The Success Factors of Building Energy Modelling Adoption for Sustainable Building Projects

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Abstract
It is critical to assess building energy modelling (BEM) usage for sustainable building projects and the potential impact of technology-guided occupant behaviour on building energy use. Considering its benefits, this study is aimed at determining the success factors of adopting BEM for sustainable building projects in the Nigerian construction industry. A post-positivist philosophical approach guided a quantitative research methodology using a questionnaire survey. The population comprised architects, builders, quantity surveyors, mechanical/electrical engineers, and facility managers within Lagos state. Using the random sampling technique, 379 questionnaires were distributed online and physically; 228 copies were retrieved, screened, and analysed using descriptive and inferential analysis, while Cronbach's Alpha tested reliability. The mean scores range from 3.85 to 4.0, indicating a generally high perception among respondents regarding the success factors of BEM usage. The most critical success factors are "Increasing the knowledge base of BEM applications", "Incorporation of BEM training and education into the curriculum of academic institutions", "Public awareness creation through workshops, seminars and conferences", and "Availability of an institutional framework for effective implementation of BEM". The Kruskal-Wallis H test outcome also revealed that the respondents' opinions were consistent for these variables since their p-values were more than 0.05; this gives the consensus standpoint of the respondents. The study recommends advocating for the integration of BEM education into academic curricula at all levels of education, from vocational training programs to university degrees, and investing in infrastructure improvements to address technological barriers such as unreliable internet connectivity and power outages.

Keywords
Building Energy Modelling, Critical Success Factors, Buildings, Sustainable Construction, Nigeria.

1. Introduction
Building energy modelling involves the use of computer simulation software to predict the energy performance of buildings. The software is used to simulate the building's energy consumption under various scenarios, such as different weather conditions, occupancy patterns, and HVAC systems. BEM has been widely used in developed countries for sustainable building projects, but its usage in Nigeria is still limited (Hong *et al.,* 2020). The assessment of building energy modelling usage for sustainable building projects in Lagos State is necessary to determine its potential benefits and challenges. Interoperability between Building Energy Modelling (BEM) and Building Energy Model is crucial for effective building energy modelling usage. BEM is a digital representation of a building's physical and functional characteristics. It provides a platform for information sharing and collaboration during the design, construction, and operation phases of a building project (Porsani *et al.,* 2021). The integration of BEM can enable designers to make informed decisions during the design phase, leading to the design of more sustainable building projects. Thus, the assessment of building energy modelling usage for sustainable building projects is critical. The use of deep learning frameworks for building energy consumption forecasting is a recent development in the field of building energy modelling. Deep learning frameworks are used to analyse large datasets and extract insights that can be used to forecast future energy consumption patterns (Somu *et al.,* 2021). This can enable building managers to make informed decisions about energy management and reduce energy waste. The

assessment of building energy modelling usage for sustainable building projects should consider the potential of deep learning frameworks for energy consumption forecasting.

Data acquisition is an essential aspect of building energy modelling. The accuracy of the data used in the simulation can significantly impact the accuracy of the results. Various data acquisition techniques can be used, such as on-site measurements, remote sensing, and historical data (Wang *et al.,* 2022). The assessment of building energy modelling usage for sustainable building projects in Lagos State should consider the different data acquisition techniques and their effectiveness. Technology-guided occupant behaviour is another aspect that can significantly impact building energy use. The use of sensors and smart devices can enable real-time monitoring of occupants' behaviour and adjust the building's HVAC system accordingly (Tang *et al.,* 2021). This can lead to reduced energy consumption and improved occupant comfort. It is important to consider the assessment of building energy modelling usage for sustainable building projects and the potential impact of technology-guided occupant behaviour on building energy use. BEM is a physics-based computational technique that simulates building energy use, considering factors such as building geometry, materials, HVAC systems, occupancy patterns, and local weather data (Clarke, 2001). Globally, BEM has proven effective in reducing building energy consumption. A study by the U.S. Department of Energy found that BEM can lead to energy savings of 20-30% in new constructions and 10-20% in retrofits (U.S. DOE, 2015). In the European Union, the Energy Performance of Buildings Directive (EPBD) mandates energy performance certificates based on BEM for all buildings (European Commission, 2010; Official Journal of the European Union). However, the adoption and effectiveness of BEM in developing countries, particularly in Africa, are less documented.

In Nigeria, the adoption of sustainable building practices is growing, but slowly (Isang & Ebiloma, 2023). The country introduced its first Building Energy Efficiency Code in 2017, which includes provisions for energy modelling (Federal Ministry of Power, Works & Housing, 2017; National Building Energy Efficiency Code). Lagos State, being at the forefront of development, has shown some initiative. For instance, the Lagos State Development Plan (2012-2025) emphasises sustainable urban development (Lagos State Government, 2013; Official Publication). However, the practical implementation of these policies, especially in leveraging tools like BEM, remains a challenge. This study is significant because the efficient use of energy plays a vital role in the sustainability of building projects. The implementation of sustainable building practices has been proven to reduce greenhouse gas emissions and mitigate climate change. Chen and Hong (2020) noted that building energy consumption accounts for approximately 40% of global energy consumption and contributes significantly to greenhouse gas emissions. Therefore, the use of building energy modelling tools can help in the design, implementation, and management of sustainable building projects by accurately predicting energy consumption patterns and reducing energy wastage. Ang *et al.* (2020) noted that there is a need for more studies on BEM to enhance the adoption of sustainable building practices. There are inadequate studies that emphasise the strategies for BEM application in the Nigerian construction industry. Considering the enormous benefits of BEM to sustainable construction, this study is aimed at determining the critical success factors of adopting BEM for sustainable building projects in the Nigerian construction industry. This study's outcomes will provide insights into the application strategies of building energy modelling tools in sustainable building design, thereby encouraging more application and research in this field and the industry.

2. Research Methodology

Using empirical data, this study adopted a post-positivist philosophical approach to establish the strategies or success factors for enhancing BEM implementation for improved sustainable building projects in Nigeria, using Lagos State as a case study. This philosophical viewpoint guided a quantitative research methodology employing a questionnaire survey. Creswell (2014) states that the quantitative research approach collects numerical data that may be categorised, ranked, or assessed using units of measurement. Using data from the reviewed literature, a closed-ended questionnaire was created for this study to collect data from the target population. The construction professionals and stakeholders involved in building projects in Lagos state were chosen to be the population of the study. These professionals are Builders, Architects, Engineers, Quantity Surveyors, and Facility Managers. A population frame of 7336 was established for the study based on the register of professionals from the directories of professional bodies in Lagos State, Nigeria. The professional bodies are the Nigerian Institute of Building (NIOB), the Nigerian Institute of Architects (NIA), the Nigerian Society of Engineers (NSE), the Nigerian Institute of Quantity Surveyors (NIQS), and the International Facility Management Association (IFMA) within Lagos state, Nigeria. Taro Yamane's formula was used to calculate the sample size, resulting in 379. The number of respondents to be allotted to each of the groups of professionals in the construction industry was determined using the proportional stratified random sampling method. The random sampling method was used to determine the

respondents to whom copies of the questionnaire were administered. Years of professional registration were used to select respondents for each group.

There were two distinct sections of the questionnaire. Section A collected background information from the respondents, while Section B concentrated on the success factors for adoption. Participants used the survey's 5-point Likert scale to indicate how much they agreed or disagreed with the factors. A 5-point Likert-type scale increased answer quality and rate while reducing respondents' frustration. Tables and charts were used to derive statistical conclusions based on their responses. Microsoft Excel and the Statistical Package for Social Science (SPSS) software were used to examine the obtained responses. The mean item scores, percentiles, and frequencies were computed from the collected data. Percentiles and frequencies were used to examine the respondents' demographic data, and the mean item score was used to sort the variables according to the respondents' answers. Out of the three hundred and seventy-nine (379) questionnaires administered to professionals and stakeholders across Lagos State, two hundred and twenty-eight (228) were filled correctly and returned, representing a response rate of 60.2%. This response rate is considered robust for a study of this nature. The high response rate can be attributed to the comprehensive follow-up with respondents and the relevance of the research topic to current industry challenges. The responses obtained provide a broad and diverse representation of the opinions and experiences of professionals in the construction industry within Lagos State, making the findings of this research reliable for analysis. Each response was carefully reviewed to ensure completeness, and only fully completed questionnaires were included in the final analysis. This high response rate strengthens the validity of the study's findings. It contributes to the depth of insights regarding adopting BEM for sustainable building projects in Lagos State. Cronbach's alpha was used to assess the study instrument's reliability; the results showed an alpha value of 0.972, confirming the validity of the data obtained from the questionnaire survey.

3. Findings and Discussion

3.1 Respondents' Socio-economic Characteristics

Table 1 presents the socio-economic characteristics of the respondents based on the two hundred and twenty-eight (228) questionnaires used for the analysis. These characteristics provide valuable insights into the demographic and professional background of the participants, which are essential for understanding their perspectives on the use of BEM in the construction industry. The key characteristics analysed include profession, years of experience, educational qualifications, professional affiliation, and registration status with relevant industry bodies. This information helps to contextualise the findings and highlights the diversity of the respondent pool in terms of expertise and professional standing within the construction industry in Lagos State.

Table 1. Socio-economic Characteristics of the Respondents

Characteristics	Frequency (n=228)	Percentage
Profession		
Architect	19	8.3%
Builder	123	53.9%
Engineer	31	13.6%
Quantity Surveyor	35	15.4%
Facility Manager	20	8.8%
Years of Experience		
1-5	125	54.8%
6-10	67	29.4%
11-15	11	4.8%
16-20	10	4.4%
21-25	12	5.3%
Above 25	3	1.3%

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Education		
OND	4	1.8%
HND	19	8.3%
B.Sc	156	68.4%
M.Sc	41	18.0%
PhD	8	3.5%
Professional Affiliation		
IFMA	20	8.8%
NIA	19	8.3%
NIQS	35	15.4%
NIOB	123	53.9%
NSE	31	13.6%

(Source: Author's Survey)

Regarding professional background, the data reveals that 13.6% of respondents are Engineers, 15.4% are Quantity Surveyors, 8.8% are Facility Managers, 8.3% are Architects, and 53.9% identify as Builders. This diverse representation emphasises the multidisciplinary nature of project management, highlighting the relevance of various professional perspectives in assessing BEM. The high representation of builders is particularly important, as this role directly involves the aspects where BEM could enhance sustainable construction. The distribution of years of experience among respondents indicates that 54.8% have 1-5 years of experience, 29.4% have 6-10 years, 4.8% have 21-25 years, and varying percentages hold experience in other brackets. This mix of experience levels is beneficial for gaining a well-rounded understanding of the industry. Notably, the significant percentage of respondents with 1-10 years of experience suggests they have been exposed to recent technological advancements, including BEM. Insights from this cohort are valuable as they can offer perspectives on the practicality and relevance of BEM in the construction industry.

The educational qualifications of respondents reveal that 68.4% hold a Bachelor of Science (B.Sc.), 18% possess a Master's degree (M.Sc.), 3.5% have a Doctor of Philosophy (PhD), and varying percentages have attained other qualifications. This diverse educational background indicates that the respondents are well-equipped with the knowledge and expertise necessary to provide informed insights into the need for BEM in project management. The data on professional affiliations shows that 8.8% are members of the IFMA, 15.4% belong to NIQS, 53.9% are affiliated with NIOB, 8.3% are affiliated with NIA, and 13.6% are part of NSE. The significant representation of professional affiliations indicates that respondents are engaged with recognised professional bodies, ensuring that the insights come from qualified professionals who are likely to be familiar with best practices and the latest construction management and technology developments. This professional engagement reinforces the validity of the study's findings, as these affiliations often require adherence to industry standards and continuous professional development.

3.2 The Success Factors for BEM Implementation in the Nigerian Construction Industry

This section presents the findings on the strategies or success factors for enhancing BEM implementation for improved sustainable building projects in Nigeria, using Lagos State as a case study. Table 2 presents a report of respondents' views as analysed using mean score and standard deviation. The data highlights several strategies that are seen as effective in implementing Building Energy Modelling (BEM) in Lagos State. The highest rated strategies are increasing the knowledge base of BEM applications and the incorporation of BEM training and education into academic curricula, both with a mean score of 4.00. This indicates a significant priority among the respondents that expanding knowledge and integrating BEM into formal education are essential strategies. Following closely, the strategy of public awareness creation through workshops, seminars, and conferences has a mean score of 3.96, reflecting a good standpoint in the respondents' opinions. The availability of an institutional framework for effective BEM implementation and conducting regular assessments of BEM implementation

performance both scored 3.95, showing that respondents agree on the importance of structured frameworks and continuous monitoring for the successful adoption of BEM. Two other important strategies include mandatory government policies and regulations encouraging BEM, and allocation of funding for research and development initiatives in BEM technologies (mean = 3.89). These scores suggest that respondents largely agree on the need for government involvement and financial investment in BEM. The strategy of developing strategic implementation plans by organisations and firms (mean = 3.88) is also viewed positively by the stakeholders, with the agreement that organisational planning is key to successful BEM adoption. Collaboration between the construction industry and BEM software vendors to provide affordable solutions scored 3.86, indicating that respondents agree on the importance of industry partnerships to reduce costs and make BEM more accessible. Clients' and users' support for BEM adoption was rated at 3.85, highlighting that gaining the backing of property owners is seen as a crucial element for effective BEM implementation.

Table 2. Strategies for Enhancing BEM Implementation for Improved Construction Delivery in Lagos State

Success Factors	Mean	Kruskal-Wallis H	Asymp. Sig.	Rank
Increasing the knowledge base of BEM applications	4.00	9.3647	0.0954	1st
Incorporation of BEM training and education into the curriculum of academic institutions	4.00	6.7998	0.2360	2nd
Public awareness creation through workshops, seminars and conferences	3.96	9.5637	0.0886	3rd
Availability of an institutional framework for effective implementation of BEM	3.95	10.5453	0.0612	4th
Conducting regular assessments of BEM implementation performance	3.95	15.3177	0.0091	5th
Mandatory government policies and regulations encouraging BEM	3.89	13.9541	0.0159	6th
Allocation of funding for research and development initiatives in BEM technologies	3.89	13.7267	0.0174	7th
Developing a strategy implementation plan by organisations and firms.	3.88	16.2133	0.0063	8th
Collaboration between the construction industry and BEM software vendors to provide affordable BEM solutions	3.86	25.1334	0.0001	9th
Clients' and users' support for BEM adoption	3.85	9.0751	0.1061	10th

(Source: Author's Survey)

The data suggests that expanding knowledge, education, raising awareness, establishing institutional frameworks, and ensuring government support are considered the most critical strategies for implementing BEM in Lagos State. However, there is also strong agreement on the need for financial support, industry collaboration, and strategic planning by organisations to facilitate the process. Table 2 also reveals the findings of the Kruskal-Wallis H test on the differences in the opinion of the respondents on the success factors for BEM adoption. Asymp. Sig. scores below 0.05 in the Kruskal-Wallis H test suggest that respondents' opinions differ significantly. The Kruskal-Wallis H test outcome revealed that the respondents' opinions were inconsistent, variant, and not uniform for five of the variables since most of the p-values were less than 0.05; however, the five of the variables which were the foremost ranked success factors, "Increasing the knowledge base of BEM applications", "Incorporation of BEM training and education into the curriculum of academic institutions", "Public awareness creation through workshops, seminars and conferences", "Availability of an institutional framework for effective implementation of BEM" and "Clients' and users support for BEM adoption" scored greater than 0.05, which showed that the respondents agreed with the variables. This outcome reflects that there is a critical need for awareness, education, training, government regulations and support to aid the fast adoption of BEM in the Nigerian construction industry.

3.3 Discussion of Findings

This study reveals several strategies that are critical to aid in implementing Building Energy Modelling (BEM) in the Nigerian construction industry. The highest rated strategies are increasing the knowledge base of BEM applications and the incorporation of BEM training and education into academic curricula. This indicates a significant priority among the respondents that expanding knowledge and integrating BEM into formal education are essential strategies. This outcome agrees with studies by Manzoor et al. (2021) and Kineber et al. (2023). The authors iterated that a concerted effort from all stakeholders, including the government, construction companies, and professionals involved in construction projects, is required. This effort involves increasing awareness, providing training and support for BEM implementation. Following closely was the strategy of public awareness creation through workshops, seminars, and conferences, reflecting a good standpoint in the respondents' opinions. The availability of an institutional framework for effective BEM implementation and conducting regular assessments of BEM implementation performance was also found critical, as the respondents agreed on the importance of structured frameworks and continuous monitoring for the successful adoption of BEM. Al-Ashmori *et al.* (2020) noted that clear BEM policies and standards play a critical role in enhancing BEM implementation. Similarly, Olanrewaju *et al.* (2020) advanced that the development of clear BEM policies and standards will provide guidelines for BEM implementation and ensure consistency in its use across the construction industry. Two other important strategies include mandatory government policies and regulations encouraging BEM, and allocation of funding for research and development initiatives in BEM technologies. These outcomes suggest that the respondents largely agree on the need for government involvement and financial investment in BEM. These findings agree with the studies by Al-Ashmori et al. (2020) and Olanrewaju et al. (2020), as discussed above. The strategy of developing strategic implementation plans by organisations and firms was also viewed positively by the stakeholders, with the agreement that organisational planning is key to successful BEM adoption. Effective stakeholder management plays a crucial role in enhancing BEM implementation and project performance (Zhang *et al.,* 2022). This strategy involves engaging stakeholders from the design stage to the construction phase, ensuring their needs and expectations are met. It also requires effective communication, collaboration, and conflict resolution. Effective stakeholder management can mitigate the resistance to change and lack of collaboration that hinder BEM implementation in Nigeria. Collaboration between the construction industry and BEM software vendors to provide affordable solutions was found significant, indicating that respondents agree on the importance of industry partnerships to reduce costs and make BEM more accessible. Clients' and users' support for BEM adoption was found important, highlighting that gaining the backing of property owners is seen as a crucial element for effective BEM implementation.

The results from the hypothesis on the variation of the responses of the professionals regarding the success factors of BEM usage indicated that there is no significant variation in the perception of the professionals on five of the factors that will influence the use of BEM in the study area. The null hypothesis was accepted for them while the alternative hypothesis was rejected. This shows that the professionals agreed that "Increasing the knowledge base of BEM applications", "Incorporation of BEM training and education into the curriculum of academic institutions", "Public awareness creation through workshops, seminars and conferences", "Availability of an institutional framework for effective implementation of BEM" and "Clients' and users support for BEM adoption", are the factors that stand as critical strategies to BEM adoption in the construction industry. However, five of the success factors of BEM usage revealed that there is significant variation in the perception of the professionals, meaning that the null hypothesis was rejected for them, while the alternative hypothesis was accepted. This means that the professionals did not jointly agree that – conducting regular assessments of BEM implementation performance, mandatory government policies and regulations encouraging BEM, allocation of funding for research and development initiatives in BEM technologies, developing a strategy implementation plan by organisations and firms, and collaboration between the construction industry and BEM software vendors to provide affordable BEM solutions – can positively influence the use of BEM for sustainable building projects.

4. Conclusion and Recommendations

This study has determined the critical success factors of adopting BEM for sustainable building projects in the Nigerian construction industry. The success factors for enhancing BEM implementation were proposed, with a focus on public awareness campaigns, collaboration between industry stakeholders, and integration of BEM education into academic curricula. The strong association between identified challenges and recommended strategies further validates the importance of these initiatives in promoting BEM adoption and improving sustainable building project outcomes in Nigeria. In conclusion, the findings of this research underscore the imperative for concerted efforts from government bodies, industry stakeholders, and educational institutions to advance BEM awareness, foster collaboration, address implementation challenges, and implement targeted strategies. By embracing BEM

technology and practices, Nigeria's construction industry can achieve greater efficiency, sustainability, and competitiveness in project delivery processes, thereby contributing to overall economic growth and development. The study recommends the following: advocating for the integration of BEM education into academic curricula at all levels of education, from vocational training programs to university degrees. This will ensure that future professionals are equipped with the necessary skills to succeed in a BEM-enabled industry. Secondly, investing in infrastructure improvements to address technological barriers such as unreliable internet connectivity and power outages. This will facilitate smoother adoption and use of BEM technology in Nigeria. Thirdly, exploring the possibility of providing financial incentives or tax breaks to construction firms that invest in BEM technology and training. This could help offset initial implementation costs and encourage greater uptake of BEM practices. Fourthly, developing and implementing regulatory frameworks that mandate the use of BEM on public infrastructure projects and encourage its adoption in private sector projects. This will create a standardised approach to BEM implementation and ensure consistency across the industry. It is also recommended that resources be allocated to support research and development initiatives aimed at advancing BEM technology and practices tailored to the Nigerian context; encourage collaboration between academia, industry, and government to drive innovation in the field; establish mechanisms for monitoring and evaluating the progress of BEM implementation initiatives; regularly assess indicators such as adoption rates, project outcomes, and industry satisfaction to identify areas for improvement and track the impact of interventions over time. Further research could focus on analysing existing policies and regulations related to BEM implementation in Nigeria. By assessing the effectiveness of current regulatory frameworks and identifying areas for improvement, researchers can inform policy development processes aimed at fostering a supportive environment for BEM adoption.

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