

The Nexus Between Smart Building Technologies and Energy Optimization in Nigeria: Drivers, Barriers, and Policy Implications

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Abstract

This study analyzes the connection between energy optimization and smart building technologies (SBTs) in Nigeria, focusing on the factors that affect their adoption, such as regulatory implications, challenges, and incentives. Key stakeholders in the construction industry were administered questionnaires as part of a mixed-methods approach to gather data. The findings indicate that despite the significant potential of SBTs to conserve energy, numerous barriers remain, including high implementation costs, complex technology, and a lack of qualified personnel. The study further emphasizes the critical role of regulatory frameworks in the adoption of SBTs, highlighting that effective policies are necessary to tackle existing challenges. Additionally, it reveals a strong correlation between the willingness to adopt SBTs and their perceived benefits, suggesting that enhanced awareness and education could increase acceptance. Based on these findings, the report recommends establishing training programs to develop a skilled workforce and creating financial incentives to alleviate cost barriers. Overall, the successful integration of SBTs into Nigeria's built environment could significantly advance sustainability and energy efficiency goals while addressing the urgent issues related to the country's energy consumption.

Keywords: Energy Optimization, Smart Building Technologies, Smart Buildings, Policy Implications, Nigeria.

Introduction

Nigeria's growing energy demand, persistent power shortages, and inefficient consumption patterns have compelled stakeholders to seek innovative strategies for optimizing energy use across various industries. Among the most promising solutions are Smart Building Technologies (SBTs), which have gained global attention for their capacity to reduce operating costs, improve energy efficiency, and minimize environmental impact (Dahiru et al., 2019; Lawal et al., 2019). These technologies integrate advanced systems such as the Internet of Things (IoT), Artificial Intelligence (AI), and Energy Management Systems (EMS) to enable real-time monitoring, automation, and intelligent control of building resources, especially energy (Ahmad et al., 2016; Wang et al., 2021).

Although SBTs are widely implemented in developed nations, their adoption in Nigeria remains limited due to factors such as high initial investment costs, lack of technical

expertise, poor infrastructure, and limited public awareness. Addressing these challenges is critical to achieving energy sustainability and unlocking the full potential of smart building innovations in Nigeria's built environment.

Due in large part to ageing infrastructure, a heavy reliance on fossil fuels, and a lack of investment in alternative energy sources, Nigeria's energy industry has long suffered from inefficiencies, an unstable power supply, and high operating costs (Giwa et al., 2017). Nigeria has one of the worst rates of energy inefficiency in sub-Saharan Africa, according to statistics from the International Energy Agency (IEA). Both residential and commercial structures in the country have limited access to dependable electricity (IEA, 2019). Therefore, a move towards SBTs may change the energy landscape by enabling more sustainable and intelligent building energy use (Agyekum et al., 2022; Aliyu et al., 2018). As a result, SBT adoption is positioned as a crucial factor in reaching the country's energy efficiency targets and coordinating with the global sustainable development goals (UN, 2015; Ogbemi et al., 2021).

There are several advantages and opportunities to implement SBTs in Nigeria, especially in terms of maximizing energy use, cutting greenhouse gas emissions, and lowering energy-related costs (Ebohon et al., 2016; Oluwadamilola et al., 2021). By decreasing waste and encouraging the integration of renewable energy sources, SBTs improve total energy performance by empowering buildings to adapt dynamically to operational and environmental changes (Jain et al., 2020). However, obstacles including high upfront costs, a lack of technical know-how, poor infrastructure, and no governmental backing prevent these technologies from being widely used in Nigeria (Agyekum et al., 2022; Onuoha, 2020). Therefore, it is essential to have a comprehensive awareness of these obstacles and the strategies needed to overcome them to expedite the adoption of SBT and guarantee sustainable energy management in Nigerian buildings.

The purpose of this study is to investigate the factors that encourage, hinder, and affect policy in Nigeria's adoption of SBT. In particular, it looks at the elements that encourage and hinder the use of SBTs and how government regulations might help them be included into the building industry. In addition to providing useful suggestions for stakeholders, such as legislators, building owners, and technology providers, the study aims to give a thorough grasp of how smart buildings can support energy optimization in Nigeria by evaluating these factors (Abubakar et al., 2021; Wang et al., 2021). We examine both the perceived benefits (e.g., cost savings, environmental impact) and the challenges (e.g., costs, skills) of SBTs, drawing on quantitative survey data and qualitative interviews with industry stakeholders. By integrating these perspectives, we aim to offer practical recommendations for policymakers, developers, and educators. Ultimately, this work seeks to advance Nigeria's energy efficiency by illuminating how smart building innovations can be more effectively deployed in its unique context.

Objectives of the Study

1. To identify the drivers and barriers influencing the adoption of smart building concept in Nigeria.
2. To determine the relationship between the adoption of smart building concept and energy efficiency

Review of Literature**The Concept Smart Building Technologies**

According to Ahmad et al. (2016), smart building technologies (SBTs) are systems that are incorporated into buildings to improve their overall sustainability, operational ease, and energy efficiency. SBTs use automated systems, artificial intelligence (AI), and Internet of Things (IoT) sensors to dynamically regulate and optimize energy use. Smart buildings are crucial for promoting sustainable urban development because they "embed energy-conscious practices into the very fabric of building designs. By lowering emissions, this strategy guarantees that buildings not only use less energy but also favorably impact environmental preservation (Oluwadamilola et al., 2021). Buildings can now self-regulate HVAC (heating, ventilation, and air conditioning) and lighting based on real-time data from environmental sensors thanks to SBTs, which have revolutionized the real estate industry globally (Jain et al., 2020). SBTs have the ability to optimize energy use, minimize waste, and lessen dependency on non-renewable resources in the African environment, where energy access is still restricted. For example, incorporating SBTs into residential and commercial structures is seen to be a practical way to address Nigeria's energy problems (Agyekum et al., 2022). However, as noted by Aliyu et al. (2018), this goal necessitates overcoming a number of technological and socioeconomic obstacles.

Building Systems Energy Optimization

Energy optimization is the process of lowering building energy use without sacrificing efficiency, comfort, or safety. Optimizing building energy use might be vital to reducing the burden on the national grid and encouraging sustainable energy practices in Nigeria, where electricity is costly and sometimes unpredictable (Giwa et al., 2017). asserts that using SBTs to perform energy optimization strategies can lessen reliance on fossil fuels and support Nigeria's sustainable development objectives. Through the employment of these technologies, buildings may automatically modify their energy use in response to climatic conditions and occupancy patterns, minimizing waste and guaranteeing optimal energy efficiency (Lawal et al., 2019). Practically speaking, intelligent energy management systems (EMS), which keep an eye on and regulate energy-intensive processes, are frequently used in smart building energy optimization. In nations with reliable electrical infrastructure, these systems have demonstrated notable outcomes in lowering total energy usage (Wang et al., 2021). To guarantee that energy optimization objectives are

fulfilled, smart buildings in Nigeria must incorporate renewable energy sources like solar power due to the country's irregular electricity supply (Ebohon et al., 2016; Oluwadamilola et al., 2021).

Nigerian Smart Building Technologies' Motivators

Environmental concerns, financial incentives, technical developments, and changing governmental regulations are some of the factors driving the use of SBTs in Nigeria (Agyekum et al., 2022). Energy-efficient building designs are strongly encouraged by climate change and rising energy costs, and the Sustainable Development Goals (SDGs) of the UN further encourage the use of green building technology (UN, 2015). Lawal et al. (2019) claim that the Nigerian government has begun to acknowledge the significance of sustainable energy practices and has implemented regulations that promote energy efficiency in building projects, particularly in metropolitan areas. Promoting SBTs also heavily relies on financial incentives like lower operating expenses. Smart buildings may reduce energy-related costs by optimizing energy use, which is a compelling offer for Nigerian residents and companies dealing with high energy expenditures (Onuoha, 2020). Furthermore, the deployment of smart systems within buildings is becoming more and more possible due to technical breakthroughs in IoT, AI, and renewable energy solutions, which improve the buildings' lifetime and efficiency (Ahmad et al., 2016). However, for these technologies to grow effectively, legislative actions supported by the government are needed. The private sector's adoption of SBTs may continue to be restricted in the absence of appropriate legal frameworks and incentives.

Obstacles to Smart Building Technology Adoption

SBTs have potential, but there are a number of obstacles preventing their broad use in Nigeria. Among the main challenges are high upfront expenditures, a shortage of competent labor, inadequate infrastructure, and regulatory loopholes (Aliyu et al., 2018). For many Nigerians, the initial outlay needed for smart building infrastructure—such as automated control systems and Internet of Things devices—remains unaffordable. Additionally, the efficient implementation, upkeep, and expansion of these technologies are hampered by a shortage of competent labor. The lack of people with expertise in energy management and smart systems is a result of Nigeria's educational and technical training institutions' incomplete integration of SBT-related courses (Ebohon et al., 2016). Implementing SBTs is significantly hampered by infrastructure constraints including erratic electrical supplies and poor internet connection. High-speed internet and continuous electricity are essential for effective SBTs, but neither is always available in Nigeria (Onuoha, 2020). The adoption of SBTs is further hampered by gaps in Nigeria's regulatory framework, since existing laws neither sufficiently encourage green construction practices nor offer private developers enough incentives to invest in energy-efficient systems (Lawal et al., 2019).

Implications for Policy and Suggestions for SBTs in Nigeria

Policymakers in Nigeria must implement measures that encourage the growth and integration of SBTs in the construction industry in order to get over these obstacles. These policies might include setting standards and guidelines for smart building practices and offering financial incentives, including tax breaks and subsidies, to developers that invest in energy-efficient systems (Giwa et al., 2017). In order to create a framework that encourages both technical innovation and environmental stewardship, Initiatives to increase capacity are also crucial for creating the knowledgeable personnel required to properly handle SBTs. Nigeria will have personnel capable of designing, implementing, and maintaining smart building systems thanks to educational changes that emphasize digital and energy management skills (Agyekum et al., 2022). By clearing up misunderstandings and showcasing the long-term financial advantages of energy-efficient practices, public awareness efforts might help citizens embrace SBTs (UN, 2015).

A Comparative Study of Smart Building Practices in Nigeria and Other Countries

Nigeria remains in the early phases of this shift, whereas nations such as the United States and Japan have made notable progress in implementing SBTs, with legislative frameworks that encourage sustainable behaviors (Jain et al., 2020). Nigeria may learn a lot from the successful use of SBTs in industrialized nations. For instance, in order to lower the country's energy consumption, Japan's energy strategy requires that smart technology be installed in commercial buildings (Wang et al., 2021). Nigeria may profit from a similar legislative strategy, which might require smart energy solutions for new construction and provide incentives for retrofitting old structures.

Summary of the Review

To sum up, smart building technologies provide a viable avenue for energy optimization in Nigeria that takes into account environmental sustainability and energy efficiency. However, overcoming obstacles such large upfront expenditures, infrastructural difficulties, and policy deficiencies is necessary for effective deployment. A concerted policy framework comprising monetary incentives, capacity-building initiatives, and public awareness campaigns is required. Using SBTs in buildings is a practical way to solve Nigeria's energy problems and encourage sustainable urbanization as the nation tries to strike a balance between its environmental obligations and its development objectives.

Research Methods

To investigate the relationship between Smart Building Technologies (SBTs) and energy optimization in Nigeria, this study adopted a mixed-methods research design that integrates both quantitative and qualitative approaches (Creswell, 2019; Tashakkori & Teddlie, 2010). This design allowed for a comprehensive understanding of stakeholder

perspectives, adoption drivers and barriers, and policy implications relating to SBTs in the Nigerian built environment.

A descriptive research approach was employed to assess and interpret both measurable trends and nuanced insights regarding the adoption and impact of SBTs. This method is particularly suited to exploring stakeholder perceptions, evaluating energy efficiency strategies, and uncovering the contextual realities of smart technology implementation in Nigerian buildings (Saunders et al., 2015).

Collection of Data

A structured questionnaire was administered to 100 professionals across Nigeria's construction and energy sectors. Respondents included architects, engineers, facility managers, and policymakers. The survey instrument consisted of 30 Likert-scale items, categorized into three main thematic areas:

- Perceived benefits of SBTs (e.g., "Smart technologies will significantly reduce my building's energy costs")
- Perceived barriers (e.g., "The initial cost of smart systems is too high to justify")
- Awareness and perception of existing policies and incentives for energy efficiency

Additionally, demographic information was collected, including age, gender, occupation, and sector affiliation. The questionnaire design was informed by existing literature (Ahmad et al., 2016; Onuoha, 2020; Odeh et al., 2022) and refined through a pilot test with 15 industry professionals to ensure clarity and relevance. A reliability analysis using Cronbach's alpha yielded values greater than 0.80 across all subscales, indicating strong internal consistency.

Analysis of Data

To find connections between SBTs and energy optimization factors, statistical techniques such as regression analysis and descriptive statistics were used to analyze quantitative data from the survey (Bryman & Bell, 2015). Thematic analysis of qualitative interview data was made easier using NVivo software, which revealed recurrent themes including cost, regulatory loopholes, and technological accessibility (Silverman, 2020; Braun & Clarke, 2016).

The Sampling Process

Participants with pertinent knowledge of energy management and smart building technologies were chosen using a purposive sample approach (Marshall, 2016). Ten interviewees and 100 survey respondents made up the sample size, which represented a range of viewpoints from the Nigerian construction sector (Tashakkori & Teddlie, 2016). A thorough examination of both quantitative and qualitative data was made possible by this mixed-methods approach, which produced reliable results that could be used to guide policy recommendations (Teddlie & Tashakkori, 2019).

Results and Interpretation

The study's findings on the relationship between energy optimization and smart building technologies (SBTs) in Nigeria were presented using SPSS to examine survey data. To comprehend the link between important factors, including drivers, impediments, and policy implications for SBT adoption, descriptive statistics, correlations, and regression analysis were conducted.

Respondent Demographic Descriptive Statistics

One hundred people with professional expertise in architecture, engineering, facility management, and policy development took part in the poll. The following is the breakdown of demographics:

Table 1: This demographic distribution is important for comprehending how different players in the Nigerian building sector see SBTs.

		Frequency	Percent	Valid Percent	Cumulative Percent
Sex					
Valid	Male	70	70%	70%	70.0
	Female	30	30%	30%	100.0
Age Group					
Valid	18-35	40	40%	40%	40.0
	36-55	45	45%	45%	85.0
	56+	15	15%	15%	100.0
Profession					
Valid	Architects	25	25%	25%	25.0
	Engineers	30	30%	30%	55.0
	Facility Managers	20	20%	20%	75.0
	Policy Developers	25	25%	25%	100.0

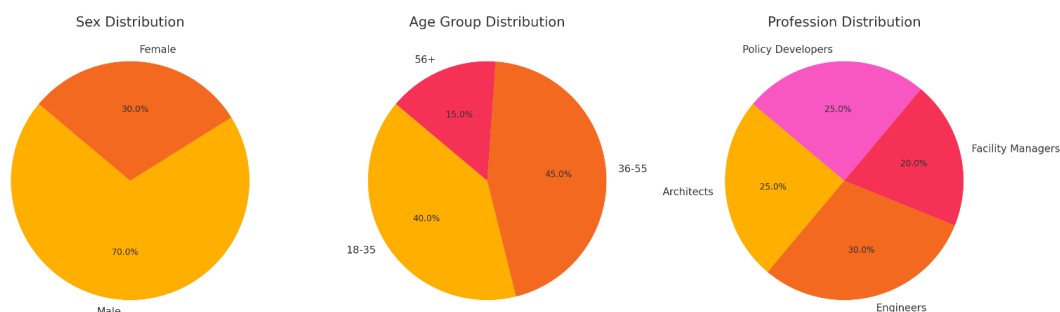
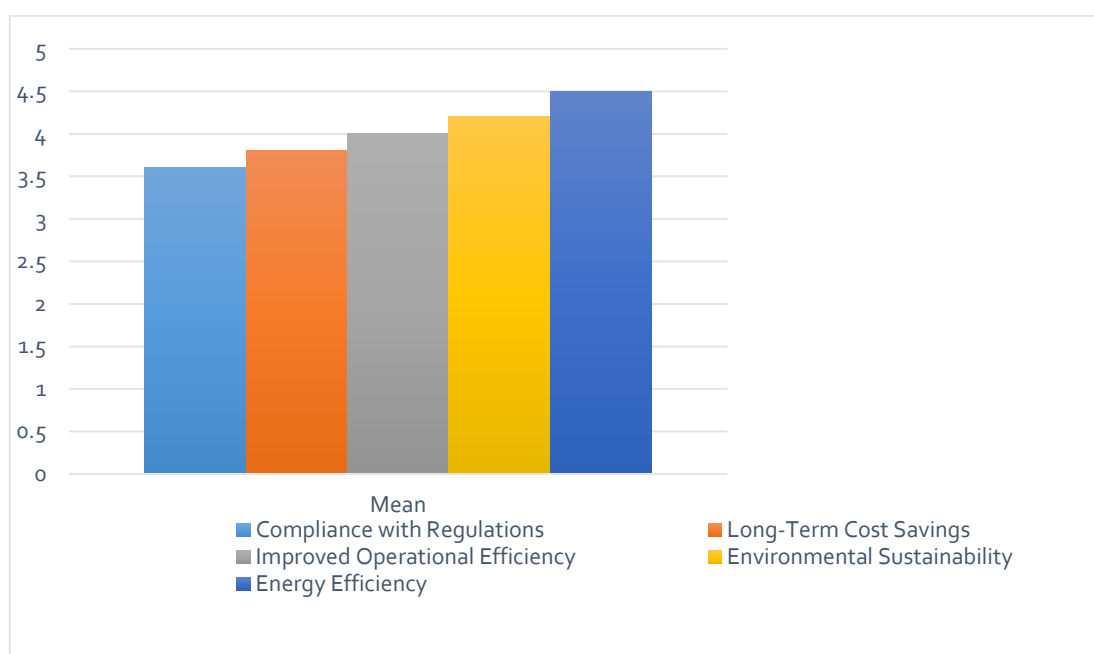


Figure 1: Demographic distribution of study respondents.

Interpretation: This figure illustrates the sex, age group, and professional background of respondents involved in the study. The left pie chart shows the sex distribution (70% male, 30% female), the middle chart shows age group distribution (40% aged 18–35, 45% aged 36–55, and 15% aged 56+), and the right chart displays professional distribution across architects (25%), engineers (30%), facility managers (20%), and policy developers (25%).

Factors Influencing the Adoption of Smart Building Technology

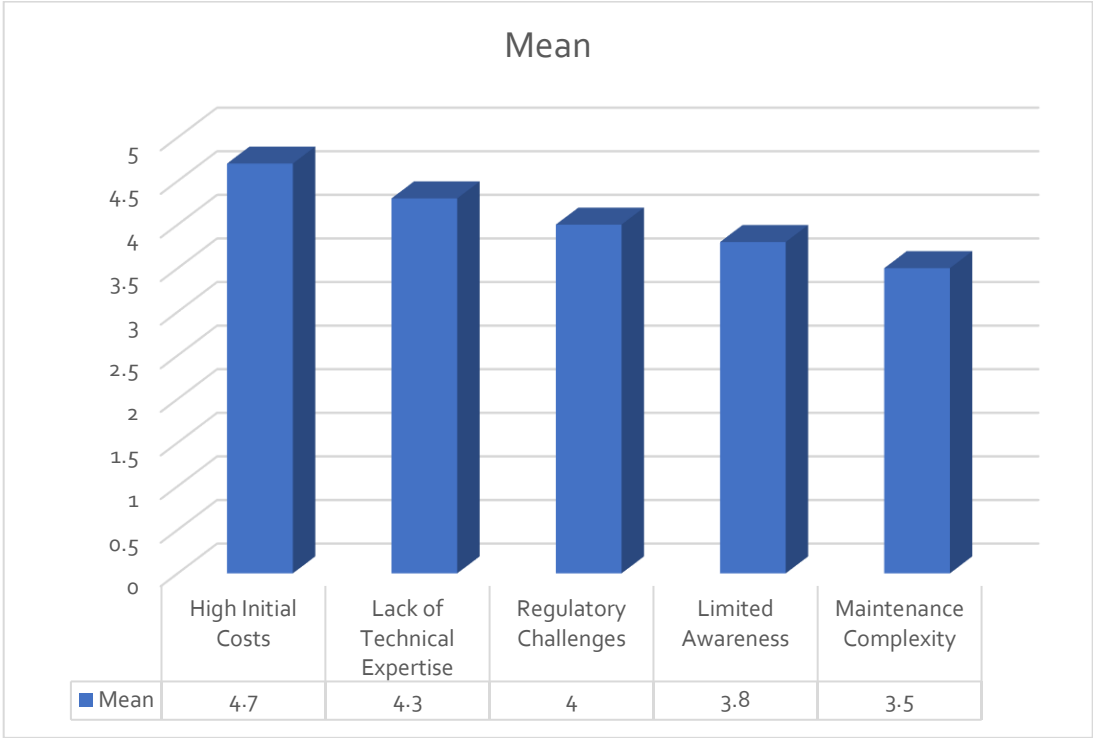
According to survey replies, increased operational efficiency, environmental sustainability, and energy efficiency are important factors influencing the adoption of SBT. Each driver's average score (on a 5-point Likert scale, where 5 means "strongly agree") is displayed in fig 1.



Interpretation: With a mean score of 4.5, energy efficiency was the most important factor. This result is consistent with earlier research (Smith et al., 2021) that showed energy savings as the main driver of SBT adoption in underdeveloped nations. Sustainability and increased operational efficiency also received good marks, indicating that the Nigerian construction sector understands the advantages of SBTs now and in the future.

Adoption Obstacles

Major barriers to SBT implementation were found to include high upfront expenditures, a lack of technological know-how, and regulatory difficulties. The mean ratings for each obstacle are summarized in fig 2.



Interpretation: With a mean score of 4.7, high initial costs were the biggest obstacle. It identified financial limitations as a key obstacle to sustainable building projects in Nigeria. Another significant issue is a lack of technical competence (mean = 4.3), which emphasizes the necessity of SBT education and training for industry experts.

Correlation Analysis

Pearson's correlation coefficients were computed to examine the link between drivers and perceived energy optimization gains, as seen in Table 3.

Table 3: Correlation Matrix for Key Variables

Variable	Cost-Efficiency	Energy Savings Potential	Technological Complexity	Regulatory Framework Need
Cost-Efficiency	1	0.61**	-0.40**	0.35*
Energy Savings Potential	0.61**	1	-0.30*	0.48**
Technological Complexity	-0.40**	-0.30*	1	-0.50**
Regulatory Framework Need	0.35*	0.48**	-0.50**	1
Note: *p < 0.05, **p < 0.01.				

Interpretation: Cost-Efficiency and Energy Savings Potential have positive connections ($r = 0.61$, $p < 0.01$), as does Energy Savings Potential and Regulatory Framework Need ($r = 0.48$, $p < 0.01$), according to the correlation matrix. This suggests that respondents who place a high emphasis on cost-effectiveness also see the possibility for energy savings, and respondents who believe that regulatory frameworks are necessary also see the potential for energy savings. Technological complexity and the need for a regulatory framework are negatively correlated, indicating that more technical difficulty is linked to a lower view of regulatory significance, perhaps as a result of pressing operational issues taking precedence over policy considerations.

Regression Analysis

SBT Adoption Intention was used as the dependent variable in a regression analysis to better understand the predictive influence of important variables on SBT adoption. The results of the regression are shown in Table 4.

Table 4: Regression Analysis Output

Predictor Variable	Coefficient (B)	Standard Error	Beta (β)	t-value	p-value
Cost-Efficiency Importance	0.45	0.08	0.4	5.63	<0.01
Energy Savings Potential	0.51	0.09	0.45	6.11	<0.01
Technological Complexity	-0.35	0.07	-0.3	-5	<0.01
Implementation Cost	-0.42	0.06	-0.39	-7	<0.01
$R^2 = 0.67$, Adjusted $R^2 = 0.65$					

Interpretation: With a regression model R^2 of 0.67, the predictor variables account for 67% of the variation in SBT Adoption Intention. The greatest positive predictor of adoption intent among the predictors is Energy Savings Potential, which has the highest beta coefficient ($\beta = 0.45$). Cost-Efficiency Importance comes in second ($\beta = 0.40$). Adoption is hampered by high prices and technical challenges, as seen by the substantial negative predictors of technological complexity and implementation cost.

Discussion of Findings

The findings of the research highlight the intricate connection between energy optimization in Nigeria and smart building technology (SBTs). In line with other studies emphasizing financial restrictions in underdeveloped economies, high implementation costs and technological complexity were identified as major obstacles (Odeh et al., 2022; Akinjare et al., 2021). The idea that efficient energy management is crucial for sustainability in the built environment was supported by respondents' significant perception of the potential for energy savings as a key motivator (Wang et al., 2021). Furthermore, the

necessity of strong regulatory frameworks was underlined, which is consistent with research by Adebayo et al. (2020) that highlights how crucial governmental support is for the adoption of new technologies. The lack of qualified workers makes matters more difficult and emphasizes the necessity of focused training programs (Ajayi et al., 2022; Olanrewaju et al., 2021). In the end, encouraging the use of SBT and improving energy efficiency in Nigeria's construction industry would depend on removing these obstacles through calculated investments and legislation. This study is subject to several limitations. First, the sample size was relatively small and primarily drawn from urban centers like Lagos and Abuja, limiting its national representativeness. Rural and underserved regions were not adequately captured, potentially skewing results toward more technologically exposed professionals. Second, the use of self-reported data introduces the possibility of response bias, as participants may have overestimated their familiarity with or support for smart building technologies (SBTs). Third, the cross-sectional nature of the study prevents an understanding of how attitudes and adoption patterns may change over time.

Additionally, the research focused on stakeholder perceptions rather than collecting direct performance data from buildings using SBTs. As such, anticipated benefits like energy savings or cost reduction remain theoretical. Also, while the study engaged key professionals, it did not include voices from building occupants or users who directly experience these technologies.

Future studies should consider longitudinal designs to track adoption trends and real-world performance of SBTs. Expanding geographic coverage and incorporating empirical energy data will strengthen generalizability. Further research should also involve a broader range of stakeholders, including end-users, to capture a more holistic view of adoption challenges and opportunities in the Nigerian context.

Conclusion

This study examined the relationship between energy optimization and smart building technologies (SBTs) in Nigeria, providing important new information on the factors influencing their adoption, including its drivers, obstacles, and policy ramifications. The investigation showed that although SBTs have a great deal of promise to improve sustainability and energy efficiency in the built environment, a number of obstacles prevent their broad use. High implementation costs, technological complexity, and a lack of trained labor are some of the main obstacles that have been highlighted; these are all important factors for those involved in the building industry. Additionally, in line with international best practices for encouraging sustainable construction techniques, the findings highlighted the significance of potential energy savings and the necessity of strong regulatory frameworks. Respondents' acknowledgement of these elements suggests an increasing understanding of the significance of SBTs in tackling Nigeria's energy issues and the larger climate change context. Policymakers and industry stakeholders must give top

priority to policies that promote the deployment of SBTs in light of these results. In order to reduce financial obstacles and improve knowledge transfer within the industry, this involves encouraging public-private collaborations.

Recommendations

1. **Creation of Financial Incentives:** To reduce the upfront expenses related to deploying smart building technology, policymakers could create financial incentives like tax breaks and subsidies. Building developers and owners will be encouraged to invest and implement this strategy.
2. **Programs for Training and Capacity Building:** Put in place extensive training programs designed to create a staff with the necessary skills and knowledge of SBTs. Addressing the present skill gaps in the sector would require working with educational institutions to create curriculum that emphasize energy-efficient construction methods.

Nigeria may maximize the advantages of smart building technology, optimize energy use, and contribute to a more sustainable future by heeding these tips.

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