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INVESTIGATION OF BUILDING INFORMATION MODELING (BIM) IN SUSTAINABLE CONSTRUCTION PROJECTS

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ABSTRACT

Building Information Modelling (BIM) is a transformative tool that significantly enhances the efficiency and sustainability of construction projects. Despite its global recognition, the adoption in of BIM in Nigeria, especially in sustainable construction, remains limited. This study investigates the role of BIM in optimizing material use, reducing waste, and promoting sustainable practices in construction projects, using Lagos State as a case study. A quantitative research approach was employed, gathering data through questionnaires distributed to construction professionals. The collected data underwent statistical analysis utilizing measures such as mean, standard deviation, and Relative Importance Index (RII) to extract meaningful insights. The findings revealed that while BIM offers substantial benefits in material optimization and project management, various barriers hinder its widespread adoption, including high software costs and limited technical expertise. Training programs, government support, and improved stakeholder collaboration are specific recommendation to increase BIM integration in sustainable construction projects.

Keywords: Benefit, Barrier, BIM, Sustainable construction, Material optimization

INTRODUCTION

The construction industry is a cornerstone of national economic development, providing essential infrastructure, stimulating employment opportunities, and shaping urban landscapes (Adekunle, Ejohwomu & Aigbavboa, 2021; Albert, Shakantu & Saidu, 2021). Despite its benefits, the construction industry has a substantial ecological footprint, characterized by excessive energy use, greenhouse gas emissions, and considerable waste production (Andriasyan *et al*., 2020; Abbasnejad *et al*., 2021). As a result, Ahn *et al*. (2020) revealed these challenges have prompted a shift towards sustainable construction practices, which aim to reduce the environmental footprint of building activities while enhancing resource efficiency and improving project outcomes. Sustainable construction is a holistic approach that integrates environmentally responsible materials, techniques, and practices across a building's life cycle, from conception to decommissioning (Matos *et al*., 2021; Aibinu and Jagboro, 2002).

According to Silva *et al*. (2016) BIM has become a game-changing technology in construction, providing innovative digital platforms that improve collaboration, project efficient, reduce waste, productivity, and project outcomes. Aghimien *et al*. (2020) and Oke *et al*. (2019) viewed BIM is a process that entails generating and managing detailed digital models of a building's or infrastructure's physical attributes and functional properties. It integrates designs into a cohesive 3D model, allowing stakeholders to collaborate more effectively and make data-driven decisions throughout a project's life cycle (Adekunle et al., 2021; Al-Ashmori *et al*., 2020). This digital approach can significantly improve accuracy, coordination, and communication among project participants, thereby enhancing the quality and sustainability of construction projects (Zhang & Huo, 2015).

The use of BIM in sustainable construction has gained considerable attention due to its ability to simulate energy efficiency, optimize resource use, and manage waste (Abubakar *et al*., 2014). According to Aghimien *et al*. (2020) BIM enables project managers to visualize energy consumption patterns and predict the environmental impact of design decisions before actual construction begins. This proactive approach to sustainable design can lead to the adoption of energy-efficient solutions, reduce rework, and improve overall project outcomes (Miettinen & Paavola, 2018). Additionally, BIM facilitates the accurate estimation of materials and resources required for a project, reducing the likelihood of over-ordering and minimizing construction waste (Arayici *et al*., 2021). In Nigeria, the journey towards adopting Building Information Modeling (BIM) and advancing sustainable practices in the built environment is shaped by a combination of infrastructural challenges, policy frameworks, and cultural factors (Olawumi & Chan, 2020). Understanding these contextual aspects is key to addressing the barriers and unlocking the potential for BIM to drive sustainability and innovation in the construction sector.

The Nigerian construction industry is experiencing rapid growth due to increasing urbanization, infrastructure development, and a rising population (Albert *et al*., 2024). This led to an increased demand for sustainable construction practices that align with global standards and the United Nations Sustainable Development Goals (Ahankoob, Manley & Abbasnejad, 2022). Despite the potential benefits of BIM in achieving these goals, its adoption in Nigeria remains limited. Research by Oke *et al*. (2019) suggests that this is due to challenges such as a lack of awareness, inadequate training, high implementation costs, and resistance to change among stakeholders. As a result, many construction projects in Nigeria still rely on traditional methods that often result in project delays, cost overruns, and environmental degradation. While prior studies identify BIM barriers in Nigeria, none quantify its impact on material waste reduction in sustainable projects.

The need to adopt innovative technologies like BIM is becoming more pressing, especially as the Nigerian government and various stakeholders push for greener construction practices to mitigate climate change impacts. BIM offers an opportunity to integrate sustainability into the planning, design, and construction phases of building projects. By enabling real-time data analysis and providing accurate simulations, BIM can enhance the decision-making process, making it easier to adopt sustainable building materials, reduce energy consumption, and manage construction waste effectively (Abubakar *et al*., 2014).

Sustainable Construction

Sustainable construction encompasses the environmentally conscious and resource-efficient practices employed throughout a building's entire lifecycle, spanning from initial planning and design to construction, occupancy, maintenance, and eventual reuse or demolition. (Albert & Shakantu, 2018). Not only that, Alhamami, Abuhussain & Dodo, (2023) revealed that Sustainable construction involves designing, constructing, and managing buildings in a manner that reduces their ecological footprint, conserving natural resources and mitigating harm to the environment. The goal of sustainable construction is to minimize the negative impact of buildings on the environment, while promoting economic viability and ensuring the well-being of the community and future generations (Al-Mohammad *et al*., 2022). This approach seeks to balance the three pillars of sustainability: environmental, social, and economic factors. The principles of sustainable construction serve as guidelines for achieving sustainability in the built environment.

Building Information Modelling (BIM) plays a crucial role in advancing sustainable construction practices by enabling the efficient use of resources, improving energy performance, minimizing waste, and supporting comprehensive lifecycle assessments (Arayici *et al*., 2021). As the construction industry moves towards adopting greener and more environmentally friendly practices, BIM's ability to model, analyse, and optimize various aspects of construction makes it a vital tool for achieving sustainable project outcomes (Abubakar *et al*., 2014).

Therefore, the importance of sustainable construction cannot be overstated, particularly in today’s rapidly changing global environment. The construction sector's considerable environmental impact and resource consumption necessitate the adoption of sustainable methods to reduce adverse effects, foster resilient growth, and achieve a balance between environmental stewardship, economic viability, and social responsibility.

Three Pillars of Sustainability

To enhance the link between Building Information Modelling (BIM) and sustainability, it's important to incorporate frameworks such as the Triple Bottom Line (TBL) and emphasize BIM's role in supporting the achievement of Sustainable Development Goals. Arowoshegbe, Emmanuel & Gina, (2016) emphasis on the Triple Bottom Line (TBL) framework assesses sustainability from three dimensions: (i) economic that is focuses on cost efficiency, profit, and the financial impact of decisions; (ii) environmental, which examines the ecological footprint, resource usage, and environmental impact; and, (iii) social, that considers social equity, well-being, and community benefits. More so, Ayman, Alwan, & McIntyre, (2020) posits that BIM’s role in sustainability fits well within the TBL framework, offering several ways to improve all three areas:

Economic: BIM enhances cost control and resource optimization, leading to cost savings throughout the building’s lifecycle. By accurately forecasting project costs and resource needs, BIM helps avoid overestimation, material waste, and unnecessary rework.

Environmental: BIM facilitates sustainable design by enabling energy-efficient building models, minimizing waste, and optimizing material use. The use of BIM for energy modeling and environmental simulations helps identify areas where energy consumption can be reduced, contributing to carbon reduction goals.

Social: BIM improves collaboration among stakeholders, fostering better communication and transparency, which supports more socially responsible decision-making. In addition, BIM can promote inclusive design by ensuring that buildings are accessible and equitable for diverse user groups.

Concept of Building Information Modelling

The concept of BIM has its roots in computer-aided design (CAD) systems used in the 1960s. However, it was not until the 1990s that BIM started to be developed in its current form. Initially, BIM was developed as a 3D modelling tool, but it has since evolved to include many other features, such as 4D and 5D modelling, clash detection, and cost estimation (Rogers *et al*., 2015). BIM has also evolved to incorporate the Internet of Things (IoT) in the construction process, leading to the development of the Physical Internet-Enabled BIM System for prefabricated construction (Chen *et al*., 2017). BIM is a rapidly evolving field, and its impact on the construction industry is significant. Researchers have examined the dynamics of BIM in construction design and have 10 reconceptualized object construction (Miettinen & Paavola, 2018; Alwan *et al*., 2017). They have identified the need for a new approach to object construction that is more collaborative, integrated, and iterative. Bibliometric analysis and review of BIM literature have shown that BIM is an area of active research, with a significant increase in the number of publications in recent years (Santos *et al*., 2017). This indicates that BIM will continue to be a critical area of research in the field of construction in the future.

Benefits of BIM in Sustainable Construction Projects

Building Information Modelling (BIM) offers significant benefits for sustainable construction projects by enhancing efficiency, reducing waste, and improving collaboration among stakeholders (Gourlis & Kovacic, 2017). One of the primary advantages of BIM is its ability to provide accurate, detailed 3D models that facilitate better planning and visualization (Djuedja *et al*., 2018; Chong *et al*., 2017). This capability allows project teams to identify potential design issues early in the process, thereby minimizing costly rework and ensuring that resources are used efficiently. By enabling precise material quantification and scheduling, BIM reduces the likelihood of over-ordering and waste, contributing to more sustainable resource management (Nechyporchuk & Bašková, 2020).

Moreover, Oladiran, Simeon & Anyira, (2022) noted that BIM supports energy efficiency by integrating with energy modeling tools that allow for the simulation of a building's performance under various conditions. This functionality enables architects and engineers to evaluate design alternatives and make informed decisions that enhance energy performance, such as optimizing insulation, selecting energy-efficient systems, and incorporating renewable energy sources. Consequently, projects that utilize BIM can achieve lower operational costs and reduced carbon footprints, aligning with global sustainability goals and enhancing the building's long-term viability (Chen *et al*., 2017).

Collaboration is another crucial benefit of BIM in sustainable construction. The platform fosters improved communication among architects, engineers, contractors, and owners by providing a shared, centralized model that all stakeholders can access (Albert, Shakantu & Ibrahim, 2020; (Rowlinson, 2017). This collaborative environment ensures that everyone is aligned on project goals and sustainability objectives, facilitating better decision-making throughout the project lifecycle. As a result, BIM not only streamlines workflows but also enhances the overall quality and sustainability of construction projects, making it an essential tool in the pursuit of environmentally responsible building practices.

Barriers to Implementing BIM for Sustainable Construction Projects

Implementing Building Information Modelling (BIM) for sustainable construction projects faces several barriers that can hinder its effective adoption (Succar, 2009). Technologically, the high cost of BIM software, coupled with limited interoperability between various software platforms, presents significant challenges (Teicholz, 2014). Many organizations struggle with insufficient hardware and infrastructure to support BIM, and integrating BIM with existing systems can be complex and resource intensive. Additionally, the limited availability of BIM-compatible tools complicates implementation, particularly for smaller firms that may lack the necessary financial and technical resources. Organizationally, the lack of trained personnel and resistance to change are critical issues that impede progress; many companies face limited resources and budget constraints, which can lead to inadequate organizational structures that do not support BIM initiatives (Silva *et al*., 2016). Insufficient support from top management further exacerbates these challenges, preventing a unified approach to BIM integration (Siew, 2015).

Culturally, there is often a lack of collaboration and communication among project stakeholders, which hinders effective data sharing and information flow (Nasila & Cloete, 2018; Albert, Shakantu & Ibrahim, 2018). Resistance to sharing data can stem from varying work cultures and languages, leading to misunderstandings about BIM's benefits and the potential for conflict between traditional practices and modern approaches (Sinclair, 2012). Finally, regulatory barriers such as the absence of clear regulations and standards can create confusion about BIM adoption, while limited enforcement of such regulations and inconsistent building codes can stifle innovation. Without sufficient government support to promote BIM adoption, the construction industry may continue to face significant obstacles in leveraging BIM for sustainable practices.

MATERIALS AND METHODS

This research utilised a quantitative research approach, which is focused on the measurement of quantities and is particularly applicable to phenomena that can be expressed numerically (Kothari, 2011). Essentially, this approach relies on statistical or numerical analysis. In quantitative research, experimental methods assess the impact of specific treatments on outcomes, while non-experimental methods provide numerical descriptions of patterns, attitudes, or opinions (Creswell & Poth, 2016). A quantitative research design is suitable for this study because it enables data collection from a large sample population, aligning with the goal of assessing Building Information Modelling (BIM) for sustainable construction projects in Lagos, Nigeria and developing practical strategies for its adoption. The population of this study consists of active construction professionals with experience in BIM such as architects, builders, engineers, and quantity surveyors who are employed by government agencies, consultancy firms, and Estate developers. Sampling is the process of choosing a portion of a population to represent the entire group of interest. It allows for the selection of appropriate respondents who can serve as representatives of the larger population from which data is gathered (Welman *et al*., 2005). Stratified random sampling was adopted. Therefore, 256 out of the expected 372 questionnaires were received and found suitable for analysis. The study achieved an overall response rate of 68.8% which is considered adequate.

The primary data for this study was gathered through a structured questionnaire, administered via a survey, to collect information aligned with the research questions. The structured questionnaire contained a sequence of questions divided into four sections. Section A covers the profile of the respondents, section B was used to gather data on ways BIM optimizes material use and reduces waste using a five-point Likert scale of 1–5 (where 1 – strongly disagree, 2 – disagree, 3 – neutral, 4 – agree, 5 – strongly agree). Section C was used to gather data on the benefits of BIM on sustainable construction projects, and section D gathered data on the strategies for enhancing BIM Implementation. Before data collection, the research questionnaire was assessed by seasoned industry experts. Their input helped refine and improve the questionnaire.

The data collected through the questionnaire was analysed using the Statistical Package for the Social Sciences (SPSS). The information was assessed, organized, and displayed in tables employing a descriptive approach. The data for the study was gathered and analysed from July to October 2024.

RESULTS AND DISCUSSION

The results were presented in the table below.

Table 1: Ways BIM Optimizes Material Use and Reduces Waste

Ways BIM optimizes material use and reduces waste	Mean	Std. Dev.	Rank
Minimized cutting waste	4.45	.67	1
Accurate quantity take-off	4.40	.72	2
Clash detection	4.35	.75	3
Design for assembly	4.30	.80	4
Waste management planning	4.20	.85	5
Optimization for material waste usage	4.15	.88	6
Material reuse and recycling	4.10	.90	7
Improved material logistics	4.05	.92	8
Material tracking	4.00	.95	9
Reduced packaging waste	3.85	1.0	10

Table 1 shows the various ways in which BIM optimizes material use and reduces waste according to their perceived importance based on a survey of the respondents. Minimized cutting waste and accurate quantity take-off have the highest mean scores with 4.45 and 4.40 respectively while material tracking standard and reduced packaging waste have the lowest mean scores with 4.00 and 3.85.

Table 2: Benefits of BIM in Sustainable Construction Projects

Benefits	Mean	Std. Dev.	Rank
Cost saving	4.32	.60	1
Reduced construction time	4.15	.65	2
Reduced material waste	4.10	.67	3
Increased return on investment	4.05	.62	4
Optimized material usage	3.98	.69	5
Improved resource efficiency	3.90	.71	6
Improved project management	3.87	.70	7
Enhanced collaboration communication	3.78	.68	8
Minimized environmental impact	3.65	.74	9
Enhanced recycling and reuse of materials	3.45	.75	10

Table 2 presents the results of benefits of BIM on sustainable construction projects in the Nigerian construction industry. Cost saving with a mean (4.32) was ranked first follow by reduced construction time with 4.15, then reduced material waste with mean (4.10). while enhanced collaboration communication, minimised environmental impact, enhanced recycling and reuse of materials were ranked low with mean scores of 3.78, 3.65 and 3.45 respectively.

Table 3: Barriers Affecting BIM Implementation

Barriers	Mean	Std. Dev.	RII	Criticality Level	Rank
High cost of BIM software	4.30	.55	0.8630	VC	1
Lack of clear regulations and standards	4.25	.58	0.8549	VC	2
Lack of trained personnel	4.20	.56	0.8412	VC	3
Limited interoperability between software	4.15	.65	0.8323	VC	4
Insufficient hardware and infrastructure	4.13	.70	0.8236	VC	5
Limited enforcement of BIM adoption	4.10	.62	0.8117	VC	6
Insufficient support from top management	4.06	.68	0.8052	C	7
Resistance to change	4.02	.66	0.8013	C	8
Limited government support for BIM adoption	4.01	.61	0.7967	C	9
Difficulty in integrating BIM with existing systems	3.99	.60	0.7926	C	10
Limited understanding of BIM benefits	3.97	.66	0.7878	C	11
Limited resources and budget	3.94	.64	0.7834	C	12
Limited availability of BIM-compatible tools	3.92	.72	0.7794	C	13
Insufficient incentives for sustainable construction	3.91	.70	0.7740	C	14
Lack of collaboration and communication	3.88	.70	0.7682	C	15
Inadequate organizational structure	3.86	.75	0.7614	C	16
Limited understanding of sustainability benefits	3.82	.73	0.7589	C	17
Resistance to sharing data and information	3.77	.68	0.7546	C	18
Limited availability of sustainable materials and systems	3.75	.69	0.7487	C	19
Different work cultures and languages	3.74	.72	0.7406	C	20
Insufficient integration of sustainability metrics	3.72	.75	0.7378	C	21
Traditional mindset and practices	3.71	.74	0.7323	C	22
Higher costs of sustainable materials and systems	3.69	.71	0.7291	C	23
Inconsistent building codes and regulations	3.67	.78	0.7235	C	24
Difficulty measuring sustainability performance	3.66	.77	0.7186	C	25

Table 3 shows the barriers affecting BIM Implementation in sustainable construction. The result reveals most common barriers affecting implementation of BIM in construction with mean value 4.0 and above are high cost of BIM software, lack of clear regulations and standards, lack of trained personnel, limited interoperability between software, insufficient hardware and infrastructure, limited enforcement of BIM adoption, insufficient support from top management, resistance to change and limited government support for BIM adoption.

Table 4: Strategies for Enhancing BIM Implementation

Strategies	Mean	Std. Dev.	Rank
Develop and enforce BIM standards	4.67	.60	1
Define BIM goals and objectives	4.64	.58	2
Establish clear communication protocols	4.60	.56	3
Provide BIM training for stakeholders	4.56	.65	4
Develop a BIM execution plan	4.51	.70	5
Collaborate with architects, engineers, and contractors	4.46	.62	6

Offer sustainable design and construction workshops	4.42	.68	7
Integrate energy analysis and simulation	4.38	.66	8
Utilize digital construction methods	4.33	.61	9
Utilize clash detection for reduced waste	4.29	.60	10
Enhance quality control and assurance	4.17	.66	11
Offer incentive for BIM adoption	4.13	.64	12
Conduct regular software updates and training	4.10	.72	13
Encourage continuous learning and development	4.07	.70	14
Establish clear data management protocols	4.04	.70	15
Incorporate material tracking and optimization	4.01	.75	16
Identify stakeholders and roles	3.96	.73	17
Conduct feasibility studies	3.92	.68	18
Use sustainable design tools e.g., green building studio	3.87	.69	19
Implement site monitoring and tracking systems	3.85	.72	20
Integrate RFID and IoT technologies	3.81	.75	21
Monitor and adjust sustainable practices	3.79	.74	22
Foster industry-wide collaboration	3.74	.71	23
Encourage sustainable construction regulations	3.71	.78	24
Identify industry-wide collaboration	3.67	.77	25

From table 4, it was observed that the majority of respondents with mean value 4.0 and above strongly agreed for strategies for enhancing BIM implementation in sustainable construction.

Discussion of results

The study examined building information modelling (BIM) in sustainable construction projects. The result in table 1 identified minimized cutting waste as the most ways BIM optimizes material use and Reduces waste. These efforts are crucial for promoting environmental sustainability by reducing resource consumption, lowering carbon footprints, and minimizing the waste sent to landfills. Here's how minimized cutting waste contributes to sustainable construction. Albert & Shakantu (2018) corroborates that minimized cutting waste in sustainable construction refers to strategies and techniques aimed at reducing the amount of material waste generated during the cutting and shaping process of building materials. Another area concern is accurate quantity take-off is the process of determining and calculating the quantities of materials, labour, and other resources needed for a construction project. It is an essential step in the preparation of cost estimates and the planning of materials and labour for the project. The results aligned with the submission of Rowlinson (2017) that the accuracy of the quantity take-off is crucial as it directly impacts the budget, schedule, and overall success of the project. More so, clash detection is a critical part of building information modeling (BIM), as it helps ensure that designs are coordinated and free from conflicts before actual construction begins (Abubakar *et al*., 2014). It improves project efficiency, reduces rework, and enhances collaboration among project teams. The finding is consistent with Aghimien et al. (2020) revealed that clash detection is the process of identifying and resolving conflicts between different elements of a construction project, especially when multiple systems, components, or trades are involved. These conflicts, or "clashes," occur when different elements occupy the same physical space or interfere with each other, potentially causing delays, increased costs, or safety hazards during the construction phase.

With regards to the benefits of BIM in sustainable construction projects, cost saving was ranked high and this implies that cost saving in construction refers to the strategies, techniques, and practices used to reduce expenses and optimize resources during the construction process (Santos *et al*., 2017). Therefore, building information modelling (BIM) offers numerous advantages in sustainable construction projects by enhancing efficiency, reducing resource consumption, and improving collaboration among stakeholders. BIM helps achieve sustainability goals by integrating design, construction, and operational data into a single digital model, which allows for better decision-making throughout the building lifecycle (Prušková, 2018). However, the widespread adoption of BIM has been slow in some parts of the construction industry due to various barriers (Chen *et al*., 2017). These barriers range from technological challenges to cultural and organizational factors. Moreso, the table 3 shows that high cost of BIM software is one of the challenges of BIM implementation due Nigeria's economic constraints such as currency fluctuations, high inflation, limited access to credit, import tariffs, and high internet costs that exacerbate the already high costs of BIM software. These factors make it difficult for many construction firms, especially small and medium-sized enterprises (SMEs), to adopt BIM and other advanced technologies. As a result, the construction industry may struggle to transition to more sustainable and efficient practices, which ultimately affects the sector's ability to modernize and meet growing infrastructural demands.

Implementing building information modelling (BIM) in sustainable construction is a powerful strategy to optimize building designs, reduce waste, improve collaboration, and manage the entire lifecycle of a project in an environmentally responsible manner (Nechyporchuk & Bašková, 2020; Siew, 2015; Teicholz, 2014). To enhance BIM implementation in sustainable construction, construction firms and stakeholders must adopt strategies that address the barriers to adoption, promote collaboration, and drive innovation.

CONCLUSION

Building Information Modeling (BIM) plays a pivotal role in promoting sustainable construction practices. It enables construction professionals to make informed decisions that optimize energy efficiency, minimises material waste, improve resource management, and reduce the environmental impact of buildings. The ability to conduct lifecycle assessments and efficient material planning through BIM contributes to achieving sustainability goals in construction projects. However, despite its benefits, BIM adoption in sustainable construction faces several barriers, including high initial costs, resistance to change, lack of standardization, and fragmented industry structures. These challenges can hinder the full potential of BIM in transforming the construction industry towards more sustainable practices. Therefore, it is essential to address these obstacles by investing in training for stakeholders, define BIM goals and objectives, fostering collaboration among stakeholders, utilize clash detection for reduced waste, collaborate with architects, builders, engineers, and contractors; and leveraging advanced BIM tools for sustainable design and construction.

Governments should encourage BIM adoption for sustainable construction projects by offering incentives such as tax breaks, grants, or subsidies for construction projects that use BIM and meet sustainability criteria. Mandate BIM training modules in professional accreditation program. Continuous research into new technologies, materials, and construction methods integrated with BIM is essential for driving further innovation in sustainable building practices. Educating clients and construction professionals on the long-term cost savings and environmental benefits of BIM can help drive demand.

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