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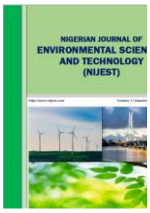

Influence of Smart Home Technology Implementation Pathways on Perceived Residential Building Performance in Nigeria

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ABSTRACT

The implementation pathway of smart home technologies may influence perceived residential building performance; however, empirical evidence comparing design-stage integration and post-occupancy retrofit remains limited, particularly in developing countries. This study investigated the influence of smart home technology implementation pathways on perceived residential building performance in owner-occupied residential buildings in Kaduna Metropolis, Nigeria. A quantitative post-occupancy evaluation approach was adopted using a structured questionnaire administered through purposive sampling to 68 owner-occupiers of residential buildings equipped with smart technologies. The response rate was 73.5%. Data were analyzed using IBM SPSS Statistics (Version 20). Descriptive statistics, Relative Importance Index (RII), and the Kruskal–Wallis test with effect size estimation (ε^2) were employed at a 5% significance level. The findings indicate that post-occupancy retrofit is the predominant implementation pathway, while smart appliances and security systems are the most widely adopted technologies. Although retrofit implementation was more prevalent than design-stage integration, no statistically significant differences were observed in perceived residential building performance across the implementation pathways ($p > 0.05$). Effect sizes were negligible to small ($\varepsilon^2 = 0.002$–0.026) indicating limited practical differences among the groups. Educational attainment was also not significantly associated with implementation pathway. Lack of technical knowledge, unreliable electricity supply, and high initial investment costs were identified as the principal barriers to adoption. Meanwhile, professional training, government incentives, and increased awareness of energy-efficient smart architecture emerged as the leading opportunities for wider implementation. The findings suggest that implementation pathway alone may not account for differences in perceived residential building performance, highlighting the importance of effective system integration, stakeholder collaboration, and enabling infrastructure in smart residential development. The study provides context-specific evidence to support lifecycle-oriented decision-making by architects, engineers, housing developers, and policymakers seeking to promote smart residential development in developing urban contexts.

Keywords: Post-occupancy; Energy efficiency; Satisfaction; Adoption; Occupants; Retrofit; Nigeria

1.0. Introduction

The rapid advancement of digital technologies has fundamentally transformed the planning, design, construction, and operation of residential buildings. Recent studies consistently recognise that the convergence of the Internet of Things (IoT), artificial intelligence (AI), cloud computing, wireless communication, digital twins, and intelligent building management systems has accelerated the transition from conventional buildings to interconnected smart built environments. These are capable of monitoring, analysing, and responding to occupants' needs (Taboada-Orozco et al., 2024; Walczyk & Ożadowicz, 2024; Mofidi & Akbari, 2020). Although these studies agree that digital integration underpins smart building functionality, they differ in their emphasis. Reviews of smart building architectures primarily characterise smart buildings as intelligent cyber-physical systems that integrate real-time data acquisition, communication, and automated decision-making, whereas engineering studies focus on how these technologies optimise operational efficiency, indoor environmental quality, and lifecycle building performance (Taboada-Orozco et al., 2024; Mofidi & Akbari, 2020). Collectively, these perspectives demonstrate that smart residential buildings are no longer viewed merely as technology-enabled structures but as integrated engineering systems whose performance depends on effective interaction among digital technologies, building components, and occupants.

As smart building technologies have evolved, research has increasingly shifted from defining smart buildings to investigating how these technologies should be implemented throughout the building lifecycle. Existing studies generally converge on two principal implementation strategies but differ in their preferred approach. One stream advocates integrating smart technologies during the design stage through Building Information Modelling (BIM), digital engineering, and coordinated design processes. The latter, arguing that early integration improves interoperability, facilitates lifecycle information management, and enhances overall system performance. In contrast, another stream focuses on post-occupancy smart retrofitting, demonstrating that intelligent technologies can significantly improve the operational performance of existing residential buildings. This can be done by enhancing energy efficiency, occupant comfort, and resource management without complete building replacement (Al Dakheel et al., 2020; Peiris et al., 2023, 2024; Walczyk & Ożadowicz, 2024). Although these approaches pursue the same objective of improving perceived residential building performance, they differ fundamentally in implementation timing, design flexibility, system compatibility, cost implications, and operational constraints. Yet, despite these differences, they have largely been investigated independently rather than comparatively.

Existing research consistently reports that smart building technologies can improve operational efficiency, energy management, indoor environmental quality, occupant comfort, and overall building sustainability. However, the reported performance gains vary considerably depending on building characteristics, technology integration, user interaction, and operational management (Mofidi & Akbari, 2020; Al Dakheel et al., 2020; Taboada-Orozco et al., 2024). Likewise, studies investigating technology adoption identify increasing awareness (Ghansah et al., 2021a), perceived usefulness, and expected performance improvements as key drivers of smart technology uptake (Olawumi et al. 2020b). Whereas financial constraints, interoperability challenges, inadequate technical expertise (Olawumi et al. 2020a), and institutional limitations remain persistent barriers, particularly within developing countries (Peiris et al., 2024; Ugochukwu et al., 2026). Collectively, these findings suggest that successful smart building performance depends not only on the availability of advanced technologies but also on the decisions governing how and when those technologies are incorporated into residential buildings throughout their lifecycle.

Despite the substantial progress made in smart building research, an important limitation remains. Existing studies have independently advanced understanding of smart building technologies, BIM-enabled design integration, energy-efficient building operation, technology adoption, and implementation barriers (Olawumi et al. 2020a). However, these research streams have evolved largely in parallel, with comparatively little empirical attention devoted to understanding how alternative implementation pathways influence perceived residential building performance.

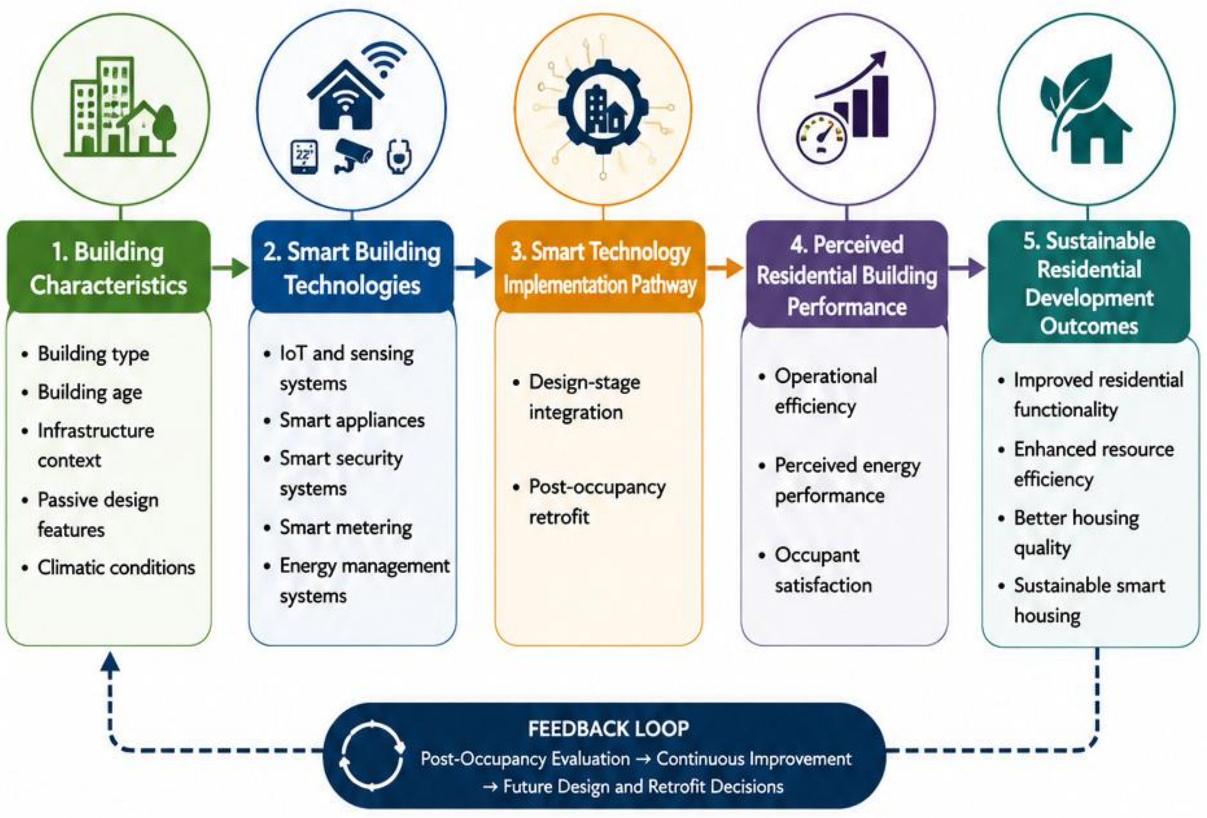
Consequently, it remains unclear whether integrating smart technologies during the design stage yields different post-occupancy performance outcomes from implementing comparable technologies through retrofit after building occupation. This limitation is particularly significant in developing urban contexts, where both newly constructed and existing owner-occupied residential buildings coexist.

Consequently, selecting an implementation pathway becomes an important engineering decision with long-term investment implications. However, empirical evidence directly comparing these alternative implementation pathways remains limited, leaving architects, engineers, developers, and policymakers with little guidance for selecting strategies that maximise lifecycle building performance under different project conditions. To address this knowledge gap, the present study compares design-stage integration and post-occupancy retrofit as alternative implementation pathways for smart residential technologies in owner-occupied housing within Kaduna Metropolis, Nigeria. Unlike previous studies that have examined technology characteristics, adoption behaviour, or retrofit outcomes in isolation, this study evaluates how implementation pathways relate to post-occupancy perceived residential building performance. By positioning implementation pathway as a critical engineering decision variable, the study contributes empirical evidence to support lifecycle-oriented planning, design, retrofit, and housing policy decisions in developing urban contexts.

Guided by the identified research gap, this study pursued the following objectives:

i) To identify the predominant implementation pathways through which smart building technologies are incorporated into owner-occupied residential buildings in Kaduna Metropolis, Nigeria.
ii) To compare the influence of design-stage integration and post-occupancy retrofit implementation on occupants' perceived residential building performance.
iii) To evaluate the relationship between smart technology implementation pathways and post-occupancy perceived residential building performance, thereby providing empirical evidence to support lifecycle-oriented planning, design, and retrofit decisions for smart residential buildings.

The theoretical relationships identified in the reviewed literature are synthesised in Figure 1, which illustrates how building characteristics, smart technologies, and implementation pathways collectively influence perceived residential building performance.



Source: Adapted from Froufe et al. (2020); Al Dakheel et al. (2020); Mofidi & Akbari (2020); Taboada-Orozco et al. (2024).

Figure 1: Theoretical Framework Underpinning Smart Residential Building Performance

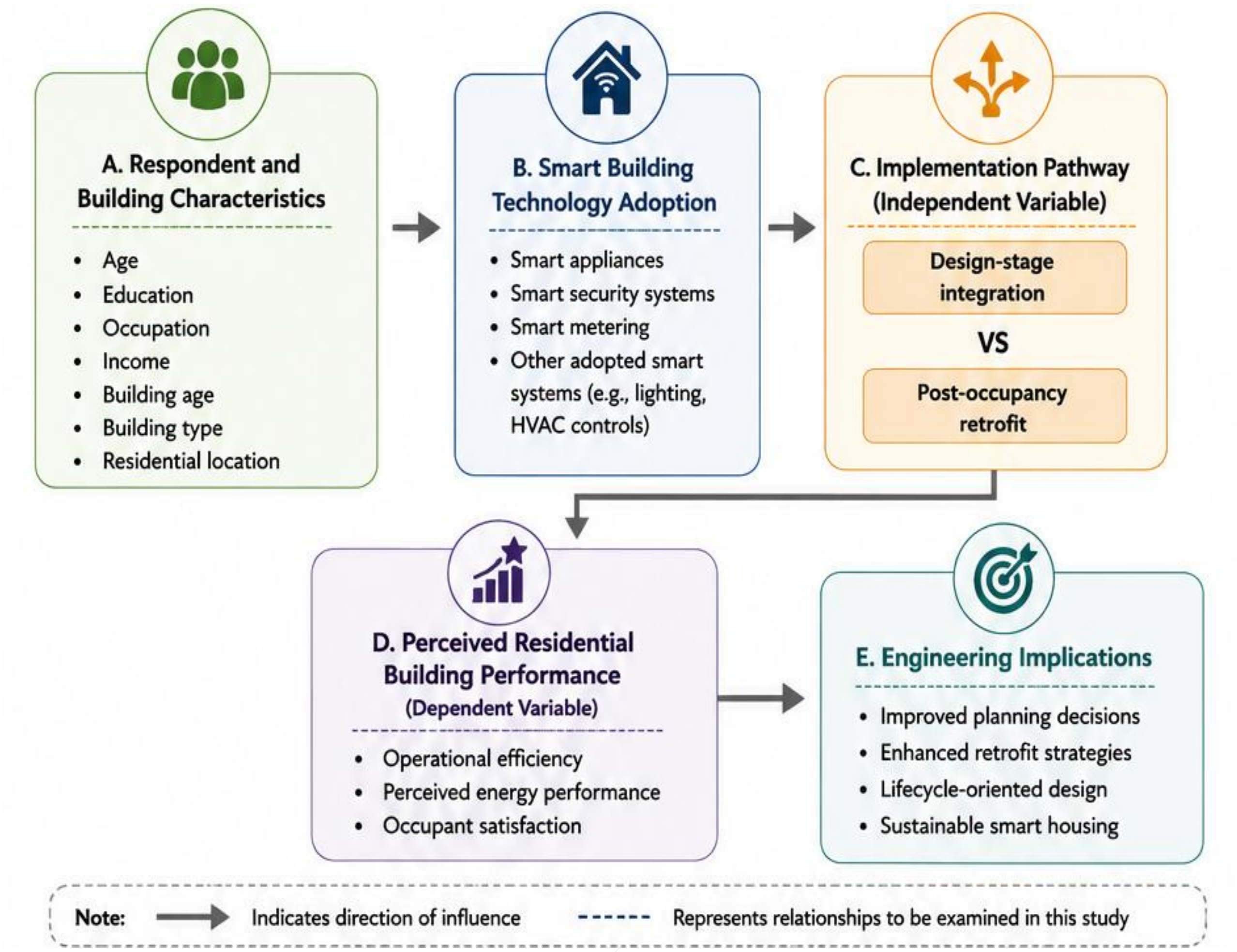


Figure 2: Conceptual Framework of the Study. **Source:** Authors Construct (2026)

Building upon the theoretical relationships presented in Figure 1, Figure 2 operationalizes the variables investigated in the present study by identifying implementation pathway as the principal independent variable influencing perceived residential building performance while accounting for respondent and building characteristics.

2.0 Methodology

2.1 Research Design

This study adopted a quantitative post-occupancy evaluation (POE) research design to investigate the implications of smart home technology implementation pathways on perceived residential building performance in Nigeria. Post-occupancy evaluation provides a systematic means of assessing the operational outcomes of building technologies under actual occupancy conditions and has been widely applied. They are found in studies examining building performance, environmental quality, and user experiences. The approach was considered suitable because the smart technologies under investigation had already been installed and were actively being utilized within owner-occupied residential buildings.

The study employed a comparative analytical framework based on the timing of smart technology implementation within the building lifecycle. Residential buildings were classified into three categories, namely design-stage integration, construction-stage integration, and post-occupancy retrofit implementation. This classification enabled an examination of whether the stage at which smart technologies are introduced into residential buildings influences subsequent performance outcomes. The research further adopted a cross-sectional survey approach in which data were collected from respondents at a single point in time.

2.2 Study Population and Sampling

The study population comprised owner-occupiers of residential buildings equipped with smart home technologies within selected urban areas of Nigeria. Owner-occupiers were considered appropriate respondents because they possess direct experience regarding the operation, functionality, and long-term performance of installed smart technologies. They are therefore capable of providing informed assessments of their effectiveness. Given the relatively limited penetration of smart residential technologies within the Nigerian housing sector and the absence of a comprehensive sampling frame of smart homes, a purposive sampling technique was adopted (Etikan et al. 2016).

The final sample comprised 68 owner-occupiers who satisfied the study's inclusion criteria and completed the questionnaire. Although relatively modest, this sample size was considered appropriate for the exploratory nature of the study, the specialised characteristics of the study population, and the use of purposive sampling. Recent methodological literature recognises that sample size in descriptive quantitative surveys should be justified in relation to the study objectives, characteristics of the target population, response rate, and intended analytical techniques rather than relying solely on universal sample size formulae (Lakens, 2022; Mursa et al., 2025).

Furthermore, the non-parametric statistical procedures employed in this study, particularly the Kruskal–Wallis test, are suitable for analysing relatively small independent groups where distributional assumptions cannot be guaranteed. Consequently, the sample was considered adequate for providing meaningful exploratory evidence on smart home technology implementation pathways while acknowledging that the findings should not be generalised beyond the study population.

2.3 Data Collection Instrument

Data were collected using a structured questionnaire developed to capture information relating to respondent characteristics, building characteristics and awareness of smart home technologies. Also to technology adoption patterns, energy-efficient architectural features, stakeholder participation, and barriers to adoption, future opportunities, and perceptions of smart architecture. Particular emphasis was placed on identifying the implementation pathway through which smart technologies were introduced into residential buildings.

Respondents were therefore required to indicate whether the technologies were incorporated during the design stage, during construction, or after occupancy through renovation and retrofit activities. This variable constituted the principal explanatory variable for the study. The questionnaire also collected information relating to perceived energy consumption reduction, electricity cost savings, thermal comfort performance, and occupant satisfaction with installed smart technologies. These variables were subsequently used to evaluate perceived residential building performance outcomes associated with the different implementation pathways.

2.4 Measurement of Variables

The principal independent variable was Smart Technology Implementation Pathway (STIP), defined as the stage within the building lifecycle at which smart technologies were introduced. The variable was operationalized using three categories: design-stage integration, construction-stage integration, and retrofit implementation after building occupancy.

Perceived residential building performance was evaluated using three operational performance indicators and one occupant-related outcome variable. Operational performance indicators comprised perceived energy consumption reduction, perceived electricity cost savings, and thermal comfort performance. Energy consumption reduction was assessed through respondents' evaluation of the extent to which smart and energy-efficient features were perceived to reduce household energy use.

Electricity cost savings were measured through respondents' assessment of changes in electricity expenditure following the adoption of smart technologies. Thermal comfort performance was evaluated through respondents' ratings of the effectiveness of their building design in providing acceptable indoor environmental conditions. In addition to these operational indicators, occupant satisfaction with installed smart technologies was assessed separately as an outcome variable. This distinction was necessary because satisfaction represents a user-centred assessment of technology performance and may not necessarily correspond directly with operational building performance indicators.

2.5 Validity and Reliability of the Instrument

The validity of the research instrument was established through expert review involving academics and professionals with expertise in architecture, building services engineering, construction management, and smart building technologies. Their recommendations were incorporated into the final questionnaire to improve content relevance, clarity, and coverage of the research objectives and comprehensiveness of the instrument.

A pilot study was conducted prior to the main survey to assess the comprehensibility and consistency of questionnaire items. Furthermore, the internal reliability of the multi-item constructs relating to stakeholder participation, barriers to adoption, and future opportunities was evaluated using Cronbach's Alpha coefficient. Consistent with established research practice, the instrument produced a Cronbach's Alpha coefficient of 0.72, indicating acceptable internal reliability for exploratory research and confirming the suitability of the questionnaire for the main survey.

2.6 Data Analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS). Descriptive statistics, including frequencies, percentages, means and standard deviations, were used to summarise respondent characteristics, building characteristics, smart home technology adoption patterns and implementation pathways.

The Kruskal–Wallis H test was employed to compare perceived residential building performance across the three smart technology implementation pathways (design stage, construction stage, and post-occupancy retrofit). The Kruskal–Wallis test is a non-parametric alternative to the one-way analysis of variance (ANOVA) and is appropriate for comparing three or more independent groups when the dependent variable is measured on an ordinal scale or when the assumptions of normality required for parametric tests cannot be satisfied. In this study, the test was used to examine whether significant differences existed in respondents' perceptions of energy consumption reduction, electricity consumption, thermal comfort, and overall satisfaction across the three implementation pathways.
Statistical significance was assessed at the 5% level ($\alpha = 0.05$). To complement the significance tests, the practical significance of the Kruskal–Wallis's test results was evaluated using epsilon squared (ε^2) effect sizes, calculated using equation 1.

$$\varepsilon^2 = H/(n-1) \quad (1)$$

where H is the Kruskal–Wallis test statistic and n is the total sample size. Effect sizes were interpreted as negligible (<0.01), small (0.01–0.08), moderate (0.08–0.26), and large(>0.26).

The Relative Importance Index (RII) was calculated using equation 2 (Osei-Kyei and Chan, 2015

$$RII = (\sum W)/(A \times N) \quad (2)$$

Where: RII is the Relative Importance Index
∑W is the Sum of the eights assigned by all respondents to a particular factor
A refers to the highest possible weight on the Likert scale
N connotes the Total number of respondents
It was used to prioritise the perceived barriers to and opportunities associated with smart home technology adoption.

The index was computed using the conventional RII procedure based on respondents' Likert-scale ratings, and enabled the factors to be ranked according to their relative importance with higher values, indicating greater perceived significance.

2.7 Ethical Considerations

Ethical principles were observed throughout the study. Participation was entirely voluntary, and respondents were informed of the purpose and objectives of the research before completing the questionnaire. All responses were treated confidentially and used exclusively for academic purposes. No personally identifiable information was collected, and participants retained the right to withdraw from the study at any stage of the data collection process without consequence.

3.0. Results and Discussions

This section presents and discusses the findings using descriptive statistics, Kruskal Wallis Tests and Effect Sizes.

3.1 Respondent and Building Characteristics

i) Demographic Characteristics of Respondents

Table 1: descriptive statistics on the demography and building information of the respondent

GENDER	Frequency	Valid percent
Male	38	55.9
female	30	44.1
AGE GROUP		
Below 31 years	2	2.9
31 to 40 years	12	17.6
41 to 50 years	14	20.6
51 to 60 years	21	30.9
Above 60 years	19	27.9
EDUCATIONAL QUALIFICATION		
Primary	1	1.5
Secondary	4	5.9
OND/NCE	6	8.8
HND/BSc	15	22.1
MSc	30	44.1
PhD	12	17.6
OCCUPATION		
Civil servant	21	30.9
Public servant	1	1.5
Retired	15	22.1
Private sector	31	45.6
TYPE OF RESIDENTIAL BUILDING		
Duplex	20	29.4
Storey Building	7	10.3
Bungalow	36	52.9
Four Bedroom Flat	1	1.5
Three Bedroom Flat	1	1.5
Compound House	3	4.4
AGE OF BUILDING		
Less than 5 years	5	7.4
5 to 10 years	17	25.0
11 to 20 years	28	41.2
Above 20 years	18	26.5

The demographic and residential characteristics of respondents provide important context for interpreting the implementation pathways and perceived performance of smart home technologies (Table 1). The relatively balanced gender distribution suggests that smart home adoption increasingly reflects household priorities rather than gender differences, consistent with Wilson et al. (2017) and Ejidike et al. (2024).
Most respondents were mature homeowners, strengthening the credibility of post-occupancy evaluations because prolonged occupancy enables more informed assessment of residential building performance (Preiser & Vischer, 2005). Unlike findings from technologically advanced economies, where younger homeowners often lead smart technology adoption (Wilson et al., 2017), the present profile reflects local homeownership patterns.
The respondents were generally well educated and economically stable, characteristics associated with greater awareness, adoption capacity, and investment in smart building technologies (Ghansah et al., 2021a; Darko et al., 2018; Owusu-Manu et al., 2022). Their concentration in urban and peri-urban areas further reflects the infrastructure conditions necessary to support smart home implementation (Ejidike & Mewomo, 2023).
The predominance of bungalow-type dwellings and relatively older housing stock provides a suitable context for evaluating retrofit-based smart technology implementation. Existing residential buildings offer considerable opportunities for integrating digital building systems (Peiris et al., 2023; Volk et al., 2014). Collectively, these characteristics provide a credible basis for interpreting the implementation pathways and perceived residential building performance reported in the subsequent analyses.

3.2 Awareness and Smart Home Technology Adoption Characteristics

Smart appliances were the most frequently installed technologies, followed by CCTV/security systems and smart electricity meters (Table 2). Their predominance suggests that homeowners prioritise technologies offering immediate functional benefits, such as convenience, safety and household control, before investing in more integrated smart building systems. This finding is consistent with Ugochukwu et al. (2026), Wilson et al. (2017), and Ejidike and Mewomo (2023), who similarly observed that visible user benefits encourage earlier adoption of smart residential technologies.

Table 2: Frequency and Percentage of the kind of smart appliances installed

The kind of smart appliances installed	Frequency	Valid Percent
Motion-sensor or automated lighting	5	7.4%
CCTV or smart security devices	9	13.2%
Smart electricity meter	7	10.3%
Smart appliances (AC, TV, fridge, etc.)	18	26.5%
None of the above	23	33.8%
others	6	8.8%
Total	56	100.0%
Missing	12	

Conversely, the substantial proportion of households without smart technologies indicates that smart residential development remains at an early stage within the Nigerian housing sector despite increasing awareness. This finding agrees with Ghansah et al. (2021a) and Ejidike et al. (2024), who attributed the gap between awareness and implementation to persistent technical, financial and institutional constraints.

3.3 Stage of Introduction of Smart Appliances

Table 3: Stage of Introduction of Smart Appliances Frequency

Time of Introduction	Frequency	Valid Percent
During design stage	9	18.0
During construction stage	10	20.0
After occupation (renovation/ retrofit)	31	62.0
Total	50	100.0
Missing Values	18	
Total	**68**	

Retrofit after building occupation was the predominant implementation pathway, substantially exceeding design-stage integration (Table 3). This finding indicates that owner-occupied households primarily incorporate smart technologies into existing buildings rather than embedding them during the design process, consistent with Peiris et al. (2023), Olawumi and Chan (2020b), and Volk et al. (2014), who identified retrofit as the principal strategy for improving the functionality and digital capability of ageing buildings. The predominance of retrofit also reflects the mature housing stock identified in Sub-section 3.1, where many dwellings predate the widespread adoption of smart technologies.

Although design-stage integration remains the preferred engineering approach for achieving system interoperability and lifecycle optimisation (Eastman et al., 2018; International Organization for Standardization [ISO], 2018), its limited uptake suggests that existing housing conditions, financial constraints, and implementation challenges continue to favour incremental retrofit adoption, consistent with Darko et al. (2018) and Ghansah et al. (2021b). These findings highlight the importance of engineering solutions that facilitate efficient smart technology integration into existing residential buildings while promoting greater consideration of smart systems in future housing developments.

3.4 Passive Design Features Available in Residential Buildings

Table 4: Energy Efficient Features found in home

Energy Efficient Features	Frequency	Valid Percent
Natural Cross ventilation	25	36.8%
Adequate day lighting	7	10.3%
	8	11.8%
Courtyard or open spaces		
None	4	5.9%
More than one	24	35.3%
Total	68	100.0%

Natural cross-ventilation was the most frequently reported passive design feature, followed closely by buildings incorporating multiple passive design strategies, while only a few respondents reported having no passive design features (Table 4). The predominance of these measures reflects the continued reliance on climate-responsive architecture in Northern Nigeria, where passive cooling strategies remain fundamental to improving occupant comfort and reducing energy demand. This finding agrees with Ejidike and Mewomo (2023) and Froufe et al. (2020), who emphasised that passive design provides the foundation upon which smart building technologies achieve optimal operational performance.

The widespread use of multiple passive design features further suggests that many homeowners have adopted integrated energy-efficient design approaches before or alongside smart technologies. Combining natural ventilation, daylighting and courtyard design with intelligent building systems can improve indoor environmental quality while reducing operational energy demand, consistent with Al Dakheel et al. (2020). Conversely, the small proportion of buildings lacking passive design features highlights opportunities to enhance residential building performance through climate-responsive architectural planning. As noted by Olawumi and Chan (2020b), the effectiveness of smart technologies depends not only on digital automation but also on their integration with well-designed building systems. These findings therefore reinforce the need to integrate passive and intelligent building systems throughout residential development.

3.5 Post-Occupancy Assessment of Perceived residential building performance

This section evaluates respondents' perceptions of residential building performance following smart home technology implementation, focusing on occupant satisfaction and perceived energy performance.

i) Occupants' Satisfaction with Smart Home Technologies

Table 5: Satisfaction with Smart Systems

Satisfaction Level	Frequency	Valid Percent
Very dissatisfied	1	1.8%
Dissatisfied	2	3.6%
Neutral	7	12.5%
Satisfied	37	66.1%
Very Satisfied	9	16.1%
Missing	12	100.0%
Total	68	

Most respondents expressed positive perceptions of smart home technologies, with over four-fifths reporting satisfaction or high satisfaction (Table 5). This suggests that homeowners generally perceive smart technologies to enhance convenience, safety and overall building functionality. The finding supports Wilson et al. (2017), who associated user satisfaction with the perceived usefulness and ease of operation of smart home technologies, and agrees with Preiser and Vischer (2005) and Ejidike and Mewomo (2023), who identified occupant satisfaction as a key indicator of post-occupancy building performance. These findings reinforce the importance of user-centred design and effective system integration in residential smart building projects.

ii) Perceived Energy and Cost Performance of Smart Home Technologies

Table 6 Respondents' perceived effect of smart home technologies on residential energy consumption

Energy Consumption	Frequency	Valid Percent
Not at all	13	21.7%
Slightly	6	10.0%
Moderately	20	33.3%
Significantly	15	25.0%
Very significantly	6	10.0%
Total	60	100.0%
Missing	8	

Table 7: Percentage and frequency of Energy Cost

Energy Cost	Frequency	Valid Percent
Increased	4	7.0%
Remained the same	14	24.6%
Slightly reduced	19	33.3%
Greatly reduced	20	35.1%
Total	57	100.0%
Missing	11	

Respondents generally perceived that smart home technologies improved both residential energy performance and electricity cost efficiency, although the magnitude of these benefits varied across households (Tables 6 and 7). Most respondents reported at least moderate reductions in energy consumption, while the majority also perceived lower household electricity costs, indicating that smart technologies contributed positively to operational performance. However, a notable proportion reported little or no improvement, suggesting that realised benefits depend on factors beyond technology adoption alone.

The variation in perceived energy and cost savings indicates that building performance is influenced by the type of technologies installed, user behaviour, system configuration and the quality of integration. This finding is consistent with Al Dakheel et al. (2020) and Froufe et al. (2020), who emphasised that improvements in smart building performance depend on the coordinated operation of interconnected building systems rather than isolated technologies.

Similarly, Wilson et al. (2017) demonstrated that occupants' interaction with smart technologies influences the extent to which operational benefits are realised. While Ejidike and Mewomo (2023) reported that intelligent monitoring and automation can improve energy efficiency and reduce operating costs when effectively integrated into residential buildings.
Overall, the findings indicate that smart home technologies can enhance both the operational and economic performance of residential buildings, although the extent of these benefits depends on effective system integration and user engagement.

iii) Thermal Comfort Performance

Most respondents reported improvements in indoor thermal conditions, indicating that intelligent building technologies contribute positively to indoor environmental quality (Table 8).

Table 8: Frequency and Percentage of effectiveness of building in providing thermal comfort

Level of Thermal Comfort	Frequency	Valid Percent
Very poor	2	2.9%
Poor	3	4.4 %
Fair	11	16.2 %
Good	36	52.9 %
Very Good	15	22.1 %
Can't tell	1	1.5 %
Total	68	100.0%

The findings suggest that smart technologies can complement passive design strategies by improving the monitoring and control of indoor conditions, thereby enhancing occupant comfort. This observation agrees with Al Dakheel et al. (2020) and Froufe et al. (2020), who reported that integrated smart building systems improve indoor environmental performance through continuous monitoring and automated control of building services.

The findings also reinforce the engineering principle that building performance should be evaluated using both energy efficiency and occupant comfort indicators. Collectively, the results demonstrate that smart home technologies contribute to improved perceived residential building performance through enhanced occupant satisfaction, perceived energy efficiency, reduced operating costs and better indoor environmental quality. These performance outcomes provide further justification for expanding the adoption of intelligent residential technologies within developing urban environments.

3.6 Stakeholder Influence on Smart Home Design and Technology Decisions

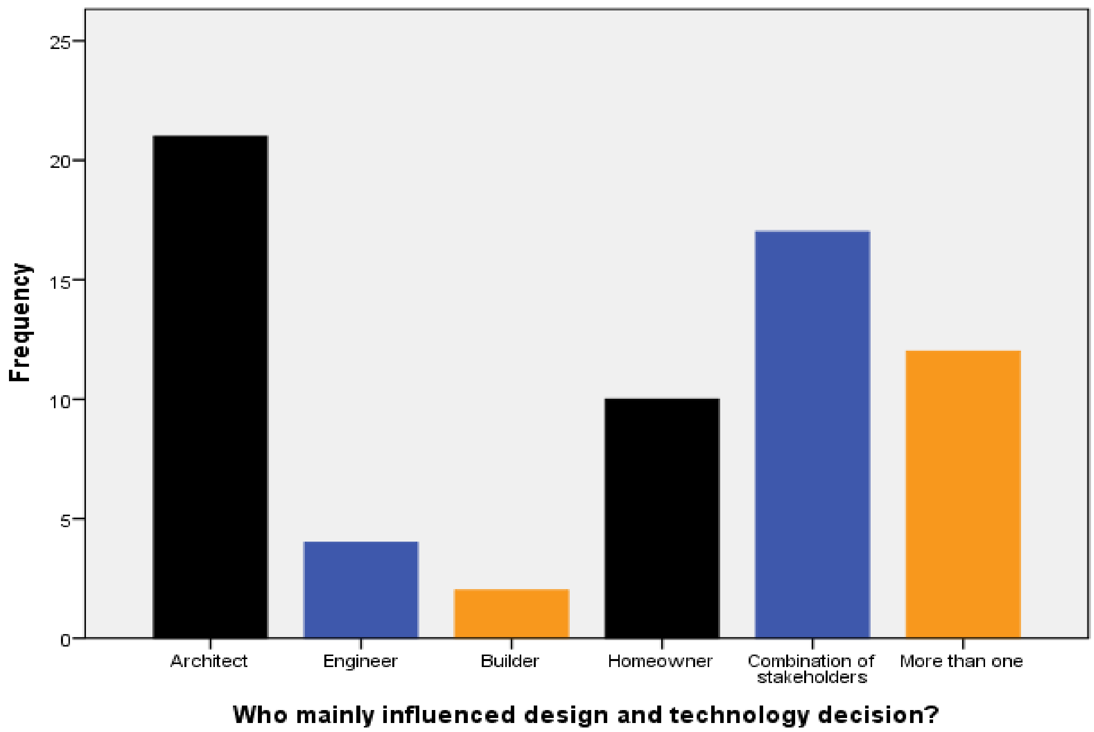


Figure 3: Highest influencer of design and technology decisions

Of the 68 respondents, 66 provided valid responses, while two (2.9%) did not respond (Figure 3). Architects emerged as the principal influencers of smart home design and technology decisions, followed by collaborative stakeholder participation, whereas engineers and builders played comparatively limited roles. This finding supports Eastman et al. (2018), ISO 19650-1 (2018), and Olawumi and Chan (2020b), who emphasised the importance of coordinated design and digital information management in smart building implementation. Likewise, the prominence of joint stakeholder participation supports Froufe et al. (2020), who argued that smart building performance depends on coordinated contributions throughout the building lifecycle. The comparatively limited influence of engineers and builders suggests that multidisciplinary collaboration in residential smart housing projects remains underdeveloped, highlighting opportunities to strengthen engineering involvement and improve long-term building performance.

3.7 Barriers to Smart Home Technology Adoption (Osei-Kyei & Chan, 2015).
Table 9: RII rank of the barriers to home technology adoption

Barrier	Mean	Standard Deviation	RII	Rank
High initial cost adoption	3.69	1.175	0.738	3
Lack of technical knowledge discourages use	3.99	1.029	0.798	1
Irregular power supply is a major challenge	3.97	1.022	0.794	2
Maintenance and repairs are difficult	3.37	1.118	0.674	5
Concerns about systems reliability and durability	3.50	1.191	0.700	4

Lack of technical knowledge emerged as the most significant implementation barrier, followed by irregular power supply and high initial adoption cost, while system reliability and maintenance concerns were comparatively less important (Table 9). These findings indicate that smart home adoption depends not only on technology availability but also on technical competence, reliable infrastructure and financial accessibility. This observation agrees with Ghansah et al. (2021b), Ejidike et al. (2024), Darko et al. (2018), Ejidike and Mewomo (2023), and Owusu-Manu et al. (2022), who similarly identified technical, infrastructural and financial constraints as major barriers to smart building implementation in developing countries. Collectively, the findings highlight the need to strengthen technical capacity, improve supporting infrastructure and enhance affordability to accelerate smart residential development.

3.8 Opportunities for Enhancing Smart Home Technology Adoption

Table 10: RII ranking of opportunities and future potential

Opportunities and future potential	Mean	Std. Dev.	RII	Rank
Smart architecture can improve energy efficiency	3.93	1.012	0.786	2
Smart homes are suitable for Northern Nigerian Climate	3.78	1.034	0.756	4
Government incentives would encourage adoption	3.88	1.100	0.776	3
Training of architects and builders will improve smart housing and delivery	4.07	0.997	0.814	1

Training architects and builders was identified as the most important opportunity for promoting smart home technologies, followed by improved energy efficiency, government incentives and climate suitability (Table 10). These findings emphasise the importance of professional capacity, integrated smart building design and supportive policies for accelerating adoption. This agrees with Ejidike et al. (2024), Olawumi and Chan (2020b), Al Dakheel et al. (2020), Froufe et al. (2020), Darko et al. (2018), and Owusu-Manu et al. (2022), who similarly identified technical competence, integrated building systems and policy support as key enablers of smart building implementation. Although climate suitability ranked lowest, respondents generally considered smart home technologies appropriate for Northern Nigeria, indicating that technical, institutional and financial factors remain the principal constraints to wider adoption.

3.9 Kruskal Wallis Test and Effect Size

Null hypothesis (H_0)
There is no statistically significant difference in the extent of energy consumption reduction, Electricity Consumption, Thermal Comfort and Occupant Satisfaction among residential buildings where smart home technologies were adopted during the design stage, construction stage, and after occupation (retrofit).
Alternative hypothesis (H_1)

There is a statistically significant difference in the extent of energy consumption reduction, Electricity Consumption, Thermal Comfort and Occupant Satisfaction among residential buildings where smart home technologies were adopted during the design stage, construction stage, and after occupation (retrofit).

The decision rule was to reject H0 if p-value ≤ 0.05

Table 11: Kruskal–Wallis Test Comparing Perceived residential building performance by Smart Technology Implementation Pathway

Test Variable	χ^2	df	p-value	ε^2	Effect Size	Decision
Energy consumption reduction	0.120	2	0.942	0.002	Negligible	Not Significant
Electricity Consumption	1.112	2	0.574	0.023	Small	Not Significant
Thermal comfort	0.522	2	0.770	0.011	Small	Not Significant
Overall satisfaction	1.260	2	0.533	0.026	Small	Not Significant

i) Kruskal–Wallis Test for Energy Cost Reduction

A Kruskal–Wallis H test was conducted to determine whether the stage at which smart home technologies were introduced (during the design stage, construction stage, or after occupation through retrofit) influenced the extent to which these technologies were perceived to reduced energy consumption (Table 11).
The mean ranks were 25.56 for the design-stage group, 26.17 for the construction-stage group, and 24.50 for the retrofit group. Although the construction-stage group recorded the highest mean rank, the differences among the three groups were minimal.

The Kruskal–Wallis test showed no statistically significant difference in perceived energy consumption reduction across the three implementation pathways, χ^2 (2) = 0.120, p = 0.942. The corresponding effect size was negligible (ε^2 = 0.002), indicating that the implementation pathway explained virtually none of the variation in perceived energy consumption reduction. This finding suggests that the stage at which smart home technologies were introduced did not significantly influence the perceived reduction in energy consumption among the residential buildings studied.

ii) Kruskal–Wallis Test for Electricity Consumption

A Kruskal–Wallis H test was performed to examine whether the implementation pathway of smart home technologies influenced changes in electricity consumption.
The mean ranks were 22.72 for the design-stage group, 21.94 for the construction-stage group, and 26.55 for the retrofit group. Although respondents whose smart technologies were installed after occupation (retrofit) recorded the highest mean rank, the observed differences were relatively small.

The test revealed no statistically significant difference in electricity consumption across the three implementation pathways ($\chi^2(2)$ = 1.112, p = 0.574). the effect size was small (ε^2 = 0.023), indicating a very limited practical influence of the implementation pathway. This suggests that the stage at which smart home technologies were introduced did not significantly affect changes in household electricity consumption.

iii) *Kruskal–Wallis Test for Thermal Comfort*

A Kruskal–Wallis H test was conducted to determine whether the implementation pathway of smart home technologies influenced the effectiveness of building design in providing thermal comfort.
The design-stage group recorded the highest mean rank (27.89), followed by the retrofit group (25.42) and the construction-stage group (23.60). However, the test showed no statistically significant difference among the three groups ($\chi^2(2)$ = 0.522, p = 0.770) and the effect size was small (ε^2 = 0.011), suggesting that implementation pathway had minimal practical importance. This implies that the implementation pathway did not significantly influence respondents' perceptions of thermal comfort.

iv) Kruskal–Wallis Test for Overall Satisfaction

A Kruskal–Wallis H test was performed to examine whether the implementation pathway influenced respondents' overall satisfaction with their installed smart systems.
The design-stage group recorded the highest mean rank (28.88), followed by the construction-stage group (25.65) and the retrofit group (23.79). The results showed no statistically significant difference among the three implementation pathways ($\chi^2(2)$ = 1.260, p = 0.533), with the effect size being small (ε^2 = 0.026), indicating that implementation pathway had only a limited practical influence on occupants' overall satisfaction. This finding suggests that respondents' overall satisfaction with installed smart systems did not differ significantly according to whether the technologies were introduced during the design stage, construction stage, or after occupation through retrofit.

Table 12: Summary of Hypothesis Testing

Performance Indicator	χ^2	p-value	Decision
Energy consumption reduction	0.120	0.942	Fail to reject H_0
Electricity Consumption	1.112	0.574	Fail to reject H_0
Thermal comfort	0.522	0.770	Fail to reject H_0
Overall satisfaction	1.260	0.533	Fail to reject H_0

The Kruskal–Wallis analyses indicate that there were no statistically significant differences in energy consumption reduction, electricity consumption, thermal comfort, or overall satisfaction based on whether smart home technologies were introduced during the design stage, construction stage, or after occupation through retrofit. Therefore, within this sample, the implementation pathway was not associated with differences in the measured aspects of perceived residential building performance.
Although statistically significant differences were not observed, the findings should not be interpreted as evidence that the implementation pathways are equivalent. The relatively small group sizes and exploratory nature of the study may have reduced statistical power to detect subtle differences.

3.10 Implications

i) Engineering Implications

The inferential analyses provide two important engineering insights. First, the absence of significant differences in perceived building performance across implementation pathways suggests that retrofit may represent a practical engineering strategy for integrating smart technologies into existing residential buildings. This refers particularly to developing countries where new smart housing developments remain limited (Peiris et al., 2023; Volk et al., 2014). Second, the lack of a significant association between educational attainment and implementation pathway indicates that infrastructure readiness, affordability, stakeholder collaboration and technical capacity are more influential than demographic characteristics in implementation decisions (Olawumi & Chan, 2020b; Owusu-Manu et al., 2022).

ii) Policy Implications

These findings reinforce the need for engineering policies that prioritise retrofit-ready building designs, interdisciplinary collaboration and professional capacity development to facilitate the sustainable integration of smart technologies into the existing residential building stock. They also support the growing emphasis on lifecycle performance, digital integration and adaptive building systems as key components of future residential development (Al Dakheel et al., 2020; Froufe et al., 2020; Taboada-Orozco et al., 2024).

4.0 Conclusion

This study investigated the influence of smart home technology implementation pathways on perceived residential building performance in owner-occupied residential buildings in Kaduna Metropolis, Nigeria. The findings showed that post-occupancy retrofit is the predominant implementation pathway, while smart appliances and security systems are the most commonly adopted technologies. Although respondents generally reported positive perceptions of energy savings, thermal comfort, electricity cost reduction, and overall satisfaction, the Kruskal–Wallis analyses indicated no statistically significant differences in these perceived outcomes across design-stage, construction-stage, and retrofit implementation pathways.

These findings suggest that perceived residential building performance depends more on effective system integration, infrastructure readiness, technical competence, and stakeholder collaboration than on the timing of technology implementation.

The study further identified inadequate technical knowledge, unreliable electricity supply, and high initial investment costs as the principal barriers to smart home adoption, whereas professional training, government incentives, and increased awareness emerged as key opportunities for wider implementation. By providing comparative evidence from a developing-country context, the study contributes to the limited literature on smart home implementation pathways and supports lifecycle-oriented planning, retrofit, and policy decisions.

However, the findings should be interpreted within the limitations of the cross-sectional design, purposive sampling, relatively small sample size, reliance on single-item perceived performance measures, and the absence of objective building performance data. Future studies should employ larger probability samples, longitudinal designs, validated multi-item measurement scales, and objective building performance indicators to further evaluate the long-term engineering performance of alternative smart home implementation pathways.

Based on the study findings, the following recommendations are proposed:

i) Develop standardized retrofit frameworks that promote system compatibility, interoperability and lifecycle performance for existing residential buildings.
ii) Strengthen professional training and multidisciplinary collaboration in smart building technologies to improve the technical capacity of architects, engineers and other construction professionals (Olawumi & Chan, 2020b).
iii) Introduce supportive policies, financial incentives and infrastructure improvements to reduce adoption barriers associated with high installation costs and unreliable electricity supply (Olawumi & Chan, 2020b).
iv) Promote both design-stage integration in new housing and retrofit solutions for existing residential buildings, reflecting the predominance of ageing housing stock in developing countries.
v) Incorporate post-occupancy evaluation into smart housing projects to monitor perceived building performance and support continuous system improvement.

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