities for broader generalization. Longitudinal studies that track the impact of AI adoption in building design over time are also recommended. Furthermore, empirical case studies of completed AI-powered sustainable buildings in Nigeria would provide practical insights and strengthen the evidence base for policy and industry adoption.

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QUESTIONNAIRE

UNIVERSITY OF BENIN

FACULTY OF ENVIRONMENTAL SCIENCES

DEPARTMENT OF ARCHITECTURE

This questionnaire is designed to gather information for a research study on the role of Artificial Intelligence (AI) in designing sustainable and energy-efficient buildings within Benin City, Edo State. Your response will assist in meeting the aim of the research. While I ask for your response to the items on the questionnaire, I promise that information supplied will be kept confidential, and will be used strictly for research purposes.

Thank you.

SECTION A: Demographic Information

Gender: Male Female

Occupation: Architect Civil Engineer Urban Planner Facility Manager
Construction Worker Real Estate Developer

Types of Buildings Worked on or Interacted With:

Libraries Government Buildings Courts Hospital School Others

SECTION B: Research Questions

INSTRUCTION: Tick (√) any response that corresponds with your opinion.

SA: Strongly Agree (5) **A:** Agree (4) **N:** Neutral (3) **D:** Disagree (2) **SD:** Strongly Disagree (1)

Table 4 Questionnaire

S/N	Research Questions	SA (5)	A (4)	N (3)	D (2)	SD (1)
Awareness and Application of AI						
1	I am aware of the use of AI technologies in building design.					
2	AI-driven technologies are currently being applied in sustainable building projects in Benin City.					
3	I have personally used or participated in projects where AI technologies were applied in building design.					
4	Awareness of AI applications in building design is generally low among professionals in Benin City.					
5	Building Information Modeling (BIM) enhances sustainable and energy-efficient					

	building design.					
6	Smart metering systems help in monitoring and reducing building energy consumption.					
7	Building Management Systems (BMS) contribute significantly to efficient energy management.					
8	AI-based tools improve overall building performance compared to traditional methods.					
9	AI supports the selection of sustainable building materials.					
10	AI improves waste reduction and resource management in building projects.					
11	AI-based designs lower the environmental impact of construction projects.					
12	AI significantly enhances the sustainability of building design compared to conventional approaches.					

Perceived Effectiveness of AI Adoption						
13	The adoption of AI in building design is cost-effective in the long term.					
14	AI technologies reduce operational costs in managing buildings.					
15	AI adoption in building design faces significant barriers in Benin City (e.g., cost, expertise, infrastructure).					
16	AI-based design solutions should be encouraged for sustainable urban development in Benin City.					

Section C

1. Have you ever been involved in or come across the use of Artificial Intelligence (AI) in the design or management of buildings in Benin City? If yes, in what context was AI used?
2. Which factors do you think hinder the implementation of sustainable building practices in Benin City?
3. What role do you believe the government should play in promoting the use of AI for sustainable building design?