Barriers to the Adoption of Smart Building Technology in Developing Countries: An Empirical Survey

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ABSTRACT:

Smart building technology (SBT) has been a prominent practical and academic topic in the built environment due to adopting sustainable development and digitization to maximize energy efficiency, reduce CO_2 emissions, and maximize thermal comfort. While the construction industry is currently adopting smart building technology (SBT), numerous obstacles have prevented its widespread use. Thus, this study aims to examine the significant barriers underlying the adoption of SBT from the perspective of construction professionals. A systematic literature review of 30 articles and a well-structured questionnaire via quantitative research was adopted to collect pertinent information from 244 construction professionals. The collected data were analyzed using the Kruskal–Wallis's test, exploratory factor analysis (EFA), and partial least-squares structural equation modeling (PLS-SEM). The study found that all the 22 identified barrier factors significantly affect the adoption of SBT. Furthermore, the high material and equipment costs for smart buildings, inadequate power supply, poor maintenance culture and inadequate well-trained staff are the five topmost barriers affecting the adoption of SBT. The factor analysis categorized the industry-relevant barriers into four groups: Awareness, Economics, human, and Management. Finally, the structural equation modelling revealed that human-related and management-related barriers are the most significant, with path coefficients of β 0.395 and 0.309, respectively. Therefore, it is imperative that the authorities of various professional organizations actively participate in the crucial implementation of smart building technology. The analysis highlighted smart building adoption opportunities and practical strategies for overcoming barriers. These findings provide evidence that building professionals should develop strategies to prevent the identified barriers from hindering the adoption and deployment of smart building technologies.

AUTHOR KEYWORDS Smart building; Sustainable construction; barriers; Smart building technologies; sustainable development.

INTRODUCTION:

Increasing public awareness of the environmental impact of construction has led to the growing popularity of smart buildings as a viable solution for sustainability in the construction industry (Junior et al., 2017; Ejidike & Mewomo, 2022). This growing awareness leads to a greater desire to develop smart buildings. Therefore, the application of smart technologies to reduce energy consumption and improve occupant satisfaction and well-being is part of the functionates of smart buildings (Buckman, Mayfield, and Beck, 2014; Attoue, Shahrour, and Younes, 2018; Mofidi and Akbari, 2020). Smart building has gained more attention in achieving sustainability in the building sector (Ortiz et al., 2009; Junior et al., 2017). Smart buildings have also received attraction among construction professionals and academics to enhance energy efficiency and thermal comfort, thereby improving the productivity of the construction industry (Lim et al., 2019; Newman et al., 2020).

A smart building is expressed as the combination of technologies and processes to produce a facility that is energy efficient, safe, healthy, and comfortable while also enabling productivity and lowering operational costs (Frost and Sullivan, 2009; Attoue, Shahrour, and Younes, 2018). Also, Buckman, Mayfield, and Beck (2014) and Eini *et al.* (2021) stressed the importance of smart buildings, which offer dynamic real-time control over the management of both the inside and exterior activities of building in achieving a sustainable built environment. Vattano (2014), revealed that smart building exhibits an integrated platform for monitoring energy use and surveillance video for the building's security systems, which is an integral part of smart technologies adoption in the building industry.

Nigeria is an example of a developing country that has introduced and is progressively integrating a number of technological advances, including smart metering sensors, smart materials, smart cities and smart devices (Adejuwon, 2018). Adopting the smart construction concept provides considerable long-term benefits far superior to traditional building techniques in developing countries such as Nigeria (Iwuagwu & Iwuagwu, 2014). According to Apanaviciene et al. (2020), the smart building learns from experience and makes the best decisions in real time to maximize comfort and productivity while using as little energy as possible. Deploying SBTs has many benefits, including improved communication, higher automation, and control technology. However, the concept can be developed based on the time, culture and specific requirements of a country or continent. While some countries use smart building technologies to improve environmental quality, others focus on the benefits they offer in achieving low-carbon economic goals (El-Motasem et al., 2021). Furthermore, several countries welcome the smart building concept owing to the improved environmental performance, operation, safety, and dependability of various technologies in automation, control, and communication linked with its application. (Ghaffarianhoseini et al., 2016; Jia et al., 2019).

The benefit of sustainability has accelerated the acceptance of the SBTs idea, which is critical in many countries (Pan et al., 2014; Häkkinen & Belloni, 2011). Despite the advantages of the adoption of the smart building, such as energy savings, safety and security, improved comfort, productivity, and collaboration (Honeywell and IHS, 2015; Ejidike & Mewomo, 2023), these benefits have not translated to the adoption and implementation of smart building technology in the Nigerian construction industry. It is therefore necessary to examine the barriers to the adoption of smart building technology in the Nigerian construction industry that have not yet been considered. Chan *et al.* (2018) expressed that the barriers must be first recognized and understood to ease the adoption process. However, a few studies have been conducted on the barriers to adopting SBTs in developing countries, such as Junior et al. (2017) on barriers and challenges to smart buildings and technologies in Brazilian social housing projects. Also, Ghansah *et al.* (2021) explored the latent barriers inhibiting project management processes in adopting SBTs in Ghana's construction industry.

In Nigeria, only a few studies have been conducted to investigate the adoption of SBTs. Awareness of SBTs (Olojede et al., 2022; Ejidike et al., 2022; Oyewole et al., 2019), integration of building automation system (Ogunde et al., 2018). Energy Efficiency and Design Optimization of Smart Buildings (Shehu Isa et al., 2016; Eseosa & I. Temitope, 2019). Economic Analysis of Smart Buildings (Eseosa & Temitope, 2019) and Acceptability of Smart Buildings by Property Stakeholders (Alohan et al., 2023). Given all these previous pieces of literature, the barriers to the adoption of smart building technology have not been examined. Therefore, this study aims to examine the critical barriers to the adoption of smart building technology in Nigeria's construction industry. The findings of this study contribute to closing the information gap in Nigeria and developing countries about smart building barriers and provide a valuable reference for policymakers and practitioners to make appropriate efforts to alleviate SBT adoption barriers and, as a result, increase adoption. Furthermore, this research would be valuable and helpful for international organizations and advocates interested in boosting SBC use in Nigeria to achieve more sustainable building developments.

The Barriers to Smart Building Concept Adoption.

The strategies for adopting and implementing smart buildings have been analyzed. Recent studies have identified smart buildings as an emerging sector in the construction industry that is expanding globally, with a focus on achieving sustainability (Maqbool et al., 2023). Smart building technologies have many limitations for developing countries as opposed to industrialized nations (Alohan et al., 2023). Environmental challenges are widely recognized in the building sector of the construction industry, and smart building technology concepts are seen as a feasible strategy for sustaining the construction industry's environmental, social, and economic sustainable development (Olawumi and Chan, 2020). However, in developing countries, smart building practices have yet to be fully adopted and implemented in the building sector of the construction industry (Chan et al., 2017). Despite the numerous benefits of the smart building concept in the construction industry, the concept has not taken full advantage due to the professional perception of the barriers, which has an immense effect on the adoption of the SBT in the building sector (Shen, Zhang, and Long, 2017).

Economic Barrier

Meryman and Silman (2004) note that professionals in the construction industry who wish to incorporate new technologies, particularly the concept of smart buildings, while prioritizing sustainable practices are likely to face significant economic challenges due to the high costs associated with implementation. The cost was recognized as a major barrier to the implementation of smart buildings. The authors stated that the perception of increased costs is a major barrier to professionals recommending the integration of environmental factors into the design and construction process to clients and other members of the design team (Lam et al., 2009).

According to Chan *et al.* (2017), direct delays in procurement requirements and construction costs are directly related to time. Any disruption to workflows caused by smart construction practices has economic consequences.

Hwang & Ng (2013) have identified several barriers to the adoption of smart buildings, including the cost of initial construction, limited interest and communication among professionals, high implementation costs, a lack of demand and interest from clients, and insufficient research on the benefits of smart buildings. Similarly, Ahn et al. (2013) identified the following barriers to smart buildings: the high upfront costs associated with the construction of smart buildings, the lack of government incentives, the lack of financing options, the lack of smart building providers, and the lack of research and development centres for smart building technologies. According to Shen, Zhang, and Long (2017), key barriers to the adoption of smart building concepts include long payback periods, procurement delays, the high cost of smart building equipment, and the high cost of developing accessible technologies.

Hamid (2016) identified the slow recovery rate of long-term cost as a barrier to adopting the smart building, which hinders the development of the smart building concept. Nawi et al. (2011) also opined that the high cost of smart building practices often discourages clients and end-users. Chan et al. (2016) discovered barriers such as the high cost of technologies. Azeem et al. (2017) identified that smart building materials and equipment are too expensive, and ignoring the life cycle cost aspects of the smart building will discourage the adoption of the smart building concept. Hwang and Tan (2012) identified that their lack of interest could negatively affect smart building adoption, and the lack of market demand for smart buildings can be attributed to the lack of awareness on the part of the public and owner.

Government Policy Barriers

Shen, Zhang, and Long (2017) point out that the success of efforts to promote the use of smart buildings in the construction sector depends largely on government policy. Azeem *et al.* (2017) claim that the implementation of smart buildings depends on government support. This assertion is based on the premise that the government plays a crucial role in the construction industry. However, lack of incentives, outdated building codes, lack of framework conditions, and insufficient promotion of smart building practices have greatly hindered efforts to promote their implementation. Ma et al. (2016) opined that one of the main barriers is the lack of framework and regulations that reflect the design elements, guidelines, and characteristics of the smart building concept. Fratu & Fratu (2012) further identified that the lack of research on concepts and their ignorance to incorporate new technologies professionals and the government are significant barriers. Ghansah et al. (2020) reiterated the lack of use of smart building design by construction professionals during the drawing stage. Ehrenhard et al. (2014) revealed that keeping the client and end-user away from the smart building design and procurement processes will not encourage adoption. Hwang & Ng (2013) opined that it requires more time to implement smart building concept practices onsite, another barrier that discourages the usage by professionals. Iwuagwu, Chioma, and Iwuagwu (2014) opined that the lack of electricity supply and low-quality maintenance culture among professionals and end-users is a significant barrier to adopting the smart building concept. Shen, Zhang, and Long (2017) opined that the major barrier to adopting smart building concepts is the scarcity of smart materials and products in the building construction industry. Environmentally friendly materials and products with less environmental impact are readily available in the building construction industry. They identified a lack of financial incentives, a legal system, and administrative issues as significant barriers to implementing a smart building.

Ahn et al. (2013) and Chan et al. (2017) discovered several factors preventing the adoption of smart buildings, including the lack of building standards and regulations, insufficient government support for smart buildings, a long payback period, insufficient financing options and the risks and uncertainties associated with the introduction of new technologies. Luthra et al. (2015) identified the lack of ability to meet electric power demand, unavailability of solar radiation data, and lack of political commitment as barriers in the construction industry. Lam et al. (2009) opined that the communication problem between stakeholders and the government could cause a conflict of interest, leading to uncertainties and inadequate documentation. Ghansah et al. (2021a) opined that a lack of government and client incentives could be a critical barrier to adopting a smart building.

Social Human and Technical Barrier

Social barriers mainly refer to the influence of public knowledge and awareness, culture, lifestyle, and behaviours (Zhang & Wang, 2013). According to Chan *et al.* (2017), information on the smart building concept is essential for acquiring relevant knowledge; it also raises public awareness and acceptance of it. It helps create awareness for the government and construction industry professionals about the importance of technical and social human involvement in successfully adopting smart buildings. Ma, Badi, and Jørgensen (2016) confirmed that sharing information is critical to successfully implementing a smart building concept in the construction industry. Similarly, the authors notice that professionals' low level of awareness toward smart building concepts is a major barrier to smart building adoption. Professionals sometimes lack the information necessary to develop smart buildings (Hamma-Adama and Kouider, 2018). According to Omopariola, Albert, and Windapo (2019), the main obstacles to the adoption and implementation of smart buildings can be attributed to a lack of technical expertise, a lack of efficiency, a poor maintenance culture, a lack of power supply, a lack of efficiency, fear of uncertainty or unforeseen circumstances. In other cases, they were unaware of viable alternatives or lacked the necessary expertise to implement them. From a broader perspective, El-Motasem et al. (2021) found that the professional use of smart buildings in Egypt is a relatively recent development. In Egypt, there are not many research works, strategies or standards that can be applied to the construction of new smart buildings. Tan and

Wang (2010) also found that the design of a smart building is more complicated than a conventional building.

In their various studies, Azeem et al. (2017) discovered professionals' resistance to change as a significant barrier to adopting the smart building concept. Chan et al. (2018) identify a lack of professional knowledge and expertise in smart buildings, a lack of smart building databases and information, lack of awareness and their benefits. The authors went on to explain that specialist knowledge and expertise are crucial for the successful adoption of intelligent building. Nguyen et al. (2017) have identified barriers to the adoption of smart buildings, including the lack of importance placed on smart buildings by senior management, resistance to change by professionals and the lack of technical and clear understanding of smart buildings by professionals, clients and subcontractors. Häkkinen and Belloni (2011)identified a lack of information, understanding, knowledge, and awareness of the smart building concept as a barrier to adoption. El-Motasem et al. (2021) found that the general difficulties were categorized into six categories: insufficient research efforts, lack of a complete definition, lack of clear characteristics, unclear objectives and lack of a framework. According to the literature review, different authors' opinions influence the key barriers. Based on the literature analysis, 22 main barriers to smart building have been distilled into a holistic picture, as shown in **Table 1.** Previous research has extensively described these barriers, making them more relevant today.

The Research Method.

The study is based on a positivist research philosophy and a quantitative research approach, applying the partial least squares structural equation modelling (PLS-SEM) approach to analyze participants' responses to the potential barriers affecting the adoption of SBTs. The PLS-SEM technique has demonstrated success in the field of construction technology research, Such as Construction organization BIM capabilities (Munianday et al., 2022), COVID-19 impacts and response strategies (Radzi et al., 2022), project cost control system (Le & Sutrisna, 2023), and Causes and effects of Poor communication in constriction (Gamil & Abd Rahman, 2023). Therefore, the following aspects were scrutinized: the development of the model, the measurement model (assessment of convergent validity and discriminant validity), and the structural model analysis.

Identifying the potential barriers affecting the adoption of SBTs.

Researchers use systematic literature reviews (SLRs) to provide readers with comprehensive summaries and evaluations of research in specific subject areas while providing a foundation for future investigations. In this study, a systematic literature review (SLR) was conducted to examine the literature on SBTs. SLRs summarise scientific knowledge to address research problems through a transparent and reproducible method that incorporates all relevant findings while critically evaluating their quality. In contrast to other reviews, this SLR applied strict inclusion and exclusion criteria to ensure that only high-quality, relevant studies were selected (Ejidike & Mewomo, 2023; Lame, 2019). The review aimed to identify potential barriers to the adoption of SBTs. In this study, the PRISMA technique stands for “preferred reporting items for systematic reviews and meta-analyses”, was used to select and analyze the studies. The PRISMA technique is a comprehensive checklist that lists the essential elements of research reports and includes a flowchart that visualizes the research process (Toyin et al., 2024; Moher et al., 2009). **Figure 1.** Shows the flowchart for the SLR study. In this review, a comprehensive evaluation was used for the literature search. The first step was to select a suitable database carefully, and Scopus was chosen. Scopus was selected as the database to search for articles because it provides comprehensive coverage of peer-reviewed journals in a variety of disciplines, ensuring access to high quality and credible research. The rigorous indexing standards, citation metrics and user-friendly search tools make the database ideal for identifying influential studies and conducting thorough literature searches (Chàfer et al., 2021; Agbajor & Mewomo, 2022; Falagas et al., 2008). The search keywords used are "barriers" AND "smart building" OR "smart building" OR "concept" OR "smart

" building " or " technologies” were employed in the “title/abstract/keyword” feature of Scopus. Based on the search, 245 articles were retrieved initially, before Inclusion and exclusion criteria were applied to the identified articles based on subject areas: Engineering. Article types: Journal paper, conference paper, and review language: English language. Eighty-five articles were selected. In order to focus the study on the assessment of literature reviews that specifically address the barriers to the adoption of smart buildings in the construction industry, it was important to exclude any work that was not relevant to the study. Subsequently, articles that were not relevant were eliminated based on an analysis of the title, abstract, and content. Finally, a total of 30 publications were selected to identify the potential barriers to the adoption of SBTs.

The study was conducted in the main phases shown in **Figure 1.** Validation of the identification of potential barriers to adoption was confirmed by a pilot study involving construction and engineering professionals and academics. The professionals had a background of two years of experience.

Data collection via survey

The researchers used an online questionnaire created via 'Google Forms to contact participants, similarly used in construction research by (Ghansah et al., 2023). They were asked to rate the significance of the identified potential barriers using the Likert scale: 1-strongly disagree, 2-disagree, 3-neutral, 4-agree, and 5-strongly agree. The reason for using this approach in the study was its ability to represent a broad population effectively, allow for convenient data collection, and minimize or eliminate observer subjectivity (Sincero, 2012; Ghansah et al., 2023). The link to the online questionnaire was distributed via a snowball sampling to the widely dispersed population of construction professionals and engineers in Lagos state, Nigeria. This approach has been utilized in the construction research (Munianday et al., 2022). Respondents were eligible if they (1) had extensive research experience and were theoretically familiar with the application of digital technologies, or SBTs, in construction; (2) had practical experience with SBTs in construction; and (3) had been involved in at least one smart building project that involved an application of digital technologies. The data collection using the snowball method took almost three months. Due to various limitations, such as the participants' lack of time, a total of 244 responses were collected in Lagos. Since this sample complies with the central limit theorem's recommended minimum sample size of 30, Ott & Longnecker (2015) and Sproull (1995) consider it suitable and representative of the target population. This survey compares favourably with other surveys conducted in the construction industry in Ghana, such as the one conducted by (Ghansah et al., 2023). The Statistical Package for the Social Sciences (SPSS) version 26.0. The critical barriers were statistically tested using the partial least squares (PLS) approach based on structural equation modelling using SmartPLS 4 software.

Data Analysis and Results.

First, the data was cleaned to eliminate duplicate responses and incomplete surveys. The dataset's duplicate responses from identical email addresses helped to achieve this. Consequently, older completed responses were included in the study, while the most recent completed responses were excluded from the email addresses. A demographic analysis is performed prior to the primary analysis.

Respondent information

The general demographic of the respondents is presented in **Table 2:** 67.6 % of participants were male professionals, and 32.4 % were female professionals. More than half of the study participants (51.2%) have an academic degree (BSc), while 27.5% have an MSc degree. A smaller percentage, 8.6%, had a PhD, and 7.8% had an HND degree. However, the response rate for OND was lower at 2.9%. The respondents satisfied the minimum and maximum educational requirements to answer the study's questions fully. The demographic study revealed that 62 quantity surveyors, 92 builders, 47 architects, and 43 engineers responded to the questionnaire. Determining the level of professional experience of respondents is crucial as it increases the reliability of the information collected (DeRue, 2009; Ghansah et al., 2023) by indicating the knowledge. The result also showed that most respondents have 96 less than five years of experience (39.3%), followed by 5 to 10 years of experience (36.5%), while those over 20 years of experience have lower respondent rates. The results indicate that respondents have acquired considerable expertise and are able to make well-informed decisions about the barriers to SBT adoption.

Cronbach's alpha (CA), normality test and descriptive analysis

The data showed a high degree of internal consistency with a coefficient alpha (CA) of 0.913, which, according to Pallant (2016) rule of thumb, falls within the range of excellent internal consistency. According to this rule of thumb, a CA value below 0.60 indicates low internal consistency and is considered unacceptable, while a value between 0.60 and 0.80 is considered moderate and acceptable. A CA value between 0.80 and 1.00 indicates excellent internal consistency. The study data set was assessed using the Kolmogorov-Smirnov (K-S) test, which is recommended for sample sizes greater than 50. Mishra et al. (2019) suggested that a data set is considered normally distributed if the p-value is less than or equal to 0.050. In this case, the data set of the study was found to be non-normally distributed, which means that it is a nonparametric data set.

Kruskal-Wallis Test

The data were analyzed using nonparametric tests, as the collected data did not show a normal distribution. A Kruskal-Wallis test was performed to determine whether there were statistically significant differences between the responses. According to Siegel & Castellan (1988), a significant difference is determined if the asymptotic significance value is less than 0.05. The results of the Kruskal-Wallis test show that all asymptotic significance values are above 0.05, which indicates that there are no significant differences between the participants.

Normalization Method.

The normalization method was used in this study because it allows for a more insightful analysis of the data, especially in identifying significant barriers. Significant barrier factors with normalized values of at least 0.50 were identified. Research by Chan et al. (2015) and Munianday et al. (2022) served as the foundation for the normalization method. The strategy used in this study was to normalize the minimum mean to 0 and the maximum mean to 1. The remaining averages were then converted to decimal values between 0 and 1. After these changes, there were 19 remarkable barrier factors with normalization values above 0.5**0 (Table 3).**

Exploratory Factor Analysis (EFA)

The application of EFA was used to identify the key barriers that are critical to the adoption of SBTs. EFA facilitates the consolidation and reduction of multiple interrelated variables into a more concise and relevant collection of constructs (Norusis, 2008; Munianday et al., 2022). There are two main types of factor analysis: exploratory factor analysis (EFA) and confirmatory factor analysis. EFA aims to uncover the underlying factors that influence a group of responses. Confirmatory factor analysis, on the other hand, examines whether a certain group of components influences the answers in the expected way. EFA was conducted to identify the different dimensions of the critical barriers to the adoption of SBT. This method makes it possible to determine the number of common factors and their corresponding components. As an alternative, the researchers should group the variables that need confirmatory analysis to validate them. The EFA sample size was determined by calculating the ratio between the number of variables and the sample size *(N:P ratio)*(Williams et al., 2010).(Williams et al., 2010; Gorsuch, 1983) suggested that the minimum value for the ratio should be 5.00. The ratio between the sample size and the number of variables for the barrier data of this study is 11.1. Using the above rules of thumb, the sample size for this study was determined to be appropriate. The Kaiser-Meyer-Olkin (KMO) test and Bartlett's test for sphericity were used to determine whether the barrier data were suitable for exploratory factor analysis (EFA). As the KMO values in this study were 0.907, well above the minimum acceptable value of 0.80, the data were deemed suitable for analysis (Pallante et al., 2020). The results of Bartlett's test of sphericity show that the correlation matrix is significant at a significance level of $p < 0.05$, with a statistical test value of 2178.034 and a significance value of 0.000. The correlation matrix is therefore not an identity matrix. The data are therefore suitable for a factor analysis.

Principal component analysis (PCA) was chosen as the extraction technique to reveal the underlying components, which are grouped. PCA is a widely used method in construction management research to group variable data (Ma et al., 2020; Munianday et al., 2022). According to Finch (2020), a sample size of 200 or more has a significant factor loading of 0.50. Therefore, weak indicators of common factors were filtered out using a cut-off value of 0.50 for the factor loading. A total of 22 data points were included in the factor analysis, resulting in the extraction of five components. The components account for approximately 60.22% of the total variance required to establish construct validity, which corresponds to the required threshold of 60% (Ghosh & Jintanapakanont, 2004). The reliability test according to Cronbach's alpha was then carried out to check the exact grouping of the components. The values of Cronbach's alpha were above Nunnally's (1994) minimum requirement of 0.60, ranging from 0.797 to 0.826 (Nunnally, 1994). Thus, each construct exhibited strong internal consistency. **Table 4** summarizes the results of the exploratory factor analysis (EFA) and the values of Cronbach's alpha. The 22 barriers to adopting smart buildings were categorized into four main factors: awareness-related barriers, human-related barriers, management-related barriers and economic-related barriers, based on the literature review. The awareness-related barriers are named after the barriers that arise from lack of SBC database information, poor knowledge of smart building technology and inadequate well-trained labour. These factors may include misunderstanding or limited understanding of how these technologies can improve energy savings, operational efficiency and occupant comfort. For example, stakeholders may lack awareness of the alignment between smart technologies and sustainability goals, as well as their integration into existing systems. Wirtz & Müller (2019) point out that knowledge gaps often lead to a reluctance to adopt innovative solutions, as decision-makers are less inclined to invest in unfamiliar technologies; as a result, the factors are similar to this study's factors. Likewise, the human-related barriers relate to the attitudes, such as resistance to change from the use of traditional technologies, risk and uncertainties involved in implementing new technologies like smart building technologies, use of traditional procurement method(s) inadequate training and institutional facilities for research, a lack of competent and limited number of smart building supplier to manage and maintain these technologies. AlSanad (2015) highlights the importance of human factors, including user engagement and behavioural adaptation to new technologies, as essential for effective adoption. The term "human" factors encompasses the various social and psychological factors that can hinder the adoption of smart technologies, which makes the factor an important factor in this study.

Furthermore, management-related barriers in this category relate to leadership and decision-making processes. These factors include, inconsistent governance policy, inadequate finance schemes, low enforcement of building law and inadequate management support and sub-optimal project management. Ghansah et al. (2021) assert that the effective deployment of smart building technologies requires active management commitment, strategic planning and cross-departmental collaboration. The term management-related emphasizes the central role of leaders in driving innovation and implementing essential structural changes for integration. Finally economic-related barrier refers to financial barriers that hinder the deployment of smart buildings. These include significant initial capital expenditure, perceived risks associated with return on investment and ongoing operational costs, low market demand and lack of interest from clients. AlSanad (2015) identifies economic burden, particularly in relation to capital expenditure, as a key barrier to the adoption of smart technologies. Labelling this category as economically driven highlights the financial considerations and cost-benefit assessments that stakeholders need to make when deciding on the adoption of smart building solutions. These categories awareness, human, management and economic, cover different aspects of the barriers to smart building technology adoption and show how organizations and stakeholders are connected. These labels help to define and understand the barriers by origin and influence and how they fit into the results of the study.

Partial least-squares structural equation modeling

The barriers were tested using structural equation modelling (SEM). Observed variables can be quantitatively assessed through the use of structural equation modelling (SEM), while latent variables can be inferred or derived from the observed variables. A structural equation model comprises measurement models and structural models. A structural model represents the links between the underlying variables. There are two different types of structural equation modelling (SEM): covariance-based SEM (CB-SEM) and partial least squares SEM (PLS-SEM). It is better to use partial least squares structural equation modelling (PLS-SEM) than covariance-based structural equation modelling (CB-SEM) for looking at data sets that are non-normal distributed and have a small sample size (Hair et al., 2014). Exploratory research with theoretical models that are not well-defined is best conducted using this approach (Joreskog, 1982; Munianday et al., 2022).

Measurement Model

To determine the relationship between the exogenous variable and its corresponding latent variable (Joseph F Hair Jr et al., 2017). The assessment at this stage includes convergent validity, discriminatory validity, and the model's internal reliability (Buniya et al., 2021). The convergent validity test determines the degree of correlation between two or more variables from the same group and includes three tests: average variance extracted (AVE), composite reliability (CR), and Cronbach's alpha (Fornell, C Larcker, 1981; Wong, 2013). The acceptable value for the AVE is above 0.5, for CR above 0.7, and for the reliability is 0.7 (Fornell and Larcker, 1981; Wong, 2013; Hair et al., 2011), presented **in Table 5 and Figure 2 .** The second test in the measurement model is the discriminant validity, which was carried out using the PLS algorithm. Discriminant validity means that a construct is unique and totally capable of displaying any phenomena that other constructs in the model do not represent. This test can be measured by using cross-loading and Fornell Larckers. Fornell Larckers, the square root of AVE should be greater than the correlation between latent variables (Joe F Hair Jr et al., 2017). **Table 6** shows additional proof that the measurement model had discriminant validity provided by this finding.

Path Model Validation

After determining that the barriers were a formative construct, **table 7 Test** of Path Analysis Models, the study checked the collinearity between the construct's formative elements by determining the relative value of the inflation factor (VIF) (Qureshi et al., 2023). It can be assumed that each subdomain contributed differently to the higher-order structures because none of the VIF values were below 3.5. Bootstrapping was used to predict the significance of the path coefficients, revealing that all of the analyzed paths are statistically significant (Fornell and Larcker, 1981).

Discussion

The inadequate implementation of technologies and performance programs in the Nigerian construction industry is imperatively addressed before smart building technology can be considered an integral part of the sector. Understanding the barriers and acceptance is critical to the adoption of smart building technology. The successful adoption of smart building technology requires a verse elucidation of the barriers and acceptance among various professionals (Ejidike & Mewomo, 2023; Ejidike et al., 2022; Oyewole et al., 2019). This result suggests that awareness of smart building technologies is somewhat similar across emerging countries (Ghansah et al., 2020).

Therefore, this study revealed that the high cost of smart building materials, inadequate power supply, lack of local institutional facilities for research, high cost of smart building equipment, poor Maintenance Culture, inadequate well-trained labour, and inadequate finance schemes are the significant barriers to adopting smart building technology in the Nigerian Built environment. The findings are consistent with

Ghansah et al. (2021) and Iwuagwu & Iwuagwu (2014), which revealed that inadequate power supply and high cost are critical constraints to adopting new innovative technology in the built environment. Also, the study is consistent with the study of Bandara et al. (2019), who examined the applicability of smart building concepts in Sri Lanka and confirmed that lack of financial resources, lack of knowledge of developers, and reluctance to use new technology are the main barriers. Likewise, in Brazil, Vargas et al. (2022) also confirmed that higher construction costs, lack of specialized professionals, and insufficient economic resources are the main barriers associated with Brazilian civil construction. Vargas et al. (2022) study further revealed that 19 of the barriers are statistically significant in limiting the adoption of smart buildings, except Lack of interest from clients, Fear of inflation and Low Market demand, which appear to be statistically insignificant to the adoption of smart buildings. The study used exploratory factor analysis and partial least squares structural equation modeling (PLS-SEM) to examine the statistically insignificant barriers.

The result of a test path analysis (bootstrapping) and **Figure 2** revealed that the STBs with four subscales, awareness (β= 0.257, p-value < 0.00), economic (β = 0.246, p-value <0.001), human (β = 0.395, p-value <0.001) and management (β = 0.309, p-value <0.001). The path result confirms that the four subscales significantly affect the barriers to smart building technology adoption. Therefore, concluding that human-related and management-related barriers are the most critical barriers as a result of their path coefficient β= 0.395 and 0.309, respectively.

Awareness related barriers

This factors component accounts for 36.136% of the total variance of the factors. This component is an awareness-related barrier because it contains an item that speaks to subjects related to awareness-based barriers. These factors include poor knowledge of smart building technology 0.699, lack of promotion of smart building practice 0.673, inadequate well-trained labour 0.618, and lack of smart building database and information 0.778. The intention of raising smart building technology awareness is to assist policymakers and professionals in better understanding the impact of awareness to facilitate the adoption of a smart building. According to AlSanad (2015), awareness, experience, and knowledge, backed with action and effort, can lead to adopting new technology.

Similarly, the measure of industry professionals and policymakers to simulate the awareness, understanding, and knowledge of smart buildings will create the needed attention to adopting smart buildings. Publicizing the benefits of adopting smart buildings can also create the required awareness to adopt a smart building, such as energy saving, improving thermal comfort, safety, and security, and improving maintenance cost-saving (Ejidike & Mewomo, 2023). Education and training programs, such as Continuous Professional Development (CPD), aim to improve workers' and professionals' awareness of smart buildings by increasing their knowledge (Ghansah et al., 2021). As a result, professionals and policymakers need to educate the general public about the importance of adopting smart buildings through channels.

Human-related barriers

This factor accounts for 7.488% of the total variance of the barriers to adopting smart buildings. This factor was termed human-related barriers because it contains items linked to human barriers to adopting smart buildings. The factors are the use of traditional procurement method(s) 0.732, fear of inflation 0.670, lack of local institutional facilities for research 0.601, alteration and variation with the design during the construction process 0.537 risk and uncertainties involved in implementing new technology 0.535, resistance to change from the use of traditional technologies 0.527 and limited number of smart building suppliers 0.481. The human-related barriers can be attributed to a lack of action by professionals toward smart building adoption(Agyekum et al., 2019). It can also be attributed to a personal belief that involves the fear of changing from traditional construction methods to a modern or new innovative construction method, thereby restricting the professionals from participating and implementing smart building technology for building project delivery. This corroborates the findings of (Ghansah et al., 2021).

Management-related barriers

This factor accounts for 6.077% of the total variance of the barriers affecting the adoption of smart buildings. This factor was named management-related barriers because it entails items addressing policy issues in management. The factors are inconsistent government policy 0.764, low enforcement of building laws 0.683, lack of smart building training for professionals 0.644, inadequate power supply 0.495, and inadequate finance schemes 0. 711. This corroborates with (Wirtz & Müller, 2019) findings that management is attributed to monitoring and regulating activities. Consequently, the authorities of various professional bodies are required to engage in more dedicated actions in critical applications to promote the adoption of smart building technology. The highest levels of authority need to show that they are willing to pay the necessary resources to ensure that the smart building technology is successfully implemented and continues to function significantly.

Lei et al. (2021) emphasize that various chances to implement smart buildings to develop innovative solutions to prepare for the new norms have opened due to changes in consumer behaviour, government legislation, and organization priorities. Therefore, to successfully implement a smart building, top management is critical, and top management's commitment to funding and responsibilities might be sufficient to ensure proper adherence to this policy. Throughout the execution of the policy, training is a crucial component in modifying stakeholder's attitudes and behaviours toward smart building adoption (Jia et al., 2019).

To ensure that participants understand the smart building technology process and, as a result, increase the usage of a smart building, management's commitment to providing training or, more importantly, enlightening programs is essential. Depending on the participant's action plan, the training can be conducted on a regular or sporadic basis, but it should emphasize performance improvement techniques that make the most of the opportunity and impact the surroundings. The training sessions could also be an excellent opportunity to receive and discuss professional information, participant feedback, and evaluations. The effectiveness of electricity efficiency programs depends on effective governance in terms of developing sensible regulations and carrying out initiatives. Effective leadership is necessary to engage stakeholders in a smart building. Integrating smart buildings depends on the strategy and has a substantial impact on the project's performance. Top management is solely accountable for attaining the goals and objectives of implementing smart buildings.

Economic-related barriers.

This factor accounts for 5.599% and 4.945% of the total variance of the barriers affecting the adoption of smart building technology. This factor was named the economic factor because the items address issues related to economic or financial barriers to adopting smart buildings. These factors are the high cost of smart building material 0.848, high cost of smart building equipment 0.833, poor maintenance culture 0.466, lack of interest from clients 0.811, and low market demand 0.809. A vibrant economy is required to fulfil the population's needs and guarantee the efficient distribution of resources (Oke & Omole, 2019). Therefore, the economic system dictates how much technological innovation is applied and how it impacts the adoption of smart building technology because technology is increasingly integrating into our different aspects of life (Nižetić et al., 2020). However, most clients are still unable to understand the benefits of adopting smart building technology, or the market is still filthy with low-quality products, which may have affected the quality of demand for smart buildings in the market (Mewomo & Ejidike, 2021).

As a result, when determining the amount of demand, particularly for product purchases, the quality of the smart material now available on the market is of the utmost importance (Vermesan & Friess, 2013). The government should establish policies to promote the use of smart buildings, disseminate information to clients to assist them in understanding practices and subsidize the pricey equipment on the market. This could have a long-term benefit in creating an effective, sustainable market. Government public awareness campaigns on smart building technologies that accomplish energy savings and environmental conservation should be strengthened to increase people's environmental consciousness.

Practical Implications of the Study.

The current research has pinpointed the most significant barriers in the way of developing countries like Nigeria embracing smart building technology practices. Additionally, the research presented the categories of barriers and factors based on the responses of construction industry professionals' points of view. The results of previous research by Ogunde et al. (2018) and Oyewole et al. (2019) in integrating smart building technology into the building industry serve as the impetus for this study. Therefore, this study's results have uncovered the barriers affecting the integration of SBTs in construction projects particularly in developing countries like Nigeria.

CONCLUSION

The study investigated the barriers to adopting smart building technology based on the existing literature towards recognizing the barriers preventing the adoption and implementation in developing countries like Nigeria. Twenty-two literature-based barriers to the study's objective were found. One sample T-test and factor analysis were used in the study to provide an interpretation of the acquired data. According to the findings, the key barriers to adopting SBTs from the point of view of construction professionals are the high cost of smart building materials, the high cost of smart building equipment, and an inadequate power supply. Using the one sample T-test, the study also highlighted that the following barriers are statistically insignificant to the barriers of SBTs: lack of government incentive, low market demand, lack of interest from clients, resistance to change from the use of traditional technology, use of traditional procurement methods, and a limited number of smart building supplier.

The use of exploratory factor analysis discovered the underlying grouping of barriers factor adopting smart buildings: awareness-related barriers, human-related barriers, management-related barriers, and economic-related barriers. SmartPLS was then used to validate the factor analysis result. The result of the PLS shows a significant influence on the barriers to SBT adoption by further consolidating the result of the EFA on barriers. Given the limited empirical studies on the barriers to SBT adoption, the empirical results of this study have contributed to the rising conversations on SBTs in developing countries such as Nigeria from the viewpoints of construction professionals and have provided the principal and significant barriers preventing the adoption of SBTs in developing countries with novelty.

In summary, anticipating and avoiding barriers is critical to preventing surprise project resource losses. Empirically, this study provides construction industry professionals with an understanding of various barriers to adopting smart buildings in developing countries, particularly Nigeria. The study further suggests that to adopt SBTs successfully and effectively in Nigeria, various stakeholders should be made aware of potential barriers to its adoption and seek possible strategies to avoid or prevent them when making decisions. This will benefit professionals and policymakers in policymaking regarding achieving sustainability within the construction industry. It will also guide various construction stakeholders in thinking ahead into the best ways to successfully adopt SBTs, enabling them to be aware of various barriers alongside the best strategies for handling and overcoming them more efficiently. To overcome the various barriers, this study suggests the education and training of construction professionals, workshops, seminars, and international and local conferences to create awareness as well as collaboration and partnership among different professional bodies to address the cybersecurity challenges of technology, cost management, piloting of successful project to develop professionals and encourage SBT's implementation in the construction industry. It highlighted the empirical barriers and proposed the best answers and directions for overcoming them. This study has adequately addressed SBT's barriers and suggested the best solutions and recommendations for overcoming them. The data for this study were collected mainly on barriers to SBT's in Nigeria, which could be regarded as a limitation in generalizing the findings to other developing countries. Consequently, the study proposes that further studies in other emerging economies should be conducted to inquire more into strategies that could better enhance smart building technology in the construction industry to attain sustainability.

DATA AVAILABILITY STATEMENT:

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

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