A Comparative Assessment of Emerging Smart Building Technologies for Energy-Efficient Operations: Lessons from the United Kingdom for Nigeria

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ABSTRACT

The building sector is a major consumer of energy and a significant source of carbon emissions, and smart building technologies are increasingly promoted as a means of improving operational energy performance. Adoption is advancing quickly in developed economies but remains limited in developing ones. This study assesses the emerging smart building technologies used for energy-efficient operation in the Nigerian building sector, compares them with practice in the United Kingdom, and identifies the lessons Nigeria can draw from UK experience. A qualitative research design was adopted, with data gathered through semi-structured interviews with 62 practitioners, 31 in the United Kingdom and 31 in Nigeria, selected by purposive sampling and drawn from engineering, policy, development, architecture, technology supply and research. The interviews were analysed using reflexive thematic analysis supported by NVivo. Three groups of technology were identified in both countries: sensor-based and automated control systems, IoT-enabled energy management systems, and renewable energy integration with smart grids. Adoption in the United Kingdom is driven by regulation that applies at the point of building control, by financial support, and by mature electrical and digital infrastructure. The same technologies are recognised in Nigeria, but adoption is constrained by four barriers: the gap between policy and enforcement, cost and access to finance, limited government support, and weaknesses in power and telecommunications infrastructure. The study finds that Nigeria does not lack energy efficiency policy so much as the means to enforce what has already been issued, since the Building Energy Efficiency Code and related instruments remain voluntary and are not embedded in state building control. Recommendations are directed at the federal and state bodies able to act on them and cover fiscal measures, adoption of existing codes, infrastructure investment and training.

Keywords: smart building technologies, energy efficiency, technology adoption, Nigeria, United Kingdom

INTRODUCTION

In recent decades there has been sustained emphasis on the need to promote sustainability and address climate change, and this has brought the energy performance of the built environment into focus. Building operations and construction together accounted for about 36 per cent of global final energy demand and 37 per cent of energy related and process carbon dioxide emissions in 2020, the latter figure including the cement, steel and glass produced for construction (UNEP, 2021). Approaches that counter the growing energy demand of the sector are therefore needed, and smart technologies in buildings have emerged as one of the more promising responses.

Countries such as Nigeria continue to face difficulty in delivering energy-efficient solutions in their building sector. Nigeria nevertheless holds significant potential, as its growing urban population and expanding construction industry provide a platform for investment in energy-efficient and renewable technologies. Its commitments under the United Nations Sustainable Development Goals and the Paris Agreement also position the country to benefit from international funding for sustainable energy (United Nations, 2015a; 2015b).

In this study, the strategies that have succeeded in the UK's building sector are compared against the Nigerian context to draw out practical insights for promoting sustainability in construction. Given the current emphasis on renewable energy, work of this kind is timely in addressing the factors that hinder adoption in developing countries such as Nigeria. The study helps to close the gap between policy and practice in the Nigerian context, supporting the wider adoption of energy-efficient technology in homes and workplaces.

Problem statement

Building energy efficiency has gained international attention, and developed countries such as the UK have made impressive strides in using smart technologies to lower energy use. The UK has taken the lead in implementing energy-efficient practices thanks to sophisticated infrastructure, financial incentives, and regulatory initiatives (BEIS, 2021). However, there is a significant gap between policy goals and reality on the ground because Nigeria lacks a similar regulatory framework and supporting infrastructure.

The energy inefficiency of the Nigerian building stock carries a growing environmental and economic penalty. National emissions per head remain low by international comparison, but demand is rising quickly, and the unreliability of the public electricity supply forces widespread reliance on diesel and petrol generators, which raises operating costs and produces higher emissions for each unit of delivered energy than grid supply. The Energy Transition Plan puts the number of Nigerians without access to grid electricity at about 90 million, which places building-level generation, storage and demand management at the centre of any credible efficiency strategy for the sector (Federal Republic of Nigeria, 2022).

Nigeria must address these issues if it hopes to meet its energy and climate goals. Inaction runs the risk of sustaining economic inefficiencies and environmental deterioration. By finding lessons from the UK's achievements and adapting them to Nigeria's particular situation, this study aims to close this gap. Nigeria may move towards sustainable development and meet international sustainability goals by removing these obstacles and realising its potential to implement smart building technologies.

Research aim and objectives

The aim of this study is to assess the emerging smart building technologies for energy-efficient operations in the Nigerian building sector, drawing on insight from the UK's building sector to address Nigeria's challenges. The purpose is to identify workable recommendations that would promote the adoption of smart technologies in the Nigerian context, in line with the objectives of sustainability and energy efficiency.

In order to achieve the aforementioned aim, the researchers adopted the following objectives:

- Identify smart building technologies used in Nigeria and the UK for energy-efficient operations.
- Analyse adoption frameworks in both countries, focusing on policies and incentives.
- Evaluate challenges limiting smart technology adoption in Nigeria.
- Highlight lessons and provide recommendations from the UK to improve Nigeria's adoption of smart technologies.

Research questions

In order to achieve the aim and objectives of the study, the following research questions were addressed:

- What types of technologies are currently being adopted in UK and Nigeria for smart building and energy-efficient constructions?
- What incentives, frameworks and policies drive these smart building technologies in UK and Nigeria?
- What are the current hindering barriers and challenges to the smart building technology adoptions in the Nigerian context?
- What are the adaptable lessons from the UK's context that can help foster Nigeria's adoption and implementation of smart building technologies for energy efficiency?

Significance of the study

The significance of the study lies in its contribution to academia and to practice, in addressing energy inefficiency in the Nigerian construction industry. Internationally, the adoption of smart and sustainable technology is recognised as a step towards environmental goals such as those set out in the United Nations Sustainable Development Goals and the Paris Agreement (United Nations, 2015a; 2015b).

In practice, the results provide a useful reference for policymakers, building industry practitioners and technology suppliers. By identifying the obstacles and setting out workable measures, the research can inform the development of policy and strategy to encourage the adoption of smart building technology in Nigeria and bring practice into line with international standards for energy efficiency.

Scope and limitations

Scope

This study compares smart building technologies for energy-efficient operations in Nigeria and the United Kingdom. It identifies the technologies in use in both countries, the frameworks and policies that encourage their uptake, and the obstacles Nigeria faces in adopting them. The study is confined to residential and commercial buildings, which together account for the greater part of building sector energy demand in both countries. It uses a qualitative methodology, drawing on semi-structured interviews with practitioners, policymakers and technology suppliers in both countries, supported by review of published policy and technical documents.

The UK, a pioneering nation in energy-efficient technologies, and Nigeria, a developing nation with enormous potential for smart technology adoption, are the only countries that are the subject of the geographical focus. Gleaning actionable lessons and frameworks from the UK's experience, the study offers practical suggestions suited to Nigeria's socioeconomic and infrastructure situation.

Limitations

One constraint of this study is its reliance on qualitative methods, which limits the extent to which the findings can be generalised. The findings rest on the accounts of the practitioners interviewed, and their transferability to other settings is a judgement for the reader on the strength of the contextual description provided. The difference in the stage of technological adoption between the Nigerian and UK building sectors also constrains direct comparison, so only those frameworks applicable in both countries form the basis of the comparison.

LITERATURE REVIEW

Definition and components of smart building technologies

Smart building technologies are the sensing, control and information systems that allow the services within a building to be operated automatically in response to conditions and to occupant demand. They are best understood as four layers working together. The field layer consists of the sensors and actuators that measure temperature, occupancy, illuminance, carbon dioxide concentration and electrical demand, and that act on plant. The control layer consists of the controllers that execute the control strategy for heating, ventilation, air conditioning and lighting. The supervisory layer, normally a building energy management system, provides scheduling, alarms, trending and central adjustment. The analytics layer applies monitoring, targeting and fault detection to the data collected. BS EN ISO 52120-1:2022, which superseded BS EN 15232-1, sets out this hierarchy and classifies building automation and control functions into efficiency classes A to D, with factors that allow the energy saving attributable to each class to be estimated by building type. It should be noted that the great majority of installed control remains rule based, using time scheduling, occupancy detection, daylight linking, weather compensation and optimum start and stop. Machine learning is a more recent addition, applied mainly to optimum start, predictive control and fault detection and diagnosis, rather than a general replacement for conventional control. Figure 1 shows these layers and the direction of information flow between them.

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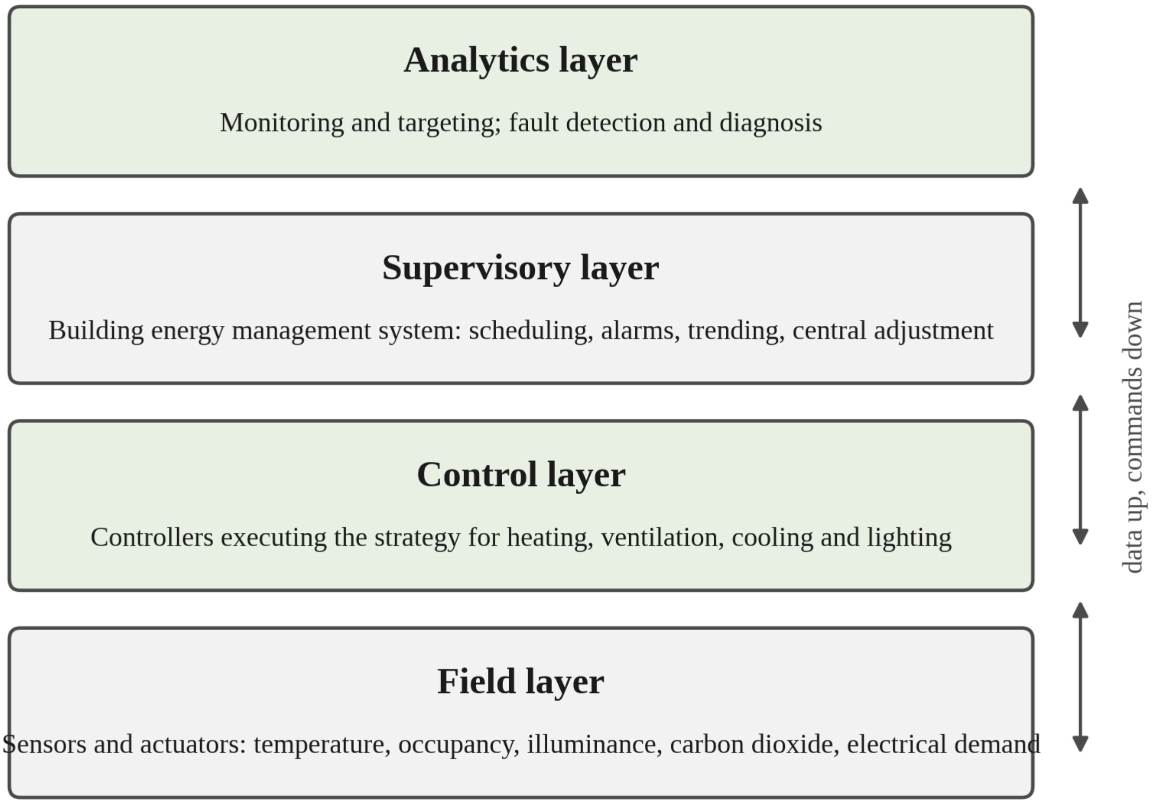

Figure 1: Functional layers of smart building technology (Authors' own work, after BS EN ISO 52120-1:2022).

Automation of IoT is one of the primary features of smart buildings. This includes the use of sensors, actuators, and cloud computing to deliver customised operation from real-time data. Because devices are networked, IoT equipment can interface with management systems allowing real-time energy control. These technologies aid remote control and predictive maintenance, increasing efficiency, and equipment life.

The role of smart building technologies in energy efficiency

One of the leading reasons for the adoption of smart building technologies has been their effect on operational energy use. Because building operations account for a substantial share of global energy demand, as noted above, the optimisation of energy in use is central to any sustainability strategy for the sector. Smart buildings reduce waste by combining continuous monitoring with automated control, using historical and real-time data to match plant output to actual demand rather than to a fixed schedule. Lighting control using occupancy sensing and daylight linking is one of the more established measures, and the efficiency classes given in BS EN ISO 52120-1:2022 provide a means of estimating the saving that a given standard of control can be expected to deliver. The four classes are summarised in Table 1.

Table 1: Building automation and control efficiency classes under BS EN ISO 52120-1:2022 (British Standards Institution, 2022).

Class	Characterisation
A	High energy performance building automation and control system and technical building management functions
B	Advanced building automation and control system, with some technical building management functions
C	Standard building automation and control system, the reference class against which the others are compared
D	Building automation and control system that is not energy efficient; buildings in this class are candidates for upgrade

A further consideration in any assessment of operational performance is the gap commonly observed between the energy use predicted for a building at design stage and the energy it consumes in service. This performance gap is well documented in the research literature (de Wilde, 2014) and arises from simplified design assumptions, changes made during construction, incomplete commissioning and patterns of occupancy that differ from those assumed. Standard UK practice now addresses it from both directions. CIBSE TM54 provides a method for estimating operational energy use realistically at the design stage (CIBSE, 2022), the Soft Landings framework carries designer and contractor involvement through handover into the early years of operation (BSRIA, 2018), and CIBSE Guide F sets out established practice for managing energy in buildings in use (CIBSE, 2012). Smart building technologies support each of these activities, since metered and trended data are the evidence on which post-occupancy evaluation depends.

Building energy management systems bring the control of the separate services within a building under a single supervisory platform. Centralised control over energy consuming plant allows demand to be matched to occupancy and to external conditions, and the continuous collection and analysis of data allows inefficiencies to be identified and corrected as they arise. A distinction should be drawn between a building energy management system, which is the control and supervisory hardware and software that operates the plant, and an energy management system in the sense of BS EN ISO 50001, which is a management framework of policy, objectives, monitoring and review. The two are complementary, and the technical system delivers little without the management framework around it. The term building energy management system, abbreviated to BEMS, is used throughout this paper.

Adoption of smart building technologies in the UK: regulatory frameworks and policies

The UK government has introduced a series of regulatory measures directed at the energy performance of buildings. The principal instrument is Part L of the Building Regulations, given effect in England through Approved Document L, Conservation of fuel and power, 2021 edition, in Volume 1 for dwellings and Volume 2 for buildings other than dwellings, which came into force on 15 June 2022 (DLUHC, 2021). Wales operates its own Part L, Scotland applies Section 6 of the Technical Handbooks and Northern Ireland applies Part F, so the requirements differ across the United Kingdom. Approved Document L sets fabric and building services performance targets and, in Volume 2, requires sub-metering and automatic monitoring and targeting in larger buildings. It does not require smart controls as such, but the metering, monitoring and control provisions it does impose have made building energy management systems the practical means of demonstrating compliance in commercial buildings. Meeting these requirements remains difficult in parts of the private sector where capital is constrained (BEIS, 2021).

The largest single deployment of smart building technology in the United Kingdom has been the Smart Metering Implementation Programme, delivered as a licence obligation on energy suppliers and overseen by Ofgem, with around 39 million smart and advanced meters operating in Great Britain by 2025 (DESNZ, 2025). The programme is directly relevant to this study because it shows that metering at national scale was achieved through an obligation placed on suppliers rather than through voluntary uptake by building owners.

Metering at scale also underpins the wider transition of the electricity system. The Smart Systems and Flexibility Plan sets out how flexibility from smart appliances, storage and demand-side response is expected to reduce the cost of operating the system as generation decarbonises, and buildings equipped with smart controls and half-hourly metering are placed to take part in that flexibility (HM Government, 2021). Table 2 draws together the principal instruments bearing on smart building technology in the United Kingdom.

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Table 2: Principal UK instruments bearing on smart building technology.

Instrument	Scope	Effect	Status
Building Regulations, Approved Document L 2021 (DLUHC, 2021)	New buildings and work to existing buildings, England	Fabric and building services performance targets; sub-metering and automatic monitoring and targeting in larger non-domestic buildings	In force from 15 June 2022
Minimum Energy Efficiency Standards (United Kingdom, 2015)	Privately rented property, England and Wales	Minimum Energy Performance Certificate rating as a condition of letting	Domestic from 2018 and 2020; all non-domestic tenancies from April 2023
Future Homes Standard	New dwellings, England	Uplift to Part L carbon and fabric requirements	Forthcoming
Smart Metering Implementation Programme (DESNZ, 2025)	Great Britain, through supply licences	Obligation on energy suppliers to roll out smart metering; around 39 million meters operating by 2025	In delivery
Energy Company Obligation (Ofgem, 2022)	Larger energy suppliers	Funded efficiency measures for the least efficient and low income homes	Running since 2013; ECO4 to March 2026
Boiler Upgrade Scheme	England and Wales	Grants of 7,500 pounds towards heat pumps	Open since May 2022
Zero rate of VAT on energy saving materials	Residential property, United Kingdom	Removes VAT from qualifying installations	In force from April 2022
Product Security and Telecommunications Infrastructure Act 2022 (United Kingdom, 2022)	Consumer connectable products	Minimum security requirements for connected devices, including smart controls	In force from April 2024

Institutions such as the UK Green Building Council (UKGBC) have played a prominent part in formulating sustainability criteria for the construction industry. To facilitate the use of smart meters, automated heating and cooling systems, as well as AI powered energy management tools, UKGBC has set limits and requirements for energy efficiency which filter down to construction.

Cybersecurity and data protection

Networked controls and metering carry obligations that are not present in conventional building services. Connecting field devices and supervisory systems to external networks creates an attack surface, and the BS EN IEC 62443 series provides the recognised framework for the security of industrial automation and control systems, including those applied in buildings. Metering and occupancy data can identify individuals, which brings such systems within UK GDPR and the Data Protection Act 2018. Since April 2024 the Product Security and Telecommunications Infrastructure Act 2022 has imposed minimum security requirements on consumer connectable products sold in the United Kingdom, including smart thermostats and controls. These obligations form part of the cost and competence required to operate smart buildings and are relevant to any jurisdiction considering a requirement for connected systems.

Incentives and funding programmes

Financial support has also been used to promote uptake, with mixed results. The Green Deal allowed energy saving measures to be financed through a loan repaid from the energy savings achieved, subject to the golden rule that repayments should not exceed the expected saving. The mechanism did not succeed. The Department of Energy and Climate Change withdrew funding for Green Deal loans in July 2015, and the National Audit Office found that the scheme did not achieve value for money, having cost around 240 million pounds between April 2011 and March 2015 while households financed only about one per cent of installed measures through a Green Deal loan (National Audit Office, 2016). The interest rate carried by the loan, set against the golden rule, meant that few measures qualified. The Energy Company Obligation, placed on larger energy suppliers and running continuously since 2013, has proved the more durable mechanism. Its current phase, ECO4, runs from April 2022 to March 2026 and is directed at the least efficient homes and at low income households (Ofgem, 2022).

The Renewable Heat Incentive supported the uptake of heat pumps and solar thermal systems. The non-domestic scheme closed to new applicants on 31 March 2021 and the domestic scheme on 31 March 2022, and both were succeeded by the Boiler Upgrade Scheme, which opened in May 2022 and currently offers grants of 7,500 pounds towards air source and ground source heat pumps in England and Wales. Both schemes fund heat generation plant rather than controls, metering or monitoring, so their relevance to smart building technology is indirect. On the fiscal side, the installation of energy saving materials in residential property has been zero rated for value added tax since April 2022. Private investment has also played a part, with a number of companies entering public-private partnerships aimed at developing smart infrastructure in cities. Figure 2 places these funding programmes and the regulatory milestones described above on a common timeline.

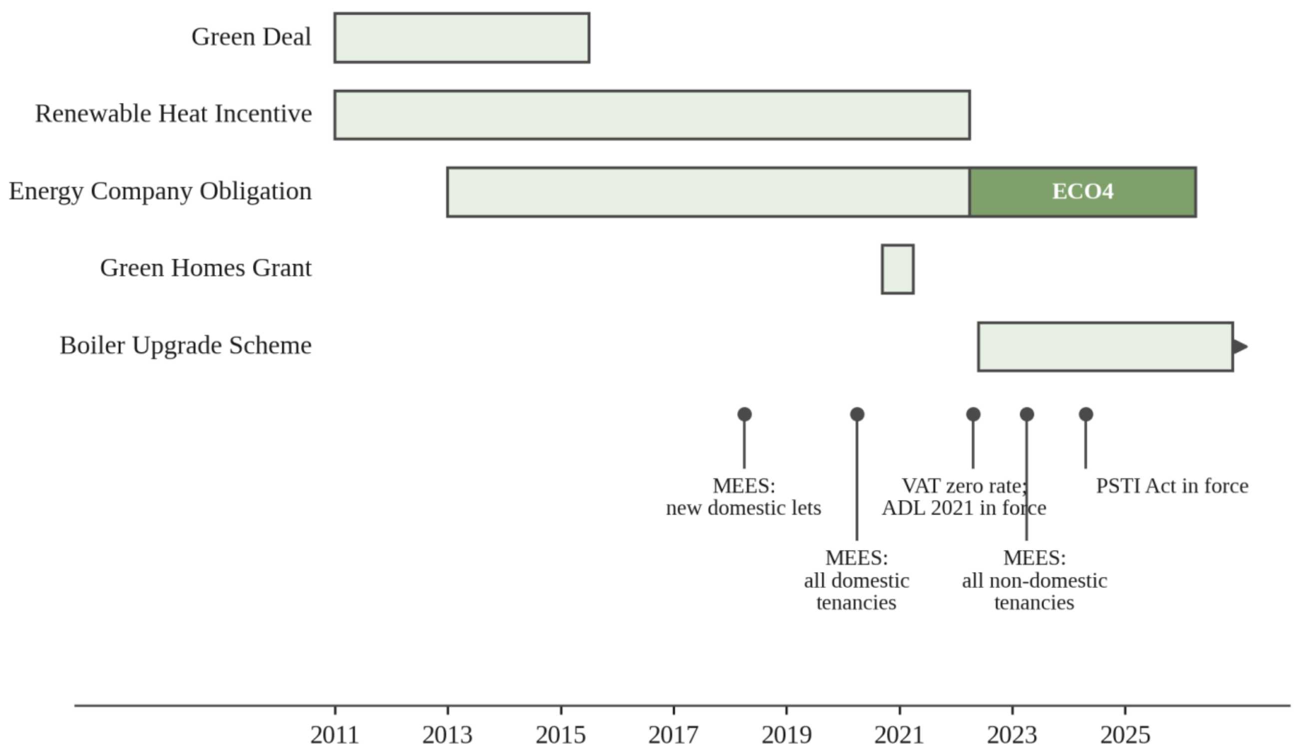

Figure 2: Principal UK funding programmes and regulatory milestones cited in this review (Authors' own work).

Case studies of successful smart building projects

The Bloomberg European Headquarters in London is the example most often cited in the United Kingdom. The building was awarded a BREEAM Outstanding rating at design stage in 2017, at the time the highest score recorded for an office development, and it combines daylight linked lighting, demand controlled ventilation and integrated metering under a single management platform. Percentage savings quoted for buildings of this kind should be treated with care unless the baseline is stated, since a saving measured against a design stage notional building is not the same as a saving measured in operation. CIBSE TM39 sets out the metering arrangements

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needed to obtain reliable operational data, and evidence of that kind carries more weight than a headline percentage.

Challenges in adopting smart building technologies in Nigeria

Infrastructure challenges

The lack of sufficient infrastructure in Nigeria, especially regarding electricity provision, internet access, and the telecommunications industry, is one of the main hindrances for technology implementation in buildings. As opposed to advanced economies where smart systems are able to function due to high availability of energy and internet, Nigeria faces constant power outages coupled with further issues of insufficient broadband saturation. Numerous smart structures rely on uninterrupted energy supply along with real-time processing of information, but the country's increasingly non-reliable grid systems force developers to engage in the use of expensive diesel generators which greatly hikes operational costs.

Telecommunications infrastructure presents a further constraint. Smart buildings depend on reliable connectivity for remote monitoring, real-time data transmission and cloud based energy management. Broadband penetration in Nigeria remains below the 70 per cent target set in the Nigerian National Broadband Plan 2020 to 2025 (Federal Ministry of Communications and Digital Economy, 2020), which limits the availability of the services on which many smart systems depend. Two effects should be distinguished. Control loop performance within a building depends on the local network and the controller polling rate rather than on national connectivity, whereas remote monitoring, analytics and supervisory functions depend on the external link. Availability in rural and semi-urban areas is weaker still, which further complicates the deployment of IoT and smart grid systems.

Metering illustrates both the scale of the difficulty and the direction of travel. A substantial share of registered electricity customers in Nigeria remain unmetered and are billed on estimated consumption, which weakens revenue collection and removes any incentive to manage use. The Nigerian Electricity Regulatory Commission introduced the Meter Asset Provider Regulations in 2018 to bring private capital into meter provision (NERC, 2018), and the National Mass Metering Programme followed in 2020 with central bank financing to accelerate installation (Central Bank of Nigeria, 2020). The institutional machinery for metering therefore exists; the constraint has been the pace of delivery rather than the absence of a framework. Table 3 sets out the principal Nigerian instruments and their present status.

Table 3: Principal Nigerian energy efficiency and related instruments.

Instrument	Year	Issuing body	Status
National Building Code	2006	Federal Government of Nigeria	Model code; not adopted into law in most states
National Renewable Energy and Energy Efficiency Policy (NREEEP)	2015	Federal Ministry of Power	Policy; voluntary
National Energy Efficiency Action Plan 2016 to 2030	2016	Federal Ministry of Power	Action plan; voluntary
Building Energy Efficiency Guideline	2016	Federal Ministry of Power, Works and Housing, with GIZ	Guideline; voluntary
Building Energy Efficiency Code	2017	Federal Ministry of Power, Works and Housing	Code; voluntary, not embedded in state building control
Meter Asset Provider Regulations	2018	Nigerian Electricity Regulatory Commission	Regulation; in force
National Mass Metering Programme	2020	Federal Government with Central Bank of Nigeria	Financing programme; in delivery
Climate Change Act	2021	Federal Government of Nigeria	Statute; in force
Energy Transition Plan	2022	Federal Government of Nigeria	Strategy
Electricity Act	2023	Federal Government of Nigeria	Statute; in force

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Financial and technical barriers

The high cost of smart building technologies remains a major barrier to adoption, as developers and businesses are reluctant to invest in innovations perceived to carry significant financial risk. Many components of a smart building, such as Internet of Things sensors, energy control systems and automated lighting, require significant investment, which makes adoption impracticable for some organisations (Ejidike and Mewomo, 2022). Limited access to credit and high interest rates further discourage developers from investing in smart building technologies.

Besides economic constraints, Nigeria faces a significant skills gap in the available workforce, which makes smart building technologies difficult to install, commission and maintain.

THEORETICAL FRAMEWORK

The adoption of smart building technologies rests on a conceptual framework that explains how new innovations are accepted, spread across, and put to use in specific societies. This study's major focus stems from two theories: The Technology Acceptance Model (TAM) and the Diffusion of Innovations Theory (DOI). These models give an explanation of what moderates or permit the adoption of smart building technologies in different contexts like the UK and Nigeria. While TAM deals with how an individual user accepts a particular technology, DOI deals with how an entire society with its different structures accepts and uses the new innovation over a period of time. These models are essential in explaining why advanced economies have managed to embrace most of the smart technologies while developing economies are struggling with them. Table 4 summarises the two models and the use made of each in this study.

Table 4: The two models of the theoretical framework compared (Authors' own work).

Aspect	Technology Acceptance Model (Davis, 1989)	Diffusion of Innovations (Rogers, 2003)
Level of analysis	Acceptance of a technology by the individual user	Spread of an innovation through a society over time
Core constructs	Perceived usefulness; perceived ease of use	Relative advantage; compatibility; complexity; trialability; observability
Outcome explained	Willingness of a practitioner to use a system	Rate and pattern of adoption across a market
Use in this study	Reads the workforce skills gap as a constraint on perceived ease of use	Explains the different market positions of the United Kingdom and Nigeria

Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), introduced by Davis in 1989, is one of the more renowned theories that deals with understanding adoption/acceptance of a technology at an individual level. The model holds that the decision to adopt a technology on two core constructs:

- Perceived Usefulness (PU): This means the level to which a certain user believes that a particular technology will improve efficiency, productivity, or effectiveness.
- Perceived Ease of Use (PEOU): Refers to the degree to which a user perceives the technology as being easy to learn and operate.

TAM has been widely applied to the study of technology uptake. In the case of smart buildings, developers, facility managers, and homeowners are more willing to use advanced technologies for building operations if these technologies are easy to use and useful. The structure of the model is shown in Figure 3.

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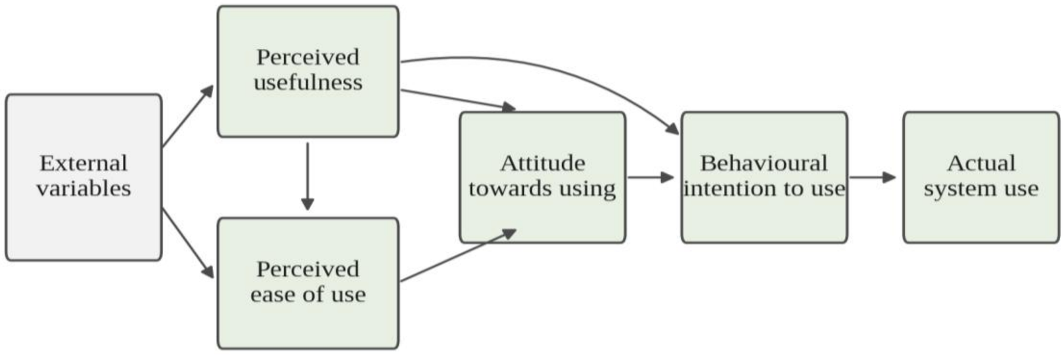

Figure 3: The Technology Acceptance Model (Authors' own work, after Davis, 1989).

Diffusion of Innovations theory (DOI)

The DOI Theory, put forward by Rogers in 2003, illustrates how technologies are adopted by a society over time. It indicates five innovation traits that are critical for the technology to be adopted:

- Relative Advantage: This refers to the level at which an innovation is considered to be better than the solution it replaces.
- Compatibility: This is a measure of how the innovation fits with the existing practices and infrastructure.
- Complexity: Refers to the apparent difficulty of understanding and using the innovation.
- Trialability: This is the extent to which the technology can be tested before a full-scale adoption.
- Observability: The visibility of the innovation's benefits to the potential adopters.

The theory further divides adopters into five categories: innovators, early adopters, early majority, late majority and laggards (Rogers, 2003; Sahin, 2006). No published classification of the two markets studied here was identified, so the positions set out below are the authors' interpretation of the interview data rather than a finding drawn from the literature. On that basis, the United Kingdom shows the characteristics of an early majority market, in which adoption has moved beyond the enthusiast and into general practice for new commercial work, supported by relative advantage, compatibility with existing energy policy and consistent enforcement. Nigeria shows the characteristics of a market still at the innovator and early adopter stage, where uptake is confined to a small number of high specification buildings. The late majority label sometimes applied to markets of this kind does not fit, since that category describes adopters who follow once the majority has already adopted, which is not the position in Nigeria. Limited trialability and low observability of the benefits restrict adoption further, since few reference installations are available for prospective adopters to inspect. Figure 4 shows the five categories and the share of adopters in each.

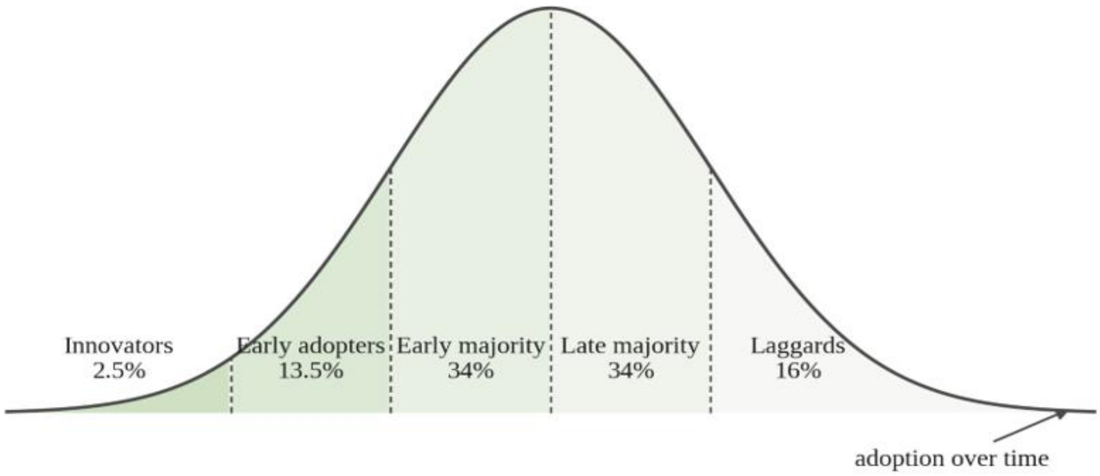

Figure 4: Adopter categories of the Diffusion of Innovations theory (Authors' own work, after Rogers, 2003).

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RESEARCH METHODOLOGY

The methodology adopted in this study was carefully designed to align with the research aim and objectives, which focus on assessing smart building technology adoption for energy-efficient operations in the UK and Nigeria. Given the comparative nature of the research, a qualitative approach was employed to explore expert insights, policy frameworks, and the technological landscapes of both countries. The research methodology serves as the foundation for collecting, analysing, and interpreting data, ensuring that findings are reliable, valid, and applicable to real-world contexts.

Research design

This study focuses on a comparative analysis between two distinct geographical contexts, the United Kingdom (UK) and Nigeria with respect to the adoption of smart building technologies for energy-efficient operations. Given the nature of the research questions, which require an understanding of not only the technological landscape but also the underlying policy frameworks, financial incentives, infrastructural challenges, and stakeholder experiences, a qualitative research design was chosen as the most appropriate approach. This design enables a deep exploration of the subject matter, capturing the complexity of human perceptions, regulatory environments, and socio-economic factors that shape the adoption of smart technologies. The decision to adopt a qualitative research design stems from the need to capture rich, detailed data that goes beyond what numerical figures and statistical correlations can reveal. Unlike quantitative research, which relies on predetermined variables and the aggregation of numerical data, a qualitative approach allows the researcher to explore the "why" and "how" behind smart building technology adoption. This is particularly important in the context of comparing the UK and Nigeria, as the factors influencing technology adoption in each country are deeply embedded in their respective cultural, economic, and regulatory environments. By engaging with industry experts, policymakers, and other stakeholders through interviews and document analysis, the study is able to uncover insights that would be otherwise missed by purely numerical analysis (Bryman, 2016).

The qualitative approach also accommodates the complexity inherent in cross-national comparisons. In the case of this study, the objective is to understand not only the state of smart building technology in each country but also to identify the underlying reasons for the differences observed. Factors such as historical development of the regulatory environment, public awareness, infrastructural robustness, and financial incentives all contribute to the disparate levels of technology adoption. These variables are interconnected and cannot be isolated easily without a comprehensive, interpretive framework. Qualitative research provides the tools to examine these complexities in depth, thereby yielding more contextually grounded findings.

Research approach

This study adopts an interpretivist position, which treats the understanding of human experience within its social and regulatory context as the route to explanation (Bryman, 2016). An inductive approach was used, allowing themes and patterns to emerge from the data rather than testing predetermined hypotheses, so that the findings are grounded in the experience of practitioners rather than in theoretical assumption.

Data collection methods

Data were collected from primary and secondary sources. Primwedesary data were obtained through semi-structured interviews with practitioners in the United Kingdom and Nigeria, drawn from engineering, policy, development, architecture, technology supply and research. A total of 62 interviews were conducted, 31 in each country, and were carried out electronically. Responses were recorded with the consent of participants and transcribed, and the transcripts were collated into a single document for analysis. The interview guide is reproduced at Appendix A. The semi-structured format was adopted for the flexibility it allows in following up responses while keeping coverage consistent between participants.

Secondary data collection involves sources from government reports, journal articles and industry white papers. This method was used to complement the primary data sources that helped in the understanding of smart building policies, incentives and adoption for improvement after understanding the lessons from the UK for Nigeria.

Questions for the respondents were structured around key research themes which include policy framework, challenges and lessons learned from the UK. After careful document selection and review of reports from regulatory agencies, research institutions and expert opinions from industry leaders, there was a cross-verification to enhance reliability.

Sampling strategy

Purposive sampling was used so that only practitioners with direct and relevant experience of smart building systems took part, which was intended to maximise the relevance and credibility of the responses. The criterion applied was current or recent professional involvement with smart building systems within one of the six categories set out in Table 6. The final sample comprised 31 practitioners in the United Kingdom, including policymakers, smart building developers and energy efficiency researchers, and 31 in Nigeria, including construction engineers, government officials and technology specialists. An equal number was sought in each country so that the two data sets would carry comparable weight. The sample size follows Guest, Bunce and Johnson (2006), who found that a sample of this order is sufficient to reach thematic saturation while remaining manageable.

Data analysis method

Reflexive thematic analysis was used to identify themes across the interview responses, supported by NVivo software for coding and retrieval. The approach allows the systematic identification, organisation and interpretation of recurring patterns within qualitative data (Braun and Clarke, 2006). Thematic analysis was preferred to content analysis because the objective was to interpret meaning across the data set rather than to count the frequency of predetermined categories, a distinction set out by Humble and Mozelius (2022). The term reflexive thematic analysis is used throughout this paper.

The six phases set out by Braun and Clarke (2006) were followed.

Familiarisation with the data. Transcripts were read repeatedly to gain an overall understanding of the accounts given by participants and to record initial observations.

Generating initial codes. The data were coded systematically in NVivo using a coding scheme developed from the research questions and extended as new concepts emerged, with the relevant extracts collated against each code.

Searching for themes. Codes were grouped into candidate themes and the extracts associated with each code were gathered under the theme to which they related.

Reviewing themes. Candidate themes were checked against the coded extracts and against the full data set, and were merged, separated or discarded where the supporting data did not hold.

Defining and naming themes. Each theme was defined and named to capture the aspect of the data it represented, and the relationship between the themes was established.

Producing the report. Extracts were selected to illustrate each theme and the analysis was written up against the research questions.

The analysis was iterative, and reflexivity was applied throughout to limit the influence of researcher bias. It produced a set of themes common to the UK and Nigerian responses, which provided the basis for the comparison presented in the following section.

Trustworthiness

The study was designed against the four criteria set out by Lincoln and Guba (1985). Credibility was supported by triangulation of the interview data against published policy and technical sources. Transferability is a judgement for the reader, and the context in both countries has been described in sufficient detail to allow that judgement to be made; the findings are not presented as generalisable beyond the settings studied. Dependability was supported by documenting the research process so that it can be followed and repeated. Confirmability was supported by an auditable coding trail held in NVivo, which allows each theme to be traced back to the extracts from which it was derived.

Ethical considerations

All participants were provided with a consent form setting out the purpose of the study and gave informed consent before taking part. Participants were anonymised and are not identified in this paper. Recordings and transcripts were held in encrypted storage. Leading questions were avoided and the findings were cross-checked against documentary sources to limit researcher bias.

RESULTS

This section presents the findings obtained from participants in Nigeria and the United Kingdom on the adoption of smart building technologies for energy efficiency. The purpose is to establish which technologies are in use and what lessons Nigeria can draw from UK experience. Data were obtained through semi-structured interviews in both countries and analysed against the research objectives. The demographic characteristics of the participants were also examined and are presented below. The findings are structured using reflexive thematic analysis supported by NVivo, which allowed patterns, recurring themes and relevant insights to be identified systematically. Coding and grouping of comparable perspectives made it possible to identify not only the differences and similarities between the two countries but also the underlying challenges and opportunities associated with adopting smart building technologies.

The process began with cleaning of the transcripts and familiarisation with the data through repeated reading of the responses. The collated transcript document was imported into NVivo as a single source, and coding was carried out within it to identify patterns and recurring themes based on shared meaning. Related codes were collated and the connections between them explored to identify coherent clusters within the data set. Themes were reviewed, defined and named to capture the substance of the patterns identified. The nodes created for the barriers reported in Nigeria, and the number of coded references held against each, are given in Table 5. The reference count is the number of coded extracts, not the number of participants.

Table 5: NVivo coding of the barriers reported in Nigeria.

Node	Codes grouped under the node	Coded references
Regulatory and Policy Gaps	Absence of enforcement; unstable regulatory environment; outdated building codes	5
Cost and Financial Constraint	Capital cost; exchange rate exposure; cost of spares and maintenance	8
Lack of Government Support and Incentives	Absence of subsidy; weak implementation of policy	4
Poor Infrastructure and Technological Limitations	Power supply; connectivity; maintenance culture	6

Demographic information

This analysis provides an insight into the practitioners driving smart building technology adoption in the two countries studied. As shown in Table 6, engineers form the largest group in the United Kingdom and developers the largest group in Nigeria, which reflects their respective roles in implementing smart building systems and integrating energy saving technologies. The contribution of engineers is central to this study, since civil, structural and building services engineers are directly involved in the development of IoT-based solutions, smart grid connections and automated building controls. Developers, who finance most building projects, are slightly more strongly represented in Nigeria, with seven participants against six in the United Kingdom, which reflects the level of interest in real estate and in the incorporation of smart technology among Nigerian developers. Policymakers are more strongly represented in the United Kingdom, with five participants against four, which is consistent with the more developed regulatory framework there.

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Table 6: Demographic representation of respondents.

Category	United Kingdom	Nigeria	UK %	Nigeria %
Engineers	7	6	22.6	19.4
Policymakers	5	4	16.1	12.9
Developers	6	7	19.4	22.6
Architects	4	5	12.9	16.1
Technology providers	5	5	16.1	16.1
Researchers	4	4	12.9	12.9
Total	31	31	100.0	100.0

Technology providers form a further group, with five participants in the United Kingdom and five in Nigeria. This is consistent with an established technology sector in the United Kingdom and an expanding Nigerian market in which a growing number of companies are investing in smart solutions.

Architects contributed four participants in the United Kingdom and five in Nigeria. Architects have an important part in incorporating energy efficient materials, passive design measures and building energy management systems into projects, and access to resources and design tools differs between the two countries, with UK architects having wider access to modelling software and computer aided design and construction methods.

Researchers are evenly represented, with four participants from each country, which indicates that research institutions in both countries are engaged in the advancement of smart building technology.

Smart building technologies used in Nigeria and the UK for energy-efficient operations

The UK and Nigeria differ in their stages of economic and technological progress, however, both countries are exploring and implementing smart building technologies for energy efficiency in recent times. The respondents presented their perspective on the suitability of using smart building technology because it signifies that smart building technologies play a significant role in increasing energy efficiency, reducing wastage, and optimising the use of resources in modern buildings.

An NVivo word frequency query was run across the coded responses to establish which technologies were referred to most often in each country. The resulting word cloud is shown in Figure 5.

Figure 5: Predominant terms in the coded responses, generated by word frequency query in NVivo (Authors' own work).

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The following technologies emerged most frequently in both countries.

- Smart Lighting and Sensors
- Smart Meters
- IoT-Based Energy Monitoring
- Renewable Energy (Solar, Smart Grids)
- Automated HVAC Systems

IoT-enabled systems and smart grids are more frequently highlighted by the UK respondents, indicating a higher level of integration of these technologies in the UK. In contrast, Nigerian participants focused more on solar energy solutions, though often without strong integration with smart grids. However, both groups mentioned smart meters and automated lighting despite the differences, albeit with varying levels of adoption.

From the analysis, the smart building technologies used in both countries fall into three thematic categories, shown in Figure 6, which capture the primary technologies employed for energy efficiency, although the extent of adoption varies between the two countries.

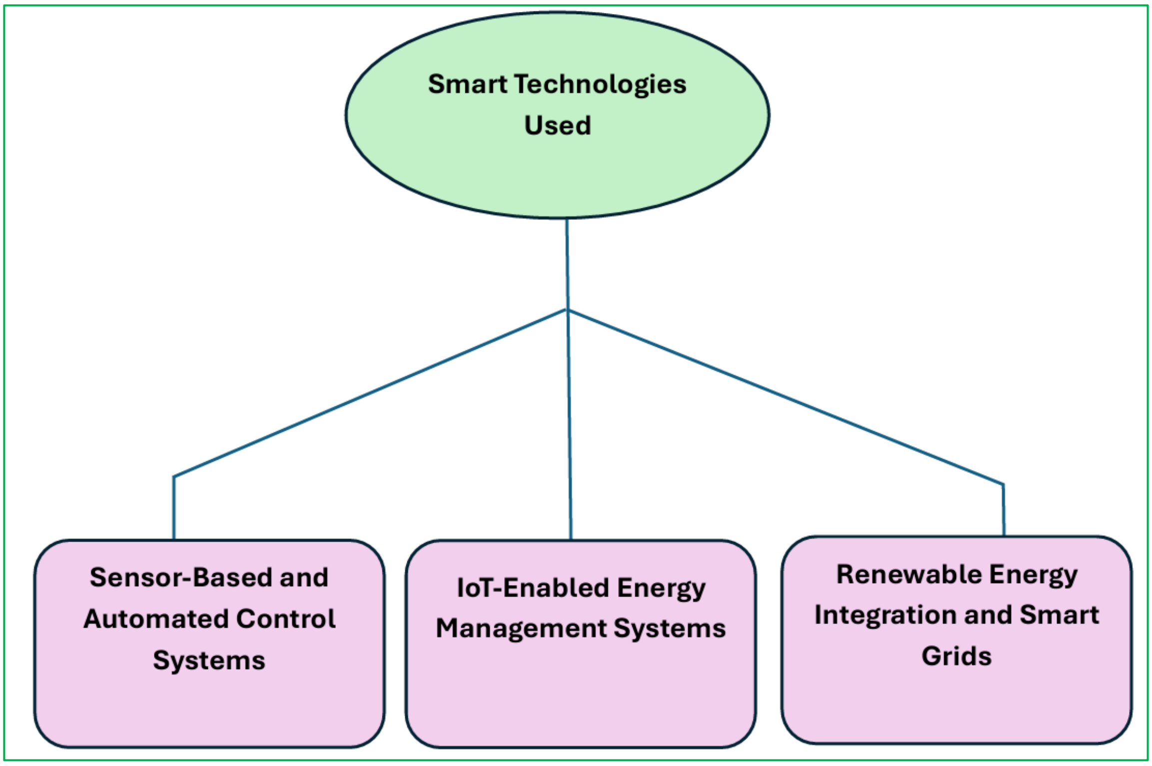

Figure 6: Categories of technology used (Authors' own work).

Sensor-based and automated control systems

The most widely adopted smart building technologies for energy efficiency are the sensor-based and automated control systems. These technologies which optimise energy consumption by responding to real-time conditions include motion sensors, occupancy-based lighting, automated HVAC systems, and smart thermostats. Most of the participants in the UK and Nigeria mentioned the use of automated lighting, motion sensors, and smart HVAC systems as part of energy-saving strategies in buildings. Prominent in the UK according to the data are the smart thermostats, occupancy sensors, and dynamic lighting control systems. While in Nigeria, some high-end buildings incorporate motion sensors and automated lighting, the level of adoption remains low.

IoT-enabled energy management systems

IoT-enabled energy management systems, including building energy management systems and smart metering, allow energy consumption to be monitored and controlled in real time. These systems use cloud computing and data analytics to optimise energy use. Integration of this kind was mentioned frequently by UK participants, several of whom emphasised the part played by grid connected renewable systems working alongside smart controls. One UK participant observed that "IoT-based energy monitoring is a game-changer. We use real-time analytics to adjust energy use dynamically". Such systems were reported far less often in Nigeria. One Nigerian participant noted that "smart meters are being introduced, but integration with broader energy management systems is still lacking". Some commercial buildings in Nigeria use smart meters, but IoT-based energy systems are largely absent.

Renewable energy integration and smart grids

One of the significant developments in the sector is the integration of solar power, battery storage and smart grids, which were mentioned frequently by participants. The responses indicated a marked difference between the two countries. In the United Kingdom, smart grids support the distribution of renewable energy, contributing to a stable supply and reduced dependence on fossil fuels. One UK participant noted that "with net-zero targets, smart grids and building-integrated solar are becoming standard in new developments". Although solar energy is increasingly used in Nigeria, it is mostly deployed as a stand-alone source rather than as part of an interconnected grid, which limits the potential for energy efficiency at scale.

Smart technology adoption frameworks in the UK and Nigeria

The adoption of smart technologies in the United Kingdom is shaped by four themes identified through the analysis: technological readiness, financial incentives, market demand and awareness, and policy and regulatory support. These themes arise from the references participants made to regulation, including the Building Regulations, the Minimum Energy Efficiency Standards and the Future Homes Standard, to financial support such as the former Green Homes Grant, to infrastructure such as IoT-based energy controls and monitoring systems, and to growing client interest in energy efficient buildings.

Adoption in the United Kingdom has been substantial, driven by regulation, financial support and market demand for sustainable construction. Regulation was a dominant theme in the responses, and it is worth being precise about what these instruments require. The Minimum Energy Efficiency Standards, made under the Energy Efficiency (Private Rented Property) (England and Wales) Regulations 2015, set a minimum Energy Performance Certificate rating for privately rented property, applying from April 2018 to new domestic lettings, from April 2020 to all domestic tenancies and from April 2023 to all non-domestic tenancies. They set a performance threshold and do not require smart technology. The Future Homes Standard is a forthcoming uplift to the Building Regulations rather than a measure in force. Participants nevertheless experienced these instruments as a driver, one UK participant observing that "The MEES regulation has made smart technology adoption a necessity rather than an option. Developers are now forced to rethink building designs to integrate energy-efficient solutions". Financial support was a further enabler, one UK participant stating that "Financial incentives have played a big role. Many property owners wouldn't have considered upgrading to smart energy systems if there weren't government-backed grants to offset costs". The former Green Homes Grant was the scheme most often mentioned, although its scope should be noted: eligible measures were insulation, low carbon heat, draught proofing, glazing and door replacement, hot water tank insulation and heating controls, and it did not fund IoT controls, analytics or grid connection. The scheme closed at the end of March 2021, six months after opening.

Technological readiness of the construction sector emerged as a further driver in the United Kingdom, supported by high speed connectivity, mature automation systems and established energy management tools. Participants referred repeatedly to the Bloomberg European Headquarters in London and to The Edge in Amsterdam as examples of buildings in which smart systems have reduced energy consumption. One UK participant reported that "with smart meters, automated lighting, and predictive energy monitoring, we've significantly reduced operational costs while enhancing occupant comfort". As sustainability has become a consideration for owners and occupiers, smart technology has also become an expectation placed on developers, which informed the theme of public awareness and market demand. One UK participant observed that "People are more conscious of energy efficiency than ever before. Clients specifically ask for smart energy systems because they know it saves them money in the long run".

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The position in Nigeria is different, although it would not be accurate to describe it as an absence of policy. A number of instruments are in place. The National Renewable Energy and Energy Efficiency Policy was approved in 2015, followed by the National Energy Efficiency Action Plan 2016 to 2030. The Building Energy Efficiency Guideline was issued in 2016 and the Building Energy Efficiency Code in 2017, both developed by the Federal Ministry of Power, Works and Housing with GIZ under the Nigerian Energy Support Programme. The Climate Change Act 2021, the Energy Transition Plan of 2022 and the Electricity Act 2023 followed. The difficulty is not that these instruments do not exist but that they are largely voluntary and are not enforced. The National Building Code of 2006 has still not been adopted into law in most states, and since building control is administered at state level a federal code has effect only where a state adopts it. The practical result is much the same as an absence of regulation: there is no regulatory pressure on the design of individual buildings, traditional energy infrastructure predominates, and energy use and cost remain higher than they need to be. Participants described "minimal or no government action in the adoption of sustainability schemes", which is better understood as an absence of enforcement than an absence of policy.

Unlike in the United Kingdom, where grants and tax benefits enable easier access to smart technologies, there is no systematic system of financial support in Nigeria aimed at encouraging adoption. Property developers and homeowner organisations therefore have no choice but to bear the total cost, which often turns out to be exorbitantly high considering the economic landscape of the country. The expensive nature of importation of the parts of the smart technology, coupled with exchange rate fluctuations, presents a challenge to investors wishing to invest in energy efficient technologies.

Infrastructure also constrains adoption in Nigeria. Participants referred to "Inadequate power supply", "outdated building codes" and "poor maintenance culture" as obstacles to the incorporation of IoT-based energy management systems and smart grids. Resistance from stakeholders accustomed to traditional building practice is a further factor slowing adoption. Table 7 provides a comparative summary of the adoption frameworks in the two countries.

Table 7: Comparative summary of the adoption frameworks for smart building technologies in the UK and Nigeria.

Aspect	United Kingdom (UK)	Nigeria
Policies Driving Adoption	Building Regulations Approved Document L 2021; Energy Performance of Buildings (England and Wales) Regulations 2012; Minimum Energy Efficiency Standards; Future Homes Standard (forthcoming); Net Zero Strategy	NREEEP 2015; National Energy Efficiency Action Plan 2016 to 2030; Building Energy Efficiency Guideline 2016; Building Energy Efficiency Code 2017; Climate Change Act 2021; Electricity Act 2023. Largely voluntary and not enforced through building control
Incentives	Energy Company Obligation; Boiler Upgrade Scheme; zero rate of VAT on energy saving materials since April 2022; Public Sector Decarbonisation Scheme	No structured incentive directed at smart building measures
Challenges	Capital cost in the private rented and small commercial sectors; cybersecurity and data protection obligations; competence in commissioning and maintenance	Funding, infrastructure and government support
Government Role	Regulation applied at building control, supported by supplier obligation through the Smart Metering Implementation Programme	Policy issued at federal level but not enforced; building control administered at state level

Challenges limiting smart technology in Nigeria

Various challenges were identified despite increasing awareness of smart building technologies in Nigeria. The analysis shows that adoption remains limited by financial, infrastructural, regulatory and governmental factors. The thematic analysis groups these barriers into four themes, shown in Figure 7.

Figure 7: Smart technology limiting challenges in Nigeria (Authors' own work).

Regulatory and policy gaps

Participants described weak enforcement of regulation as a major setback, one Nigerian participant stating that "Regulation and government policies are a major barrier; we don't have proper enforcement to encourage developers to implement smart systems". This is consistent with the position set out above: the instruments exist but do not bite on individual projects. Some participants also considered that "the regulatory environment is unstable, making it difficult for developers to invest in long-term smart solutions", which suggests that the policies in place do not provide the long term certainty developers need. It is the absence of mandatory efficiency standards at the point of building control, rather than the absence of policy at federal level, that contributes to the slow uptake of smart building technologies.

Cost and financial constraints

The acquisition and implementation of smart technology carries a high cost in Nigeria. Several participants acknowledged the benefits but considered the technology costly and in most cases financially out of reach. One Nigerian participant stated that "The major barriers will be the funding as they are expensive to acquire and install". Economic instability and the need to import equipment drive costs higher still, and another participant observed that the "cost of materials, which is usually in either dollars or pounds, makes it difficult for developers to afford". Given exchange rate movement and inflation, affordability remains a major obstacle to widespread adoption. A further participant noted that "Even when smart technologies are installed, maintaining them is another challenge because parts are expensive and not readily available locally", which indicates that cost affects maintenance and long term operation as well as initial investment.

Lack of government support and incentives

Participants generally considered government effort to be weak, one Nigerian participant describing it as "very, very poor, the government doesn't do much to encourage smart buildings or energy-efficient technologies". Several participants echoed this view, indicating that government involvement in promoting smart building technologies is seen as ineffective. One linked this to institutional weakness, stating that "the government's role is low; corruption is the main cause. Policies that could help adoption are not properly implemented". The responses point to the importance of subsidy, financial incentive and mandatory efficiency requirements, without which there is little commercial motivation for developers to invest.

Poor infrastructure and technological limitations

Inconsistent connectivity and unstable power supply present a major challenge, since the effectiveness of smart building technologies depends on both. Participants pointed to the lack of supporting infrastructure as a limit on the feasibility of smart solutions. One Nigerian participant asked "When you say smart, it simply means unique lifestyle, but how do you implement that when we barely have a steady power supply?". Beyond electricity, internet availability is a further concern, since remote monitoring and real-time data transmission are difficult to achieve in parts of the country. Participants also raised the question of maintenance culture, one stating that "maintenance culture is poor, and most clients believe they don't need these technologies because they see them

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as unnecessary luxuries rather than necessities”. These weaknesses make it difficult for smart buildings to operate effectively and deter both developers and users.

Lessons from the UK

The United Kingdom provides a model for adoption built on regulation that applies at the point of building control, principally the Building Regulations Approved Document L 2021, supported by the Minimum Energy Efficiency Standards for privately rented property and, in prospect, the Future Homes Standard. These instruments set performance requirements that make monitoring and control the practical route to compliance in commercial buildings, rather than mandating smart technology directly. Financial support through the Energy Company Obligation, the Boiler Upgrade Scheme and the zero rate of value added tax on energy saving materials has reduced the cost of measures for owners, and the Smart Metering Implementation Programme demonstrates what an obligation placed on suppliers can achieve at national scale. Public awareness campaigns and professional training have raised acceptance of the technology, and reliable electricity supply and widespread connectivity allow automation, IoT equipment and energy management systems to operate as intended. The key lessons are summarised in Table 8.

Table 8: Summary of key lessons from the UK.

Key Lesson	Explanation
Regulation applied at building control	Approved Document L 2021 sets fabric and building services performance requirements and, for larger buildings, sub-metering and automatic monitoring, which makes control and monitoring the practical route to compliance. MEES sets a minimum EPC rating for privately rented property.
Financial Incentives	The Energy Company Obligation, the Boiler Upgrade Scheme and the zero rate of VAT on energy saving materials reduce the cost of measures for owners and occupiers.
Public Awareness	Media campaigns and professional training have increased awareness and acceptance of smart buildings.
Infrastructure Support	Reliable electricity supply and robust telecommunications allow smart building technologies to operate as designed.
Supplier obligation at national scale	The Smart Metering Implementation Programme delivered metering through a licence obligation on energy suppliers rather than through voluntary uptake by building owners.

Nigeria, by contrast, faces policy that is not enforced, financial constraint, limited public awareness, unreliable infrastructure and weak institutional support. Addressing these will require the adoption of existing codes into state building control, financial incentives, public education, investment in infrastructure and cooperation between the bodies concerned.

DISCUSSION

The integration of Smart Building Technology (SBT) in buildings is becoming a necessity for enhancing energy efficiency and sustainability. There are various types and categories of SBT used around the world. In addressing RO1, this study identified three themes that classify these technologies prevalent in the UK and Nigeria. These include Sensor-Based and Automated Control Systems, IoT-Enabled Energy Management Systems, and Renewable Energy Integration and Smart Grids. Smart Lighting and Sensors and Automated HVAC Systems are integral components of sensor-based and automated control systems. These technologies utilise sensors to monitor environmental conditions and occupancy, enabling automated adjustments to lighting and HVAC systems. The IoT-enabled Energy Management Systems are smart meters and IoT-based energy monitors which facilitate real-time monitoring and management of energy consumption, allowing for data-driven decisions to optimise energy use. Additionally, the integration of renewable sources such as solar power, together with the development of smart grids is now a common feature of sustainable energy systems. These types of SBT identified in this study were in line with the findings of Hamma-Adama (2020), Nwankwo et al. (2023), and

Mohanty et al. (2016). While these technologies are identified and supported by global and local literature in the context of this study, the level of adoption differs largely due to the framework in place in both the UK and Nigeria.

The framework in place in a country has a significant influence on the level of adoption, and this study demonstrates that in comparing the two countries. Adoption in the United Kingdom is more advanced, which addresses the second research objective. The United Kingdom has been proactive in issuing policy and, more importantly, in making it bite at the point of building control through the Building Regulations, supported by the Minimum Energy Efficiency Standards, the forthcoming Future Homes Standard and the Net Zero Strategy. None of these instruments makes smart technology mandatory in itself; their effect is to set performance requirements that make monitoring and automated control the practical means of compliance. Building information modelling, sometimes cited alongside these instruments, is an information management process under the BS EN ISO 19650 series and relates to digital delivery rather than to operational energy performance, and it is treated separately here. This approach is consistent with Bamgbose et al. (2024), who emphasise the part played by government mandates in driving technology adoption in construction and who also identify financial incentives as a facilitator, which aligns with the findings of this study in both countries. Nigeria's position is characterised by emerging frameworks, growing awareness among stakeholders and a slow rate of adoption attributable to cost, infrastructure and the gap between policy and enforcement. Ejidike (2022) identifies these barriers as a significant impediment to the adoption of the smart building concept in Nigeria, and Hamma-Adama (2020) addresses the related question of building information modelling adoption in the country.

The study identified four primary barriers in Nigeria, which addresses the third research objective: the gap between policy and enforcement, cost and financial constraint, limited government support and incentives, and weak infrastructure and technological capability. The most significant deterrent for organisations and individuals is the initial cost of implementation. Insufficient government support and the absence of incentives compound this, and participants were reluctant to commit to systems that carry neither a regulatory requirement nor financial assistance. Financial constraint and the absence of government support are identified in the literature as common barriers to adoption in developing countries (Ejidike and Mewomo, 2022). The regulatory and infrastructural barriers identified here are consistent with the financial, regulatory, infrastructural and technological groupings reported by Affonso et al. (2024), who identified 23 barriers in their review of the literature and narrowed these to the eight considered most significant by practitioners. The well developed energy and digital infrastructure of the United Kingdom provides a stable foundation for IoT-driven smart grids and building energy management systems. Nigeria faces unreliable electricity supply and inadequate broadband, and the instability of the national grid obliges many owners to rely on standby diesel generation, which reduces the effectiveness of automated energy management. Limited high speed connectivity also constrains cloud based systems that depend on real-time data exchange.

Interpretation through the theoretical framework

The findings can be read against the two models set out earlier. In terms of the Diffusion of Innovations Theory, relative advantage is clear in both countries, since the technologies reduce energy cost. Compatibility is where the two diverge. In the United Kingdom the technologies fit an existing regulatory and infrastructural context: the Building Regulations require metering and monitoring in larger buildings, the electricity supply is reliable and connectivity is widely available. In Nigeria the same technologies sit awkwardly against an unreliable supply, standby generation and building control that does not require them. Complexity is raised by the skills gap reported by participants, while limited trialability and low observability follow directly from the small number of reference installations, which leaves prospective adopters with little opportunity to see the benefit demonstrated before committing capital.

In terms of the Technology Acceptance Model, perceived usefulness is not in question in either country, since participants in both recognised the operational benefit. Perceived ease of use is the binding constraint in Nigeria, where the difficulty of installing, commissioning and maintaining these systems, and of obtaining spare parts, was raised repeatedly. This suggests that measures aimed only at capital cost will not by themselves change the rate of adoption. Support for competence, through training, commissioning standards and access to spares,

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addresses perceived ease of use, while regulation and fiscal measures address compatibility and relative advantage. The recommendations that follow are framed accordingly. Figure 8 summarises this mapping.

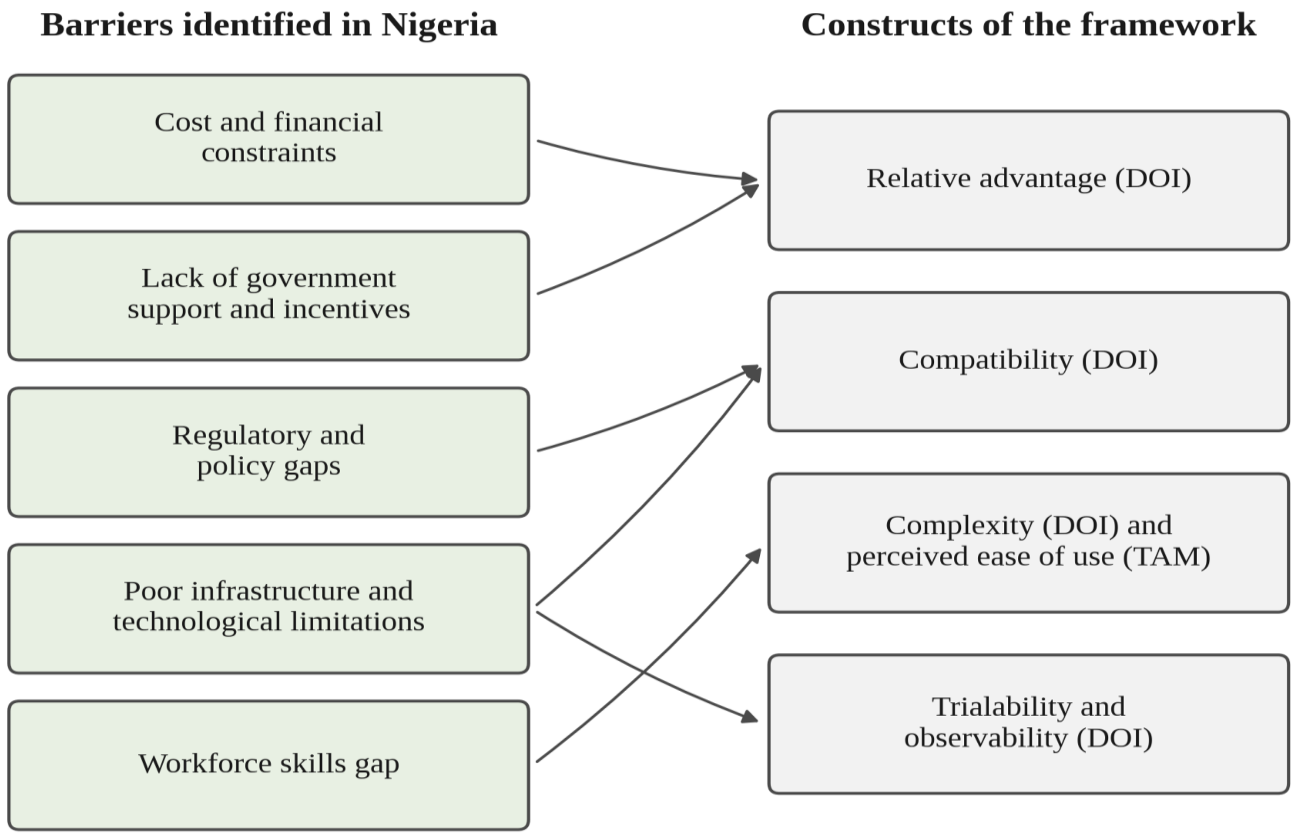

Figure 8: Mapping of the Nigerian adoption barriers to the constructs of the theoretical framework (Authors' own work).

CONCLUSION AND RECOMMENDATIONS

Conclusion

This research was conducted to assess the emerging smart building technologies for energy-efficient operation in the Nigerian building sector, drawing on insight from the UK's building sector to offer solutions and recommendations for Nigeria. From the outset, the research was driven by a critical question: How can Nigeria leverage smart building technologies to improve energy efficiency, and what lessons can be drawn from the UK to accelerate adoption? The specific objectives guiding this question involve identifying the type of smart building technologies used in Nigeria and the UK; analysing their adoption frameworks; evaluating challenges limiting the adoption in Nigeria, and finally, highlighting the lessons learnt from the UK and providing recommendations. These objectives were met through reflexive thematic analysis of interview data obtained from professionals in both countries. The research findings provide a comprehensive understanding of the different levels of adoption, the factors influencing the diffusion of smart building technologies and the broader implications for energy efficiency policies.

The study concludes that smart building technology is more advanced in the United Kingdom than in Nigeria. The higher rate of adoption in the United Kingdom results from regulation that applies at the point of building control, financial support, public awareness and reliable infrastructure. Nigeria remains at an early stage of adoption, constrained by cost, by infrastructure and by the gap between the policy that has been issued and the enforcement of it through building control. The case for adopting smart building technology in the Nigerian construction industry is considerable, and the direction of travel internationally makes it increasingly difficult to avoid.

Recommendations

The findings, and the barriers identified, inform the following recommendations. They are drawn from UK experience and are directed at the bodies able to act on them.

Improve financial incentives

Cost is one of the principal barriers to adoption in Nigeria, and three measures would address it. First, the Federal Ministry of Finance should extend the existing concessions on renewable energy equipment to metering, controls and building energy management equipment, against a defined list of tariff headings, so that the relief is administrable at the point of import. Second, the Standards Organisation of Nigeria should set product standards for imported meters and controls, so that duty relief does not simply admit equipment that cannot be supported or maintained. Third, the Central Bank of Nigeria should add smart building measures to an existing intervention fund window rather than establish a new facility, which would allow lending at concessionary rates without new institutional machinery. Encouraging public-private partnership in the local assembly of components would reduce exposure to exchange rate movement over the longer term.

Establish a robust policy framework

The regulatory recommendation is not that Nigeria should create new energy efficiency regulation but that it should give effect to what already exists. The Building Energy Efficiency Code of 2017 should be adopted as a mandatory schedule to the National Building Code, and the Federal Ministry of Housing and Urban Development should work with state governments to secure its adoption into state building control, since building control is administered at state level and a federal code has effect only where a state adopts it. A phased approach is more likely to succeed than a general mandate. Mandatory sub-metering and automatic monitoring on new commercial buildings above a stated floor area would be the sensible first step, since it is inexpensive, straightforward to verify at completion and produces the consumption data on which any later requirement must be based. Requirements for automated lighting control, efficient heating, ventilation and air conditioning, and building energy management systems could follow once the metering base is established. The Nigerian Electricity Regulatory Commission should also require smart metering on new connections above a stated capacity, following the UK precedent of placing the obligation on the supplier rather than on the building owner. The metering element of this recommendation can build on machinery that already exists, since the Meter Asset Provider Regulations 2018 and the National Mass Metering Programme provide both the commercial route and the financing precedent for deployment at scale (NERC, 2018; Central Bank of Nigeria, 2020).

Improve infrastructure to support SBT implementation

Weak infrastructure remains a major constraint. Investment in generation and network capacity is needed to provide the stable supply that automated systems require, and expansion of broadband coverage is needed to support remote monitoring and analytics, with progress against the 70 per cent penetration target in the National Broadband Plan 2020 to 2025 directly relevant to the feasibility of cloud based building systems. Establishing technology innovation hubs would also encourage local development of cost effective solutions suited to Nigerian operating conditions, including systems designed to work with intermittent supply and standby generation.

Establish training and raise public awareness

Awareness and competence should be addressed together. Government and industry bodies should support awareness campaigns aimed at owners, developers and occupiers, and smart building content should be integrated into engineering and construction curricula and into vocational training, so that practitioners are equipped to specify, install, commission and maintain these systems. The shortage of competence to maintain installed systems was raised repeatedly by participants and is as significant a barrier as capital cost. Collaboration with UK institutions and professional bodies would provide a route to training and to the transfer of practice.

Limitations of the study

The study presents a comparative analysis of smart building technology in the United Kingdom and Nigeria, and several limitations should be noted. Documentation of smart technology is more extensive in the United Kingdom than in Nigeria, which affects the depth of the comparison. The principal data source was interviews with practitioners, so the findings reflect the experience and perceptions of those interviewed. Researcher bias is a further consideration in thematic analysis, and reflexivity was applied throughout to limit it. Differences in economic conditions, infrastructure and regulatory environment between the two countries also constrain direct comparison. The findings are not presented as generalisable, and their transferability to other settings is a judgement for the reader.

Future research

Future research should undertake comparative studies between the UK and Nigeria to examine how cultural, economic, regulatory, and infrastructural factors influence the adoption and implementation of smart building technologies. Such studies could identify transferable best practices while highlighting the need for context-specific strategies to support the effective integration of smart building technologies across diverse socio-economic environments. Furthermore, future research should consider employing mixed-methods approaches that combine quantitative and qualitative research methods to capture both objective and subjective perspectives. This would provide a more comprehensive and balanced comparative analysis of the factors influencing smart building technology adoption in the two countries. A quantitative extension of this work could apply the unified theory of acceptance and use of technology, which consolidates the constructs of the models used here into a form designed for survey measurement (Venkatesh et al., 2003). Post-occupancy evaluation of completed smart buildings in both countries, using metered data of the kind described in CIBSE TM39 and TM54, would also allow reported savings to be tested against performance in use.

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APPENDIX A: INTERVIEW QUESTIONS

The following questions were used to gather insight from practitioners and stakeholders in Nigeria and the United Kingdom against the objectives of the study.

General questions for stakeholders in both countries

- Can you describe your experience with smart building technologies in your industry?
- What types of smart technologies have you implemented or worked with in your projects?
- What do you believe are the primary benefits of using smart building technologies for energy efficiency?

Questions for Nigerian stakeholders

- What is the current level of awareness about smart building technologies among industry professionals in Nigeria?
- What are the main barriers to adopting smart building technologies in Nigeria?
- How do financial constraints affect the adoption of smart building technologies in Nigeria?
- What part does infrastructure, or the lack of it, play in the adoption of these technologies in Nigeria?
- Are there any current initiatives or projects focused on introducing smart building technologies in Nigeria?
- How do you regard the government's role in promoting energy-efficient building technologies in Nigeria?
- What do you envisage as the future of smart building technologies in Nigeria?
- What recommendations would you give to policymakers to accelerate the adoption of smart building technologies for energy efficiency?

Questions for UK stakeholders

- What policies or regulations have been most effective in driving the adoption of smart building technologies in the United Kingdom?
- What incentives have been provided to encourage the adoption of energy-efficient technologies in the United Kingdom?
- Can you give examples of successful smart building projects in the United Kingdom that have significantly improved energy efficiency?

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- How has public awareness and acceptance contributed to the success of smart building technology adoption in the United Kingdom?
- What challenges, if any, have you encountered during the implementation of these technologies in the United Kingdom?
- What do you envisage as the future of smart building technologies in the United Kingdom?
- What recommendations would you give to policymakers to accelerate the adoption of smart building technologies for energy efficiency?