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BARRIERS TO SMART BUILDING TECHNOLOGY ADOPTION THROUGH THE LENS OF TECHNOLOGY-ORGANIZATION-ENVIRONMENT (TOE) IN CALABAR, NIGERIA

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Abstract

Smart building technologies are new resource that need effective adoption and integration for sustainable development in built environments. This study looked into professionals' views on barriers to adopting smart building technology, the outcomes for building performance, and how they are connected in Calabar, Nigeria, using the Technology-Organization-Environment (TOE) framework. Mixed-method approach was used to collect data from 60 survey respondents and 12 interview participants, including Architects, Engineers, Contractors, Developers, Facility Managers, and Policymakers. Participants were selected using a purposive sampling technique to ensure that only professionals directly involved in the design, construction, management, and regulation of buildings were included in the study. The analysis included descriptive statistics, mean ranking, thematic analysis, and a review of policies. The findings revealed five main barriers: High Initial Costs (Mean = 4.63), Lack of Technical Skills (Mean = 4.41), Weak Regulatory Support (Mean = 4.15), Low Public Awareness (Mean = 3.87), and Limited Technology Availability (Mean = 3.72). The results also showed different priorities among professionals: developers concentrate on costs, engineers prioritize technical skills, policymakers deal with regulatory issues, and facility managers focus on maintenance challenges. Mean ranking analysis confirmed these differences among stakeholder groups, showing varied views on adoption barriers. Correlation analysis indicated significant positive links between overcoming barriers, especially through "Skills Development," "Regulatory Support," and "Strengthened Supply Chains," and key building performance outcomes such as "Operational Efficiency," "Energy Savings," and "Occupant Satisfaction." This strongly suggests that tackling economic, technical, and institutional challenges collaboratively will improve the integration and performance of smart buildings in developing cities like Calabar. In conclusion, the study establishes that addressing these barriers is essential to achieving higher efficiency, sustainability, and functionality in the built environment. It is therefore recommended that policymakers strengthen regulatory frameworks, professionals pursue continuous skill development, and developers explore innovative financing models to reduce cost burdens and promote widespread adoption of smart building technologies in Nigeria and similar developing contexts.

Keywords: Barriers, Smart technology, Smart building adoption, TOE framework.

INTRODUCTION

The conception, design, construction and upkeep of physical structures that facilitate human living and activities are encompassed by the built environment. In recent years, this environment has been transformed by the increasing incorporation of digital technologies, resulting in the rise of the idea of the smart building. The growing incorporation of digital technologies in recent decades has transformed this environment, leading to the concept of the smart building. A smart building can be broadly defined as a technologically enhanced facility that employs interconnected systems and data-driven processes to optimise energy efficiency, sustainability, comfort, and security (Ahmad, Aibinu, & Stephan, 2020; Dagou, Gurgun, Koc, & Budayan, 2025). The International Energy Agency (2021) indicates that such structures are crucial for diminishing carbon emissions, facilitating renewable integration, and attaining global climate objectives. Their significance is derived not only from technological advancement but also from their enhancement of urban resilience, economic efficiency, and the quality of life for residents (Building and Construction Authority, 2021).

Conceptually, smart buildings extend beyond automation to encompass a holistic system of sensors, controls, communication networks, and analytics that collectively enable adaptability, responsiveness, and efficiency (Klein et al., 2021). They represent both a physical and organizational transformation, wherein data streams continuously inform operations such as heating, ventilation, lighting, and security management (Al Dakheel, Del Pero, & Aste, 2020). Smart buildings integrate technical and social dimensions, necessitating synchronization among technological infrastructure, user requirements, organizational objectives, as well as[5] environmental policies.

Smart building technologies are spreading around the world, especially in advanced economies where there are strong supply chains, financial incentives, and regulatory frameworks (European Commission, 2018). However, adoption remains uneven in developing contexts, especially in sub-Saharan Africa, where multiple barriers hinder implementation. Scholars have identified high initial investment costs, insufficient technical expertise, weak institutional support, low public awareness, and fragile supply networks as key impediments (Agyekum-Mensah, Knight, & Mahamadu, 2020; Kithuka, Likhole, & Ochieng, 2018; Olanrewaju, Okubena, Garba, & Ismail, 2019). Recent research underscores that these constraints are further compounded by socio-cultural perceptions of smart technologies as luxury features, rather than essential sustainability tools (Odefadehan, Victor, & Gabriel, 2023; Mba, Oforji, & Ogbodo, 2025).

In Nigeria, the real estate and construction sectors are critical drivers of economic growth and urban development, yet the penetration of smart building technologies remains low (Olanrewaju et al., 2019). This paradox is striking given the rising demand for modern, sustainable, and technologically enabled spaces in urban centres. While national policies recognize the importance of energy efficiency and technological integration, city-level adoption has been inconsistent due to institutional fragmentation, poor enforcement, and limited investment in technical training.

Consequently, Nigeria risks lagging behind in the global transition toward smarter, more sustainable built environments (Odefadehan et al., 2023).

Calabar, the capital of Cross River State, is a small example of these problems. The city is experiencing steady urban expansion, with increasing demand for residential, commercial, and institutional buildings. However, the adoption of smart building technologies is minimal, particularly at the design and construction stages, where digital tools, automation, and integrated systems are rarely incorporated into project planning or implementation. Limited use is also observed during the contract administration stage, as most procurement and project monitoring processes remain manual. At the post-construction stage, adoption is almost non-existent, with very few facilities utilizing smart maintenance, energy management, or occupant monitoring systems. Local challenges include unreliable power supply, lack of technical expertise among construction professionals, weak regulatory incentives, limited awareness among clients, and inadequate supply chain networks. These barriers collectively limit the city's ability to align with global innovation trajectories, raising concerns about efficiency, sustainability, and long-term competitiveness (Ahmad et al., 2020; Mba et al., 2025).

To explore these issues systematically, this study adopts the Technology–Organization–Environment (TOE) framework (Tornatzky & Fleischer, 1990), a robust theoretical model widely applied to examine technology adoption (Oliveira & Martins, 2011; Hsu, Kraemer, & Dunkle, 2014). The TOE framework uniquely integrates technological characteristics (such as cost, complexity, and relative advantage), organizational factors (resources, competencies, and leadership), and environmental conditions (policy, competition, and supply chain dynamics). Compared with narrower frameworks such as the Technology Acceptance Model (TAM) or Diffusion of Innovation (DOI), the TOE approach provides a more holistic, multi-level understanding of adoption dynamics in construction and real estate contexts (Zhang, Shen, & Wu, 2017).

Accordingly, this study is guided by three objectives:

i. To identify and rank the major barriers to smart building technology adoption in Calabar, Nigeria.

ii. To examine how these barriers align with the TOE framework dimensions.

iii. To explore the relationship between overcoming barriers and building performance outcomes, including efficiency, sustainability, and occupant satisfaction.

By addressing these questions, the research contributes both empirically and theoretically. Empirically, it provides one of the first systematic analyses of smart building adoption barriers in a mid-sized Nigerian city, thereby filling a gap in African urban sustainability literature. Theoretically, it demonstrates the applicability of the TOE framework to localized contexts, enriching understanding of how global technological trends interact with local socio-economic realities. Practically, it offers policymakers, developers, and construction professionals evidence-based strategies for overcoming barriers and advancing sustainable built environment outcomes in Nigeria and similar developing contexts.

Theoretical Framework

The present study is anchored on the Technology–Organization–Environment (TOE) framework originally developed by Tornatzky and Fleischer (1990) to explain how organizations adopt and implement technological innovations. The TOE framework posits that technology adoption is influenced not only by the characteristics of the technology itself but also by the internal context of the adopting organization and the external environment in which it operates. Over the years, it has been widely applied in diverse fields including information systems, e-business, healthcare, and construction (Oliveira & Martins, 2011; Baker, 2012; Aboelmaged, 2014), making it one of the most robust and adaptable theoretical models for studying innovation adoption.

The framework comprises three interrelated dimensions:

1. ***Technology:*** The technological context of the TOE framework relates to both the internal technologies already in use within an organization and the external innovations available in the market that can potentially be adopted (Zhu, Kraemer, & Xu, 2006). It encompasses characteristics of the innovation that determine its perceived feasibility, desirability, and long-term benefits. In the case of smart building technologies, several key attributes have been widely discussed in the literature, including cost, complexity, compatibility, and relative advantage (Oliveira & Martins, 2011; Baker, 2012).

    i. *Cost:* The financial requirement for acquiring and deploying smart building technologies is consistently reported as the most significant adoption barrier, particularly in developing economies (Agyekum-Mensah et al., 2020; Odefadehan, Victor, & Gabriel, 2023). The costs go beyond just buying hardware like sensors, meters, and control systems. They also include installation, integration with existing infrastructure, training staff, and ongoing maintenance. This problem is made worse in Nigeria by high rates of inflation, volatile currency exchange rates, and restricted credit availability, which deters developers from investing in clever solutions. However, while the upfront costs are high, studies have demonstrated that smart technologies can deliver significant long-term savings through reduced energy consumption, improved operational efficiency, and enhanced asset longevity (Ahmad, Aibinu, & Stephan, 2020; Dagou, Gurgun, Koc, & Budayan, 2025). Thus, cost functions both as a deterrent and a driver, depending on whether stakeholders adopt a short-term or long-term financial perspective.

    ii. *Complexity:* Complexity refers to the degree of difficulty associated with understanding, implementing, and using smart building systems (Rogers, 2003). Using Internet of Things (IoT) platforms, smart buildings usually integrate several subsystems, including lighting, fire detection, security, and high-voltage air conditioning. In settings with limited professional expertise, the technical complexity needed for system design, installation, and interoperability can be daunting (Kithuka, Likhole, & Ochieng, 2018). In Nigeria, the lack of structured training programs and limited exposure of construction professionals to advanced building automation systems exacerbate perceptions of complexity. This often discourages adoption, as stakeholders associate these technologies with technical risks and uncertainties. On the other hand, advancements in user-friendly dashboards, cloud-based platforms, and modular systems have the potential to reduce perceived complexity, thereby encouraging gradual adoption (Al Dakheel, Del Pero, & Aste, 2020).

iii. *Compatibility:* According to Oliveira and Martins (2011), compatibility measures how well new technologies mesh with current procedures, infrastructure, and cultural norms. In Calabar, many existing buildings lack the structural provisions, electrical capacity, or digital infrastructure required for smart technology integration. Older buildings can be expensive and logistically difficult to retrofit, which makes developers and property owners reluctant. Cultural fit is also important because many customers see smart systems as luxuries rather than necessary sustainability tools, which influences consumer demand (Mba, Oforji, & Ogbodo, 2025). However, compatibility can act as a catalyst for developers to match the adoption of smart buildings with more general sustainability agendas, CSR objectives, and legal compliance needs.

iv. *Relative Advantage:* Relative advantage describes the perceived benefits of the innovation compared to existing alternatives (Rogers, 2003). For smart building technologies, advantages include lower energy bills, reduced carbon emissions, improved occupant comfort, enhanced safety, and increased property value (Klein et al., 2021). In contexts such as Nigeria, these benefits could be transformative, especially in reducing operational costs and improving resilience against unstable power supply. However, limited public awareness and the absence of standardized performance benchmarks reduce the visibility of these advantages, leading to undervaluation of smart solutions (Odefadehan et al., 2023). Evidence from advanced economies shows that once stakeholders recognize measurable returns on investment such as reduced utility costs or improved tenant satisfaction, the perception of relative advantage becomes a strong driver of adoption (Dagou et al., 2025).

Taken together, these characteristics show that the technological background is a dynamic interaction of obstacles and drivers, rather than a static determinant. High costs and complexity limit short-term adoption, while compatibility concerns highlight infrastructural and cultural misalignments. However, when the high relative benefits of smart technologies are successfully explained and demonstrated, they can influence adoption decisions. As a result, the technology factor is both the most immediate impediment and the most compelling motivator of smart building deployment in Calabar.

2. ***Organization:*** The TOE framework defines the organisational context as the adopting entity's internal resources, structures, culture, and competences that either assist or hinder the introduction of new technologies (Oliveira & Martins, 2011). In construction and real estate development, the organisation is not confined to a single firm but also includes a network of players such as architects, engineers, contractors, developers, facility managers, and policymakers that work together to determine adoption outcomes (Baker, 2012). Several organisational aspects are particularly important for the deployment of smart building technology in Calabar.

    i. *Resource Availability:* Organisations' ability to acquire and operate smart technology is determined by their financial, technical, and human resources. Many Nigerian construction companies have low resources and thin profit margins, limiting investment in costly or experimental technologies (Olanrewaju, Okubena, Garba, & Ismail, 2019). Skilled professionals skilled in building automation, data analytics, and IoT integration are in short supply, indicating a shortfall in higher education curriculum and professional training (Mba, Oforji, & Ogbodo, 2025). On the plus side, multinational developers and large institutions like colleges and government organisations frequently have more resources, putting them as early adopters who can show viability to others.

    ii. *Leadership and Management Support:* Organizational leadership influences attitudes towards technological innovation. Leaders with a long-term strategic perspective are more willing to invest in smart technologies because they have the potential to lower lifetime costs and improve organizational reputation (Hsu, Kraemer, & Dunkle, 2014). Risk-averse CEOs who prioritise short-term profitability may resist adoption, considering smart systems as expensive indulgences. Anecdotal research in Calabar reveals that organizations exposed to international standards or donor-funded sustainability efforts have the highest level of management buy-in.

    iii. *Organizational Structure and Culture:* Centralized decision-making, bureaucratic procedures, and ineffective interdepartmental communication frequently stifle innovation in construction enterprises (Agyekum-Mensah et al., 2020). Employees in organizations without innovation-oriented cultures may be hesitant to accept technology that upset existing procedures. Organizations that foster experimentation, engage in professional development, and use collaborative ways are better positioned to integrate smart systems. Globally, enterprises with strong innovation cultures, such as those involved in green building certifications, report easier adoption of smart technologies (Klein et al., 2021).

    iv. *Knowledge and Training:* One of the most frequently reported barriers to innovation in the built environment is the shortage of skilled professionals (Kithuka, Likhole, & Ochieng, 2018). In Nigeria, construction education remains largely focused on conventional methods, leaving limited space for smart technologies, Internet of Things (IoT) applications, or digital construction management tools. This gap in training is reflected in practice: contractors and facility managers often find themselves unprepared to handle the installation, operation, or maintenance of more advanced systems. Yet, these shortcomings are not insurmountable. Well-structured training programs, industry-focused workshops, and international partnerships can provide the necessary upskilling, turning current limitations into opportunities for growth and professional development (Dagou et al. 2025).

Taken together, these insights suggest that the capacity to adopt smart building solutions depends not only on resources but also on leadership, organizational culture, and the circulation of knowledge. In Calabar, gaps in these areas continue to slow adoption. However, with deliberate efforts to strengthen organizational readiness, there is clear potential to accelerate the integration of smart building practices.

3. ***Environment:*** In the TOE framework, the environmental context captures the external forces that push or limit an organization's ability to adopt new practices. These forces range from regulatory policies and market competition to client expectations and supply chain relationships (Baker, 2012). For cities like Calabar, this aspect tends to carry particular weight, since the broader conditions of the environment shape both the practicality of investments and the collective behaviour of the actors involved.

    i. *Regulatory Frameworks and Policy Support:* In advanced economies, strong regulatory frameworks and targeted government incentives have been central to driving the adoption of smart buildings. As the European Commission (2018) noted, mandatory building codes alongside financial incentives have been particularly effective in ensuring compliance and encouraging investment. By contrast, regulatory enforcement in Nigeria remains relatively weak. Building codes are rarely updated to reflect sustainability goals or the integration of new technologies, and while policies on energy efficiency are in place, they tend to be fragmented, underfunded, and inconsistently monitored (Olanrewaju et al., 2019). In the absence of enforceable standards and coherent policy support, developers often lack the incentive to embrace smart technologies. Even so, global and regional sustainability agendas, including the United Nations Sustainable Development Goals (SDGs), are beginning to create indirect pressures that may stimulate reforms in the future.

    ii. *Market and Competitive Pressures:* Competition within the real estate sector often functions as a catalyst for innovation. In markets with high demand, such as Lagos and Abuja, developers face pressure to differentiate their projects by incorporating advanced amenities, including smart technologies. By contrast, Calabar presents a smaller and more price-sensitive market, where limited purchasing power weakens competitive pressures and reduces the incentive for such differentiation. Over time, however, as urban growth accelerates and middle-class demand expands, competitive dynamics are likely to strengthen, positioning market rivalry as a significant driver of smart technology adoption.

iii. *Supply Chain and Infrastructure:* The presence of reliable suppliers, contractors, and service providers is widely recognized as a critical factor in technology adoption, as Zhu et al. (2006) highlight. In Nigeria, however, supply chains for smart building equipment remain underdeveloped, with most components imported at considerable cost. This reliance on imports not only inflates prices but also prolongs installation timelines and complicates long-term maintenance. The situation is further compounded by weak energy infrastructure; as Ahmad et al. (2020) observe, unstable power supply continues to undermine the feasibility of energy-dependent technologies. At the same time, the growing penetration of mobile internet and digital services provides a partial counterbalance, since smart systems increasingly depend on reliable connectivity.

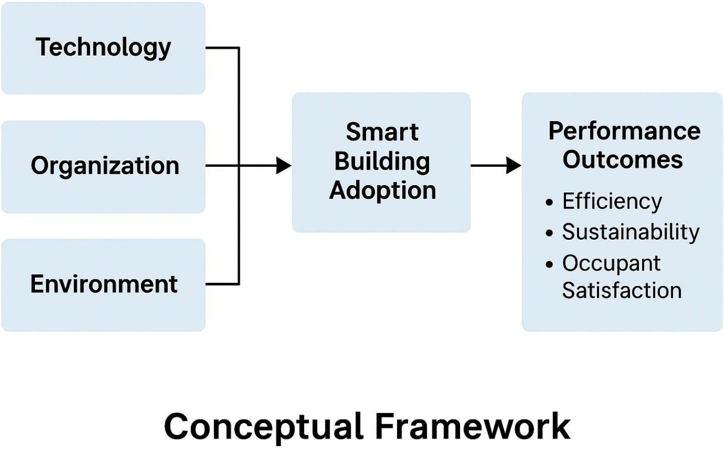
iv. *Public Awareness and Client Demand:* Low levels of public awareness continue to serve as a significant environmental barrier to smart building adoption. As Odefadehan et al. (2023) observed, many clients still regard smart features as unnecessary or even extravagant, favoring traditional construction methods that appear more affordable. This perception weakens market demand and, in turn, discourages developers from pursuing substantial investments. Encouragingly, awareness is beginning to shift, particularly among younger and more educated populations who place greater value on sustainability and modern conveniences (Mba et al., 2025). In addition, international investors and high-income clients are starting to demand smart-enabled properties, creating emerging niche markets with the potential to expand over time.

In sum, the environmental context in Calabar is defined by weak regulatory support, fragile supply chains, and limited public awareness, yet it also presents emerging drivers in the form of global sustainability pressures, expanding middle-class demand, and improvements in digital infrastructure. Addressing these external conditions through coherent policy reform, market sensitization campaigns, and the strengthening of supply chains will be essential to creating an enabling ecosystem for smart building adoption. Turning inward, the organizational context highlights the internal dynamics that shape a firm's readiness to adopt new technologies. Key considerations include the skill sets and technological knowledge of employees, the availability of financial resources, and the degree of leadership commitment to innovation. In Calabar, many construction firms still have limited exposure to advanced technological systems, which diminishes both their confidence and their capability to implement smart building initiatives effectively. Beyond technical capacity, organizational culture and openness to change remain equally pivotal, as they can either facilitate or constrain the adoption process.

Compared with other adoption models, the Technology–Organization–Environment (TOE) framework offers a broader and more multi-level perspective. The Technology Acceptance Model (TAM), for instance, emphasizes user perceptions such as perceived usefulness and ease of use

(Davis, 1989), while the Diffusion of Innovation (DOI) theory highlights the characteristics of innovations and the categories of adopters (Rogers, 2003). TOE, however, brings together both internal organizational dynamics and external environmental conditions, making it particularly valuable for complex sectors like construction, where technological attributes, firm-level readiness, and policy environments all interact to shape adoption outcomes (Zhang, Shen, & Wu, 2017).

In this study, the TOE framework is employed to analyze how the interplay of technological, organizational, and environmental factors influences the adoption of smart building technologies in Calabar. By aligning identified barriers, including high costs, limited technical expertise, weak regulatory support, and low public awareness with the respective TOE dimensions, the analysis provides a structured explanation for the slow pace of adoption. More importantly, the framework not only offers a theoretical lens but also serves as a practical tool for informing policy and organizational strategies aimed at fostering adoption in resource-constrained contexts.



Conceptual Framework

Figure 1: Conceptual framework

LITERATURE REVIEW

Smart building technologies have become a central theme in the transformation of the global built environment. These systems integrate advanced innovations such as the Internet of Things (IoT), artificial intelligence, smart sensors, and building management platforms, enabling buildings to operate more efficiently while enhancing comfort, safety, and sustainability (Ahmad, Aibinu, & Stephan, 2020; Klein et al., 2021). In developed economies particularly in Europe, North America, and parts of Asia, adoption has accelerated in response to stringent regulations, strong market competition, and rising awareness of climate change imperatives. For example, the European Union's Energy Performance of Buildings Directive mandates higher energy efficiency standards, compelling developers to embed smart technologies into both new and existing structures (European Commission, 2018). In North America, adoption is often tied to financial gains such as reduced operating costs, increased asset value, and improved tenant retention (Dagou, Gurgun, Koc, & Budayan, 2025). These cases illustrate that where supportive policies, robust supply chains, and informed markets exist, smart systems are no longer viewed as optional, but as integral to sustainable urban development.

By contrast, adoption trajectories in developing contexts have been slower and more uneven. Studies from Ghana, Kenya, and South Africa consistently identify high upfront costs, weak regulatory enforcement, limited technical expertise, and fragile supply chains as the primary obstacles (Kithuka, Likhole, & Ochieng, 2018; Agyekum-Mensah, Knight, & Mahamadu, 2020). In many African cities, smart technologies are still perceived as luxury features reserved for elite clients, rather than as essential components of sustainable infrastructure. This perception is reinforced by the absence of sustained awareness campaigns and the lack of incentives for developers. Nonetheless, opportunities are emerging. Agyekum-Mensah et al. (2020), for instance, show that even in resource-constrained settings, the integration of smart systems with renewable energy solutions can reduce dependence on unreliable grids, offering both environmental and economic benefits. This suggests that while structural barriers remain, carefully designed interventions can unlock adoption potential in less developed contexts.

In Nigeria, the construction and real estate sectors play a vital role in economic development and urban growth, yet smart building adoption remains limited. Olanrewaju, Okubena, Garba, and Ismail (2019) highlighted the persistence of high capital costs, a shortage of skilled professionals, and weak policy frameworks, while Odefadehan, Victor, and Gabriel (2023) pointed to low public awareness, fragile supply chains, and minimal government incentives. Mba, Oforji, and Ogbodo (2025) further observed that these barriers are not evenly distributed: while Lagos and Abuja show higher levels of adoption, driven by intense competition and international investment, secondary cities such as Calabar face additional hurdles including smaller markets, lower purchasing power, and weaker institutional capacity. The outcome is a growing divide between national policy ambitions and the realities of city-level implementation, leaving secondary urban centres at risk of lagging behind in the global transition toward smarter, more sustainable buildings particularly in aspects such as design innovation, construction processes, and post-construction facility management where digital and automated technologies remain largely underutilized.

The Technology–Organization–Environment (TOE) framework offers a useful lens for systematically analysing these barriers. Within the technological dimension, concerns about cost, complexity, and compatibility dominate. High upfront investment remains the most prohibitive factor, especially in Nigeria's volatile economic climate, where inflation and limited access to credit amplify financial risks (Agyekum-Mensah et al., 2020; Odefadehan et al., 2023). Complexity adds another layer of difficulty, as smart buildings require the integration of multiple subsystems such as HVAC, lighting, and security through digital platforms, demanding significant technical expertise (Kithuka et al., 2018). Compatibility is equally problematic, since many existing structures lack the infrastructural readiness for retrofitting. At the same time, the relative advantages of smart technologies such as energy savings and improved occupant comfort remain undervalued due to limited awareness and the absence of standardized performance benchmarks (Mba et al., 2025).

The organisational dimension provides further insight. Many Nigerian construction firms operate with constrained resources and thin profit margins, limiting their ability to absorb the costs of innovation (Olanrewaju et al., 2019). The shortage of trained professionals in building automation and facility management compounds these limitations. The leadership of construction and real estate firms are also decisive: innovation-oriented managers tend to adopt smart technologies for their long-term strategic benefits, whereas risk-averse leaders prioritise short-term profitability over sustainability (Hsu, Kraemer, & Dunkle, 2014). Organizational culture exerts a similar influence. Firms that are bureaucratic, fragmented, or resistant to change often struggle to implement new technologies, while those that cultivate collaboration and continuous learning are better positioned to succeed (Agyekum-Mensah et al., 2020). Thus, organizational readiness reflects not only financial and technical capacity but also leadership vision and adaptability.

The environmental context arguably carries the strongest weight in Nigeria and similar developing economies. Building regulations remain outdated, with codes seldom revised to incorporate sustainability or digital innovation (Olanrewaju et al., 2019). Where policies do exist, enforcement mechanisms are weak, limiting their impact. Market dynamics are similarly uneven: while developers in Lagos and Abuja face strong competitive pressure to differentiate their projects, those in smaller cities such as Calabar encounter less demand, as clients often prioritize affordability over advanced features. Supply chain limitations further constrain adoption, since most smart building components are imported at high cost and subject to long delays (Ahmad et al., 2020). Low public awareness adds another barrier, as many clients remain unfamiliar with the long-term benefits of smart technologies, discouraging developers from investing. Even so, important drivers exist. Global sustainability agendas, rising middle-class aspirations, and expanding digital infrastructure all present opportunities that could, over time, stimulate wider adoption (Dagou et al., 2025).

Despite these insights, important knowledge gaps remain. Much of the existing Nigerian scholarship addresses barriers at the national level (Olanrewaju et al., 2019; Odefadehan et al., 2023), overlooking the distinct conditions of secondary cities where market size, institutional capacity, and enforcement vary significantly. Few studies examine Calabar specifically, despite its unique combination of smaller demand, weaker infrastructure, and lower investment flows. In addition, the literature rarely links adoption barriers directly to performance outcomes such as energy efficiency, operational cost savings, or user satisfaction, even though these metrics are crucial for demonstrating the value of smart systems. Addressing these gaps, the present study applies the TOE framework to examine how technological, organizational, and environmental factors interact to shape adoption in Calabar. By connecting barriers to measurable outcomes, it offers both theoretical insights for the academic literature and practical guidance for policymakers and industry stakeholders pursuing sustainable urban development in resource-constrained settings.

Table 1 illustrates that while smart building adoption is well established in developed regions due to strong regulatory enforcement and technological readiness, developing economies remain hindered by systemic barriers. The consistent identification of high initial costs and lack of technical skills across multiple African studies demonstrates that financial and human-capacity constraints remain the most persistent obstacles. Moreover, the recurring issues of weak regulatory frameworks and low public awareness in Nigeria indicate structural gaps that transcend technical limitations. The reviewed literature therefore highlights two major trends: first, the predominance of cost and skill barriers in developing countries, and second, the limited exploration of city-level dynamics that capture the local realities of adoption. These gaps justify the present study's focus on Calabar, where context-specific factors such as smaller market size, weaker institutional enforcement, and lower investment inflows likely exacerbate national-level challenges.

Table 1: Comparative Summary of Prior Studies on Smart Building Technology Adoption

Author(s) & Year	Country/Context	Focus	Key Barriers/ Findings
Ahmad, Aibinu & Stephan (2020)	Australia / Global	Benefits of smart building systems; energy & cost efficiency	Smart systems reduce costs & improve sustainability; adoption hindered by high costs
European Commission (2018)	European Union	Regulatory framework driving adoption	Strong policy & regulation drive adoption in Europe
Dagou, Gurgun, Koc & Budayan (2025)	Turkey(Global Perspective)	Integration of innovative technologies in construction	Global push towards innovation; technological integration improves project management
Agyekum-Mensah, Knight & Mahamadu (2020)	Ghana	Barriers to adoption in developing economies	High costs, weak regulation, lack of technical expertise
Kithuka, Likhole & Ochieng (2018)	Kenya	Adoption barriers in African contexts	Low awareness, weak supply chains, limited expertise
Olanrewaju, Okubena, Garba & Ismail (2019)	Nigeria	Challenges of smart building uptake in Nigeria	Limited adoption due to cost, weak policies, lack of skills
Odefadehan, Victor & Gabriel (2023)	Nigeria	Barriers and implications for sustainable energy management	High costs, lack of skills, weak regulatory incentives
Mba, Oforji & Ogbodo (2025)	Nigeria	Challenges and opportunities in adoption of smart buildings	Low public awareness, poor supply chains, minimal government support

.METHODOLOGY

Research Design

This study employed a mixed-methods research design to address the complex and multi-dimensional nature of smart building technology adoption in Calabar, Nigeria. A single methodological strategy was deemed insufficient to capture the interplay of technological, organizational, and environmental factors; thus, a combined approach was adopted. The quantitative component enabled the measurement and ranking of barriers across a broad sample of professionals, while the qualitative component provided in-depth insights into contextual realities, professional experiences, and nuanced perceptions not easily captured through surveys. Integrating these methods produced a more comprehensive and credible understanding of the research problem.

The research design was underpinned by a pragmatist philosophical stance, which emphasizes methodological pluralism and practical problem-solving rather than strict allegiance to a single paradigm (Creswell & Plano Clark, 2018). Pragmatism acknowledges that reality can be both objective and subjective, requiring methodological choices to be guided by the research questions. In this study, the central objective understanding barriers to smart building adoption and their implications for performance outcomes necessitated both quantification (to assess severity and relative importance of barriers) and exploration (to uncover professional reasoning, cultural perceptions, and institutional dynamics). By adopting pragmatism, the study avoided the limitations of relying solely on either positivist or interpretivist traditions, ensuring a fuller representation of the adoption landscape in a developing city context.

The research was theoretically grounded in the Technology–Organization–Environment (TOE) framework, which shaped both data collection and analysis. The TOE framework posits that technology adoption is influenced by three interrelated dimensions: technological characteristics, organizational readiness, and environmental conditions (Tornatzky & Fleischer, 1990). Its holistic structure made it particularly suitable for this study, as it corresponds directly with barriers identified in prior research on smart building adoption in developing economies (Agyekum-Mensah et al., 2020; Odefadehan et al., 2023). Within this study, the TOE framework was operationalized as follows:

i. Technological Dimension: Examined attributes such as cost, complexity, compatibility, and relative advantage of smart building technologies, focusing on their perceived feasibility.

ii. Organizational Dimension: Investigated factors including firm resources, leadership commitment, technical expertise, and organizational culture to assess adoption readiness among construction and real estate stakeholders.

iii. Environmental Dimension: Considered external influences such as regulatory frameworks, market demand, supply chain strength, and public awareness, which together define the enabling or constraining ecosystem for adoption.

Embedding the TOE framework into both the questionnaire and interview guide ensured theoretical and methodological alignment. This structure also facilitated triangulation, as quantitative findings could be interpreted alongside qualitative themes and policy document reviews within the same three-dimensional framework. Such integration enhanced internal validity, strengthened explanatory depth, and increased the applicability of the findings for policy, practice, and future research.

Study Area

The research was conducted in Calabar, the capital city of Cross River State in southeastern Nigeria. Calabar was deliberately selected as the study area due to its rapid urbanization and the growing scale of construction activities across both public and private sectors. Despite this growth, the city has not yet fully integrated smart building technologies into its architectural and infrastructural landscape. Its construction profile encompasses a wide spectrum from large government projects to private residential developments reflecting the socio-economic diversity of the urban fabric. This eclectic mix provides an appropriate context for examining the interplay between technological innovation, policy frameworks, and market dynamics that shape the adoption of emerging building practices. By situating the investigation within Calabar, the study seeks to uncover the barriers and opportunities associated with integrating sustainable and intelligent building solutions in a city undergoing significant transformation.

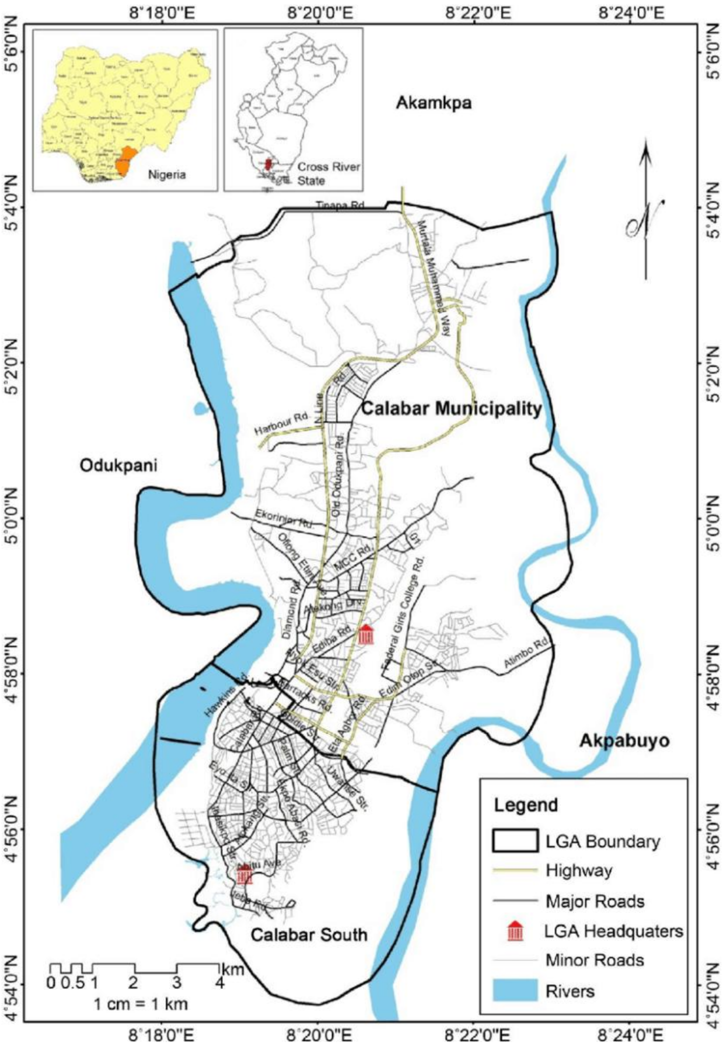


Figure 2: Map of Calabar

Population and Sampling

The study population comprised professionals and stakeholders within the construction and real estate sectors of Calabar, Nigeria. These groups were selected because they represent the key decision-makers, implementers, and regulators of building technologies, whose perceptions directly shape adoption outcomes. Calabar's built environment is influenced by multiple actors across the project lifecycle from conception and design to construction, regulation, and facility management. To capture this diversity, the study focused on six professional categories: Architects, Engineers, Contractors, Developers, Facility Managers, and Policymakers.

Inclusion and Exclusion Criteria: Eligible participants were required to have a minimum of three years of experience in the construction or real estate sector to ensure sufficient exposure to industry practices and the realities of technology adoption. Individuals engaged solely in administrative functions without direct influence on construction or building technology decisions were excluded. Policymakers were included only if they were directly involved in housing, urban development, or related regulatory activities.

Sampling Technique: A purposive sampling strategy was employed to deliberately select participants with the expertise most relevant to the study's objectives. This approach is well suited for exploratory research aimed at uncovering professional perspectives rather than achieving statistical generalizability (Etikan, Musa, & Alkassim, 2016). To enhance diversity and capture a broad range of insights, heterogeneous sampling was integrated within the purposive framework, ensuring the representation of multiple professional backgrounds.

Sample Size: The quantitative phase engaged 60 respondents through structured questionnaires, a sample size considered sufficient to generate reliable descriptive statistics and mean score rankings within Calabar's focused professional population. Complementing this, the qualitative phase involved 12 semi-structured interviews, which facilitated deeper exploration of themes and contextualization of quantitative results. The choice of 12 interviews aligns with Creswell's (2013) guidance that thematic saturation in qualitative studies is typically achieved with 5 to 25 interviews, depending on scope and complexity.

Professional Representation: The final sample consisted of 15 Architects, 10 Engineers, 12 Contractors, 8 Developers, 7 Facility Managers, and 8 Policymakers. This distribution reflected the accessibility of professionals within Calabar's networks while ensuring balanced representation across private and public organizations. Participants were drawn from residential, commercial, and institutional projects, thereby broadening the contextual scope of perspectives captured.

By employing purposive and heterogeneous sampling, the study ensured that respondents were not only directly engaged with building development processes but also collectively represented the breadth of professional perspectives necessary to evaluate barriers across the technological, organizational, and environmental domains of the TOE framework. This diversity enriched the analysis and provided a nuanced understanding of adoption dynamics in Calabar.

Data Collection Methods

To address the study objectives and capture the multidimensional barriers to smart building technology adoption in Calabar, three complementary data collection methods were employed: a structured questionnaire survey, semi-structured interviews, and a review of relevant policy and regulatory documents. The triangulation of these methods enabled the integration of both quantitative and qualitative insights, thereby ensuring a comprehensive and credible understanding of the research problem.

1. *Structured Questionnaire (Quantitative Phase):* The questionnaire served as the primary instrument for collecting quantitative data from professionals within the construction and real estate sectors. Its design was guided by the TOE framework to ensure systematic coverage of

technological, organizational, and environmental barriers to adoption. The instrument was structured into five sections:

a) **Demographic Information** Captured basic respondent characteristics such as professional background, years of experience, and organizational affiliation, alongside general awareness of smart building technologies (e.g., automated lighting, smart HVAC, integrated energy management systems).

b) **Technological Barriers** Assessed factors including high capital costs, system complexity, compatibility with existing infrastructure, and perceived relative advantage of adoption.

c) **Organizational Barriers** Focused on financial capacity, managerial support, availability of technical expertise, and the influence of organizational culture.

d) **Environmental Barriers** Examined external influences such as regulatory frameworks, market demand, supply chain reliability, and public awareness.

e) **Measurement Scale** Responses across barrier-related items were captured using a 5-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree. This scale was selected for its ability to capture varying degrees of perception and facilitate statistical analysis, including mean score rankings and correlation tests. Prior to full deployment, the questionnaire was subjected to a pilot test involving 10 professionals. Feedback from the pilot phase informed minor revisions to wording and structure, thereby enhancing clarity, contextual suitability, and overall reliability of the instrument.

2. *Semi-Structured Interviews (Qualitative Phase):* To complement the survey data, 12 semi-structured interviews were conducted with purposively selected participants representing the six professional categories identified in the study population. The interviews provided an opportunity to explore themes in greater depth and capture insights that might not have been fully reflected in the questionnaire responses. An interview guide was developed in alignment with the TOE framework, ensuring consistency with the study's theoretical foundation. While the guide offered structure, participants were encouraged to elaborate freely, thereby generating rich, context-specific perspectives. For example, questions within the technological dimension probed participants' views on cost, complexity, and compatibility of smart technologies; the organizational dimension emphasized managerial attitudes, financial capacity, and technical skill gaps; while the environmental dimension explored regulatory enforcement, client demand, and supply chain realities. Interviews lasted between 30 and 45 minutes, were audio-recorded with participants' consent, and subsequently transcribed verbatim to ensure accuracy in analysis. This qualitative method was particularly valuable for uncovering nuanced professional experiences, institutional dynamics, and cultural perceptions that could not be adequately captured through quantitative data alone.

3. *Document Review (Policy and Regulatory Analysis):* In addition to primary data, secondary sources were analysed to situate the findings within the broader institutional and regulatory landscape. The review covered Nigerian building codes, energy efficiency policies, urban development regulations, and relevant international sustainability guidelines with applicability to the local context. This process served two purposes: first, to validate participants' claims regarding weak enforcement, regulatory gaps, and policy inconsistencies; and second, to identify existing opportunities for reform and alignment. The document review highlighted Nigeria's formal commitments to international agendas, such as the United Nations Sustainable Development Goals (SDGs) and global frameworks for green and smart construction. These policy linkages provided a critical backdrop for interpreting both the barriers and the potential drivers of smart building adoption in Calabar.

Triangulation of Methods

The integration of the three data collection methods enhanced both the validity and reliability of the study. The questionnaire generated a structured and quantifiable overview of adoption barriers, while the semi-structured interviews provided deeper insights into the lived experiences, professional reasoning, and cultural dynamics underlying these barriers. The document review further situated these perspectives within the broader institutional and regulatory context, offering an external benchmark against which participant claims could be assessed. By combining these approaches, the study achieved both convergence (where different methods confirmed similar findings) and complementarity (where each method revealed distinct dimensions of the research problem). This methodological triangulation ensured that the results captured not only measurable patterns but also the contextual subtleties necessary for a holistic understanding of smart building adoption in Calabar.

Data Analysis

The study employed a multi-step data analysis strategy integrating both quantitative and qualitative techniques, consistent with the mixed-methods design. This approach ensured that measurable patterns were identified while also capturing deeper contextual insights. Data analysis was carried out in three streams: quantitative survey analysis, qualitative thematic analysis, and triangulation with policy documents.

1. *Quantitative Analysis:* All questionnaire responses were coded and entered into the Statistical Package for the Social Sciences (SPSS) Version 26 for statistical analysis. The analysis proceeded in several stages:

    a) *Descriptive Statistics:* Frequencies, percentages, means, and standard deviations were computed to summarize respondents' demographic profiles and provide an overview of their awareness of smart building technologies. This stage helped to characterize the professional landscape of Calabar's construction sector.

b) *Mean Score Ranking:* To identify the most critical barriers to smart building technology adoption, the mean scores of individual items were calculated and ranked. This ranking allowed for clear comparison across the three TOE dimensions, technological, organizational, and environmental, and highlighted the relative importance of each barrier as perceived by professionals.

c) *Correlation Analysis:* Pearson's correlation tests were conducted to examine the relationships between key barriers and perceived building performance outcomes (operational efficiency, energy savings, and occupant satisfaction). The purpose was to assess whether overcoming barriers such as improving technical skills or strengthening regulatory frameworks was statistically associated with improved performance outcomes. Correlation coefficients were interpreted based on Cohen's (1988) guidelines: $r = 0.10$–0.29 (small), $r = 0.30$–0.49 (medium), $r \geq 0.50$ (large).

d) *Reliability Testing:* The internal consistency of the barrier constructs was assessed using Cronbach's alpha. A threshold of 0.70 was applied to confirm reliability, ensuring that items grouped within each TOE dimension measured consistent underlying concepts.

2. *Qualitative Analysis*

i. The interview data were transcribed verbatim and analysed using thematic analysis, following the six-phase procedure outlined by Braun and Clarke (2006). The process included:

ii. Familiarization with the data through repeated reading of transcripts.

iii. Generating initial codes, both inductive (emerging from participant narratives) and deductive (guided by the TOE framework).

iv. Searching for themes within the technological, organizational, and environmental dimensions.

v. Reviewing and refining themes to ensure coherence and distinctiveness.

vi. Defining and naming final themes, such as "cost as a prohibitive driver," "leadership vision and resistance," and "weak regulatory enforcement."

vii. Producing thematic reports supported by direct quotations from participants to enhance credibility.

viii. NVivo software was not used; instead, manual coding was adopted to maintain close engagement with the data, which is common in exploratory studies with relatively small sample sizes.

3. *Policy Document Analysis:* Policy documents, such as national building codes, energy efficiency regulations, and sustainability guidelines, were examined to provide context for the survey and interview results. Content analysis was utilized to pinpoint provisions associated with the adoption of smart buildings, as well as areas lacking enforcement and implementation. This phase enabled the research to connect professional viewpoints with the institutional circumstances influencing adoption in Calabar.

4. *Triangulation:* Finally, the three data streams were triangulated to improve validity and offer a comprehensive interpretation. For instance, survey findings that identified' high initial cost" as a major barrier were supported by interview stories emphasising financial risks and policy documents showing weak incentive frameworks. Likewise, shortages in organizational skills noted in survey rankings were echoed by interview accounts of insufficient training and curricular deficiencies. This triangulation not only validated the results but also uncovered some differences, which were carefully examined to understand the complex adoption processes in Calabar.

Ethical Considerations

This study strictly followed established ethical guidelines for research involving human participants. Multiple measures were implemented to protect respondents' rights, dignity, and well-being throughout the process.

- ***Ethical Approval:*** Before collecting data, we obtained approval from the relevant Institutional Review Board (IRB) to ensure the study adhered to ethical social science research standards. This approval emphasised the need to protect participants and reinforced responsible research practices.
- ***Informed Consent:*** All participants received an information sheet explaining the study's purpose, objectives, data collection methods, potential risks and benefits, and their rights as respondents. Informed consent was secured before participation, either in written form for survey respondents or verbally recorded for interview participants. The consent underlined that participation was voluntary and individuals could withdraw at any time without repercussions.
- ***Confidentiality and Anonymity:*** All personal identifiers like names, organizational affiliations, or job titles were removed from the data analysis and report to ensure privacy. Responses were assigned numerical codes to protect identities, and results were presented in aggregated

form to prevent identifying individuals. Interview quotations were anonymized, only referencing professional roles such as 'Architect' or "Engineer' for context.

- Participation was completely voluntary, without any incentives to prevent coercion or undue influence. Participants were also reminded that declining or withdrawing from the study would not adversely affect their professional reputation.
- ***Data Management and Security:*** All collected data were securely stored in password-protected digital files accessible only to the researcher. Audio recordings of interviews were transcribed and anonymized prior to analysis, then permanently deleted. Survey questionnaires were digitized and stored electronically, while physical copies were shredded to prevent unauthorized access.
- ***Respect for Professional Integrity:*** *Since* participants were professionals in sensitive industries, extra caution was exercised to prevent their opinions from being mistaken as official stances of their organizations. The study was explained as an independent academic project, with results presented in summary form to safeguard organizational reputations.

By maintaining these ethical safeguards, the study adhered to international research ethics standards like the Belmont Report principles of respect for persons, beneficence, and justice (National Commission for the Protection of Human Subjects, 1979). This commitment to ethical rigor improved the credibility of the research and built trust between the researcher and participants.

RESULTS

Respondents' Profile

Sixty professionals took part in the survey, spanning six categories: Architects (25%), Engineers (17%), Contractors (20%), Developers (13%), Facility Managers (12%), and Policymakers (13%). Most respondents (68%) had over five years of experience, 22% had three to five years, and 10% had less than three years. This suggests that the majority were well-qualified to share insights on smart building technology adoption. Participants were from both the private sector (72%) and the public sector (28%), capturing a range of market and regulatory viewpoints.

"Even when clients recognize the long-term benefits, the initial cost often deters them" (Developer).

"We frequently have to fly technicians in from Lagos or other countries, which increases both time and expenses" (Engineer).

The second obstacle is the deficiency in technical skills and expertise, with an average score of 4.41. More than 70% of participants considered this a major problem. Local construction and engineering companies often lack adequately trained personnel to design, install, and maintain smart building systems. As a result, they need to hire specialized technicians from Lagos, Abuja, or even outside Nigeria, which prolongs project timelines and raises costs. Delays also happen when foreign technicians are unavailable. Participants highlighted that after-sales maintenance poses a significant challenge because local facility managers frequently lack the training to repair or troubleshoot these systems, leading to early system failures or underuse.

The third obstacle is the lack of adequate regulatory and policy support, with an average score of 4.15. Stakeholders observed that Calabar's existing building codes and planning laws neither mandate nor promote the use of smart technologies. While Nigeria has national policies aimed at energy efficiency, these are mainly broad guidelines without specific requirements for smart systems. Enforcement at the local level remains weak, and the absence of mandatory rules causes developers to prioritise short-term cost savings rather than long-term efficiency. Policymakers acknowledged that there is no local framework or incentives to encourage smart building adoption, leaving private developers to decide independently.

Low public awareness and demand stand as the fourth significant barrier, with an average score of 3.87. Many participants mentioned that building owners and tenants often see smart technologies as luxury items tailored for high-end developments. This perception is further reinforced by a lack of public education about the long-term savings and environmental advantages of smart systems. Developers tend to hesitate in investing in features that the market does not strongly demand, particularly in a price-sensitive context. Some stakeholders pointed out that awareness campaigns or demonstration projects in other cities have successfully boosted demand, though such efforts have not yet occurred in Calabar.

The fifth barrier is the limited availability of smart technologies, which scored an average of 3.72. The absence of local suppliers means that even basic smart components often need to be imported. This leads to extended procurement times, higher costs, and uncertainty regarding delivery schedules. Developers are concerned that unreliable supply chains could delay projects and cause clients to hesitate in approving these technologies. Additionally, the lack of local after-sales support and spare parts hampers ongoing system maintenance. The review of documents confirmed these issues. Calabar lacks a dedicated smart building policy, and local building codes do not include performance standards for automation or energy management systems. Though the national energy policy acknowledges the role of technology in improving efficiency, it does not mandate smart technology adoption. As a result, market forces are the only drivers, and they have yet to cause significant adoption.

Table 2 shows the five barriers identified include high initial costs, technical skills gaps, weak regulatory support, low awareness, and limited supply.

Table 2: Ranked Barriers to Adoption

Barrier	Mean	SD	Rank
High initial costs	4.63	0.54	1
Lack of technical skills	4.41	0.62	2
Weak regulatory support	4.15	0.71	3
Low awareness and demand	3.87	0.65	4
Limited technology availability	3.72	0.70	5

DISCUSSION

This study confirms that barriers to adopting smart building technology in Calabar are multi-faceted, spanning technological, organizational, and environmental factors within the TOE framework. While international research often highlights the performance and sustainability advantages of smart buildings (Ahmad, Aibinu, & Stephan, 2020; Dagou, Gurgun, Koc, & Budayan, 2025), this research shows that in Calabar, adoption is still hindered by economic, technical, institutional, and cultural challenges.

Technological barriers were the most prominent, with high initial costs (Mean = 4.63) and a lack of technical skills (Mean = 4.41) consistently identified as key obstacles. These results align with studies from Ghana and Kenya, where financial constraints and expertise gaps were major limiting factors (Agyekum-Mensah, Knight, & Mahamadu, 2020; Kithuka, Likhole, & Ochieng, 2018). In Calabar, these issues are further intensified by Nigeria's unstable economy and limited financing options, which deter developers from investing in technologies with uncertain returns. While the long-term advantages of smart systems are recognised, the immediate affordability challenge remains a priority, reflecting the concerns raised by Odefadehan, Victor, & Gabriel (2023).

Organizational barriers significantly hinder progress. The lack of skilled professionals in building automation and data-driven facility management remains a major obstacle. Many companies lack the internal capacity to implement and sustain smart systems. Engineers and facility managers highlighted significant gaps in technical training, and interview results showed limited exposure to smart technologies in current university curricula. This supports Hsu, Kraemer, and Dunkle (2014)'s view that organizational readiness largely depends on leadership vision, financial capacity, and technical expertise. In Calabar, numerous firms with narrow profit margins and cautious leadership continue to face low adoption rates.

Environmental barriers played a significant role, with weak regulatory support (Mean = 4.15) and low public awareness (Mean = 3.87) ranking among the top five challenges. Policymakers admitted that, although sustainability policies are in place on paper, enforcement is weak, and compliance is often overlooked. This aligns with Olanrewaju et al. (2019), who also noted outdated building codes and loose regulatory frameworks in Nigeria. Additionally, limited technological availability (Mean = 3.72), hindered by supply chain issues and dependence on imports, worsens these problems. These findings reflect broader trends across Africa, as highlighted by Agyekum-Mensah et al. (2020), where fragile logistics and high import costs significantly slow technology adoption.

This study's key contribution is identifying statistical links between barriers and building performance outcomes. Correlation analysis showed that high upfront costs negatively affect operational efficiency, lack of technical expertise is strongly tied to occupant satisfaction, and limited regulatory support hampers energy savings. These findings highlight that addressing barriers has tangible effects on both financial and functional aspects of buildings. This extends previous Nigerian research (Odefadehan et al., 2023; Mba, Oforji, & Ogbodo, 2025), which noted barriers but did not directly tie them to performance results.

The study also identified differences in perceptions among various professional groups. Developers mainly focused on financial issues, while engineers and facility managers emphasised technical skills. Policymakers, on the other hand, highlighted the importance of regulatory enforcement. These role-specific concerns reveal the fragmented nature of stakeholder viewpoints and point to the necessity of interdisciplinary cooperation. Similar trends have been found in international research, where cross-professional alignment is seen as vital for developing unified adoption strategies (Zhang, Shen, & Wu, 2017). In Calabar, if these perspectives are not aligned, it could lead to disjointed efforts and inconsistent results in adoption.

Overall, the results underscore the need for a comprehensive strategy to encourage the adoption of smart building technology in Calabar. Financial measures like subsidies, tax incentives, or innovation funds can help lower costs and reduce perceived risks. At the organizational level, capacity-building efforts are crucial, including curriculum reforms in engineering and architecture programs and professional development for practitioners. Environmentally, stricter enforcement of regulations and updated building codes are vital to ensure accountability. Additionally, public awareness campaigns can boost demand and generate market pressure for adoption.

Focusing on Calabar, this study offers new insights into the adoption of smart buildings in smaller cities. While most Nigerian research has concentrated on Lagos and Abuja (Olanrewaju et al., 2019; Odefadehan et al., 2023), this study highlights that adoption in smaller urban areas faces even greater obstacles due to weaker institutional support, less purchasing power, and lower market competitiveness. This emphasises the need for localized strategies instead of uniform national policies and calls for customised solutions that address the specific challenges faced by secondary cities in Nigeria and other developing countries.

RECOMMENDATIONS

This study suggests that to promote the adoption of smart building technology in Calabar, a comprehensive approach is needed to tackle economic, technical, institutional, and socio-cultural barriers at the same time. The following recommendations are offered:

i. ***Technological:*** The high upfront costs of smart technologies can be mitigated through specific financial incentives. Cross River State's government, working with national agencies, might implement tax rebates, import duty exemptions, and low-interest loans for developers who adopt certified smart systems. Such incentives have proven effective in countries like Singapore, where the Green Mark Scheme has significantly encouraged the adoption of green and smart technologies (Building and Construction Authority, 2021). Additionally, public–private partnerships could be leveraged to co-fund large-scale smart building projects, helping to distribute costs over time and lessen financial burdens on individual developers.

ii. ***Organizational:*** To tackle the shortage of technical skills, investment in education and training is essential. Universities, technical colleges, and professional organisations should develop courses and certification programs in smart building design, installation, and maintenance. Collaborating internationally with technology providers can promote knowledge transfer via workshops and apprenticeships. These initiatives should also include facility managers to ensure proper maintenance and effective use of installed systems.

iii. ***Environmental:*** Developing a dedicated smart building policy for Calabar is essential. Local building codes should be revised to set minimum standards for energy efficiency, automation readiness, and system integration, with phased implementation to give the industry time to adapt. Additionally, introducing performance-based building approval systems that reward projects exceeding standards can motivate progress. These regulations must include clear enforcement mechanisms to ensure compliance. Public Awareness and Demand Generation: Shifting public perceptions is crucial for fostering market demand. Awareness campaigns showcasing benefits like energy savings, improved comfort, and enhanced security should be conducted via media, industry exhibitions, and community outreach. Demonstration projects in public buildings, such as schools, hospitals, and government offices, can serve as tangible examples of the technology's value, helping to normalize its adoption.

iv. ***Enhancing Supply Chains and Local Availability:*** Promoting local businesses as authorized distributors and service providers for smart technologies can decrease reliance on imports and reduce procurement times. Offering incentives may attract reputable suppliers to set up in Calabar. Furthermore, forming partnerships with regional markets can generate economies of scale, lowering costs and increasing supply reliability. Holistic Strategy: These suggestions should be implemented together for maximum effect. Financial incentives work better when paired with capacity building, and regulatory reforms gain strength with awareness campaigns. A coordinated approach led by the government and supported by private sector actors will create a cycle that overcomes various barriers simultaneously and speeds up adoption.

v. ***Include feasibility considerations:*** While financial incentives are anticipated, fiscal constraints in Cross River State may hinder implementation. Forming targeted partnerships with local banks and international development agencies such as the World Bank and United Nations could offer alternative sources of funding.

CONCLUSION

This study analysed barriers to smart building adoption in Calabar using the TOE framework, identifying five key interconnected barriers: cost, skills, regulation, awareness, and supply. It contributes by contextualising the TOE framework within an African mid-sized city, identifying Calabar-specific challenges, and proposing a combined policy and industry roadmap. Future research should evaluate pilot smart projects' cost-benefit outcomes and user satisfaction in Calabar. The findings highlight major obstacles such as high initial costs, skill shortages, regulatory gaps, low awareness, and limited technology supply, which are interconnected through economic, technical, institutional, and socio-cultural factors. Although these challenges resemble those in other developing regions, Calabar's limited supply chains, lack of targeted policies, and low market demand pose unique difficulties for smart technology integration. Without intervention, the gap between Calabar and more developed cities in building performance and technology will likely grow. Addressing these barriers requires an integrated approach-combining economic incentives, skills development, regulatory reforms, awareness campaigns, and strengthening local supply networks. Coordinated implementation can foster an ecosystem that supports adoption, benefiting developers, occupants, and the urban environment. The findings are also relevant for other mid-sized developing cities facing similar issues, illustrating how technological, organizational, and environmental factors influence adoption. This research adds to the growing understanding of smart building implementation in resource-constrained settings. Future work should assess the cost-benefit results of pilot projects, as well as user satisfaction and operational performance over time, providing evidence to support large-scale adoption and practical guidelines for integrating smart technologies into new and existing buildings.

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