



ORIGINAL RESEARCH ARTICLE

**BARRIERS TO ADOPTION OF CONSTRUCTION 4.0 FOR CIRCULAR ECONOMY:
A QUALITATIVE APPROACH**

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ABSTRACT

Despite global advances in Construction 4.0 technologies for supporting circular economy (CE) goals, adoption remains limited in developing countries particularly Nigeria where contextual barriers remain poorly understood. Digital tools such as Building Information Modelling (BIM) and Internet of Things (IoT), drive sustainability through resource efficiency, waste minimization, and a closed-loop material flow. However, the extent to which these technologies are adopted in developing countries like Nigeria remains under-researched. This study investigates the specific challenges impeding the adoption of Construction 4.0 technologies in advancing CE practices within the Nigerian construction industry. While global literature highlights barriers such as cost, regulatory gaps, and resistance to change, this research uncovers localized obstacles including infrastructural deficiencies, poor internet reliability, dominance of the informal construction sector, and limited technical training opportunities. Using a qualitative research design, semi-structured interviews were conducted with industry professionals in Lagos State, Nigeria who were selected through purposive and snowball sampling to ensure relevance insights. Thematic analysis revealed that while most of the barriers identified mirror those already established in global literature such as high implementation costs, general lack of awareness, regulatory inadequacies, lack of standardization, skill shortages and implementation capacity, the study also uncovers additional, context-specific challenges that deepen understanding of these barriers in Nigeria's setting. These include chronic infrastructural deficiencies such as unreliable internet and power supply, the dominance of an informal construction sector that resists standardization and technological uptake, and deep-seated cultural resistance to digital transformation. Furthermore, the study finds that even where awareness of technologies like BIM exists, practical adoption remains minimal due to the absence of policy support, technical training frameworks, and adequate incentives. For instance, several participants noted that Construction 4.0 tools are seen as "premium" and often incompatible with the cost and workflow structures of small- and medium-sized firms, especially those operating informally. This paper contributes to the literature by situating global adoption challenges within a localized Nigerian context, highlighting how familiar barriers are amplified by the institutional dynamics specific to developing countries, particularly Nigeria. The findings offer insights for policymakers, construction firms, and educators seeking to promote CE through construction 4.0. The findings also have practical implications for improving policy, workforce training, and infrastructure investment strategies tailored to Nigeria's construction sector. By revealing how global challenges manifest in context-specific ways, the study supports the development of targeted interventions that bridge the gap between innovation and local feasibility.

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1.0 Introduction

The construction sector in Nigeria is a vital component of the country's economic progress, with a notable impact on its GDP (Ajayi *et al.*, 2019). However, the industry faces numerous challenges that hinder its sustainable growth. One of the primary issues is the industry's linear model of production, which is characterized by a "take-make-waste" approach (Ajayi & Kolo, 2018; Muhammad *et al.*, 2020). The reliance on this linear model not only drains our natural resources but also leads to significant waste and environmental harm, challenging the very essence of sustainability (Akinade *et al.*, 2018). Additionally, the industry's reliance on traditional construction methods and technologies often results in low productivity, inefficient resource utilization, and increased greenhouse gas emissions (Oke *et al.*, 2019). A circular economy (CE) represents a shift from the conventional linear economy, focusing on maximizing the longevity and value retention of products, materials, and resources. (Akinade *et al.*, 2020). The CE model emphasizes the principles of reduce, reuse, and recycle, with the goal of minimizing waste and maximizing resource efficiency (Ajayi & Kolo, 2018; Bakar *et al.*, 2021). In the context of the construction industry, the adoption of a circular economy (CE) can lead to significant environmental, economic, and social benefits, such as reduced waste, improved resource efficiency, and the creation of new job opportunities (Akinade *et al.*, 2020; Amusan *et al.*, 2019). However, the implementation of CE in the Nigerian construction industry faces several challenges, including a lack of awareness, limited access to technology, and regulatory barriers (Oke *et al.*, 2019; Dada *et al.*, 2020). Construction 4.0 technologies, which encompass a range of digital tools and technologies, such as Building Information Modeling (BIM), the Internet of Things (IoT), and additive manufacturing, can help address some of these challenges (Ajayi *et al.*, 2019). These technologies can enhance resource efficiency, improve waste management, and facilitate the transition towards a more sustainable construction industry (Akinade *et al.*, 2018; Adeyemi *et al.*, 2021). For example, BIM provides detailed information about a building's materials and components, enabling better decision-making about resource use and waste management (Succar, 2019). Furthermore, Construction 4.0 technologies can facilitate the reuse and recycling of materials in the construction industry. For example, IoT devices can track the usage and condition of materials and components, providing valuable data for decision-making about reuse and recycling (Opoku & Ahmed, 2019). Construction 4.0 technologies can also promote energy efficiency in the construction industry, contributing to a reduction in carbon emissions. For instance, AI can be used to optimize energy use in buildings, reducing their environmental impact (Ogunnusi *et al.*, 2020). Globally, the construction industry is increasingly turning to these Construction 4.0 technologies to facilitate a shift towards circular economy practices. BIM exemplifies this by enhancing design and construction efficiency, leading to significant waste reduction and fostering material reuse (Ajayi & Kolo, 2018). IoT-enabled sensors can provide real-time data on resource consumption and waste generation, allowing for more informed decision-making and the implementation of circular strategies (Akinade *et al.*, 2020). Additive manufacturing, or 3D printing, can enable the production of custom-made components, reducing material waste and facilitating the reuse of materials (Ajayi *et al.*, 2019; Oladapo *et al.*, 2020).

Table 1: Circular economy principles and the corresponding Construction 4.0 technologies

Circular Economy Principles	Construction 4.0 Technologies that can facilitate it
Design for Circularity	- Building Information Modeling (BIM) - Augmented and Virtual Reality (AR/VR)
Resource Optimization	- Internet of Things (IOT)
Extended Lifecycle	- Internet of Things (IOT)
Collaborative Partnerships	- Artificial Intelligence (AI)

Source: (El-Omari *et al.*, 2018)

The slow adoption of Construction 4.0 technologies for a circular economy in the Nigerian construction industry is a critical issue that requires further investigation. While there is a growing body of research on the potential benefits of CE and Construction 4.0 in the industry, there is a lack of empirical studies that specifically examined the barriers to the adoption of these technologies in Nigeria (Ojelabi *et al.*, 2017). Previous studies have identified various obstacles to the adoption of circular economy practices in the construction industry globally. For instance, Gunduz & Almuajebh (2020) highlighted the lack of awareness and understanding of circular economy among industry stakeholders as a significant barrier. Ajayi & Oyedele (2018) pointed out the inadequate government policies and regulations that fail to support circular economy initiatives. Additionally, Bohari *et al.* (2017) noted the limited access to financing and investment for circular economy projects, while Akinade *et al.* (2018) emphasized the lack of collaboration and coordination among different stakeholders as a critical challenge. While these studies provide valuable insights into the barriers to circular economy

adoption, they are predominantly based on research conducted in other countries. The applicability of their findings to the Nigerian construction industry is limited due to the distinct cultural, economic, and regulatory environments. For instance, Aghimien *et al.* (2018) argue that these differences necessitate a localized investigation to understand the specific challenges faced in Nigeria. Moreover, existing research has largely focused on general circular economy practices in the construction industry, without specifically addressing the role of Construction 4.0 technologies in facilitating the transition towards a circular economy. Oesterreich & Teuteberg (2016) suggest that the integration of advanced digital technologies is crucial for the successful implementation of circular economy principles in the construction sector, as these technologies enable efficient waste reduction, resource optimization, and closed-loop material flows. The current research discussion on this topic suggests that the successful implementation of Construction 4.0 technologies for a circular economy in the Nigerian construction industry requires a deeper understanding of the specific challenges and barriers faced by industry stakeholders (Oke *et al.*, 2019; Osunsanmi *et al.*, 2020). These barriers may include technological, organizational, financial, and regulatory factors, as well as cultural and behavioral aspects (Osunsanmi *et al.*, 2020; Ugochukwu *et al.*, 2021). Hence, to address this research gap, this study seeks to examine the barriers to the adoption of Construction 4.0 technologies for a circular economy in the Nigerian construction industry.

2. Materials and Method

2.1 Research Area

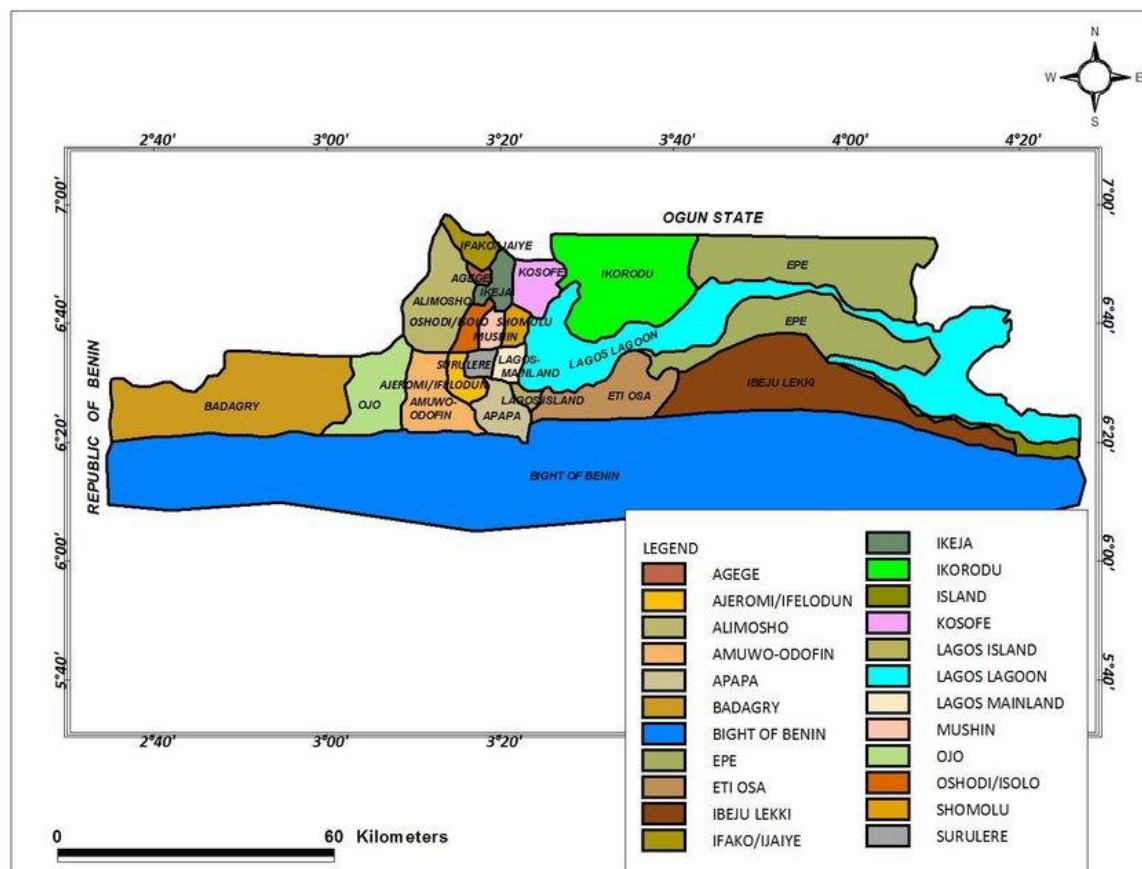


Figure 1: Map of Lagos State showing Local Government Areas

Source: Adapted from Aderamo and Magaji (2010).

The research area for this study is Lagos State, Nigeria. As shown in Figure 1, Lagos State comprises a dense mix of urban and peri-urban regions, many of which are characterized by infrastructural limitations and informal construction practices. Lagos is strategically located in the southwestern part of Nigeria, with its borders defined by Ogun State, the Republic of Benin, and the Atlantic Ocean. A rapidly growing city with a dense population, and a significant hub for construction activities in the country. The city is characterized by an urgent demand for sustainable construction practices, making it an ideal location to investigate the barriers to the adoption of Construction 4.0 technologies aimed at promoting a circular economy. The city's fast-paced growth and need for modernization highlight the importance of integrating advanced technologies in construction processes to achieve sustainable development goals.

2.2 Sampling Technique and Method of Data Collection

This study employs a qualitative research design, Semi-structured interviews were conducted to gather in-depth insights. The flexibility of semi-structured interviews allowed for a deeper exploration of the challenges and perceptions regarding the adoption of these advanced technologies in the context of a circular economy. The study population consists of construction professionals, including project managers, builders, engineers, and site supervisors within the Lagos State construction industry who are involved in construction projects that are working towards adoption of Construction 4.0 technologies aimed at fostering a circular economy. When conducting interviews, it is recommended to use saturation as a measure of importance. When the research aims to explore the most frequent concepts, a sample size of 10 units is considered adequate Weller *et al.* (2018). This aligns with Hennink & Kaiser (2022) who opined 9-17 interviewee is sufficient for interviews that necessitates the identification of particular trends. Therefore, this study sought to gather 15 (fifteen interviews). Eventually, the total interview conducted were 10 (ten) out of 15 (fifteen) consulted experts in Lagos state which is in line with Hennink & Kaiser (2022) recommendation for sample size.

Interviewees were intentionally selected using purposive and snowball sampling technique, based on their extensive experience in the construction industry and their active engagement with Construction 4.0 technologies, along with their understanding of the potential for these technologies in supporting a circular economy. The collected data was transcribed, coded, and thematically analyzed using qualitative data analysis software. The numerous data collected during the field survey was subjected to a Computer-Assisted Qualitative Data Analysis Software (CAQDAS). The CAQDAS that was used to support the analysis of this study is NVivo, it was used to generate word clouds. Key themes were identified, and the findings were presented using charts, tables, and narratives to provide a comprehensive understanding of the barriers to the adoption of Construction 4.0 technologies for circularity.

3. Results and Discussion

Figure 2 shows the demographic information of the participants, the analysis reveals that 80% of the respondents were male, while 20% were female, indicating a predominance of male professionals in the study. This gender distribution is consistent with the typical male-dominated nature of the construction industry. Although this study did not specifically examine gender-based differences in the adoption of Construction 4.0 technologies, the demographic distribution is consistent with the broader industry context and supports the relevance of the sampled perspectives. In terms of professional designations, 50% of the participants were Construction Managers, Registered Builders accounted for 20%, and Quantity Surveyors made up 10% of the participants. Material Flow Scientists, Environmentalists, and Green Building and Sustainability Experts were also represented, each constituting 10%. This diversity in professional roles ensures a broad perspective on the barriers to adopting Construction 4.0 technologies for circularity. While it may seem like some professions were not duly represented, the selection strategy prioritized experts who could offer informed insights into Construction 4.0 adoption, regardless of traditional job titles. The work experience distribution shows that 10% of participants had 0-10 years of experience, 50% had 10-20 years, and 30% had 20-30 years of experience. This suggests that most respondents were mid to senior-level professionals with substantial experience in the construction industry. Overall, the demographic profile indicates that the study captured insights from a diverse, experienced, and knowledgeable group of professionals, making the findings on the barriers to adopting Construction 4.0 technologies in the Nigerian construction industry both credible and comprehensive.

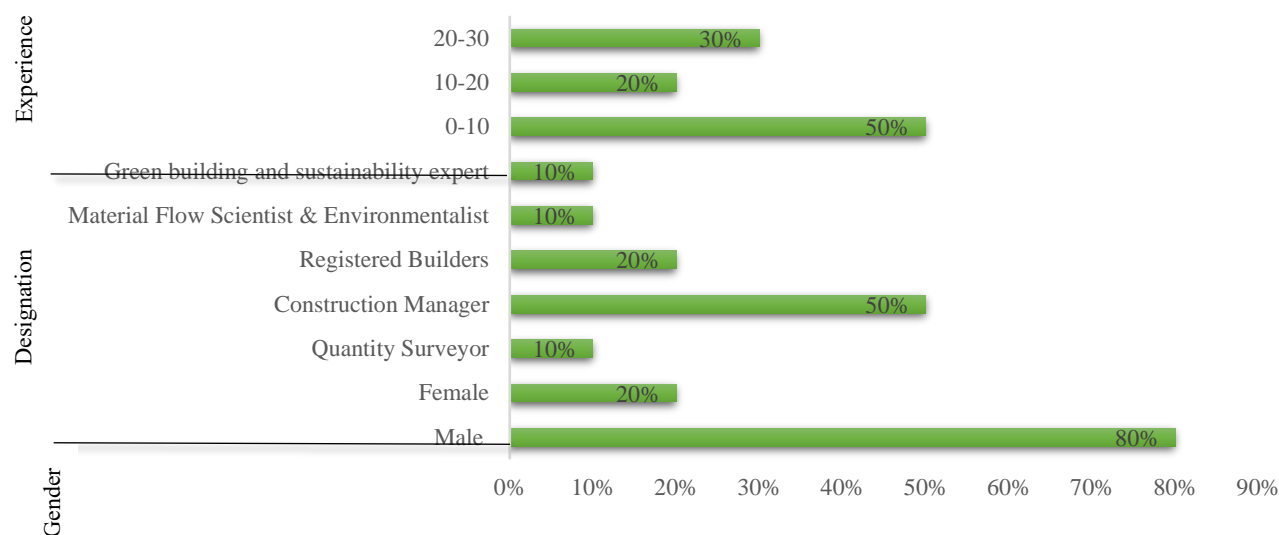


Figure 2: Demographic information of participants

Table 2: Themes that emerged from the qualitative data analysis

Codes	Theme
Awareness	Barriers to Adoption of construction 4.0 for Circularity
Knowledge Gap	
Steep learning curve	
Culture Shock	
Resistance to change	
Cost	
Transparency	
Informal sector	
Enabling Environment	
Incentives	
Maintenance	
Downtime from service providers	
Sustainable materials	
User Friendly	
Regulation	
Design Integration	
Client demand	
Advocacy	
Training	

Thematic analysis of the interview transcripts led to the identification of several codes that were clustered into major themes. This theme represents the barriers to the adoption of Construction 4.0 technologies for circularity. Table 2 presents the codes generated during analysis and their corresponding theme. These themes explored the hurdles stakeholders in the construction industry face before, during and after the primary adoption of construction 4.0 technologies for circular economy.

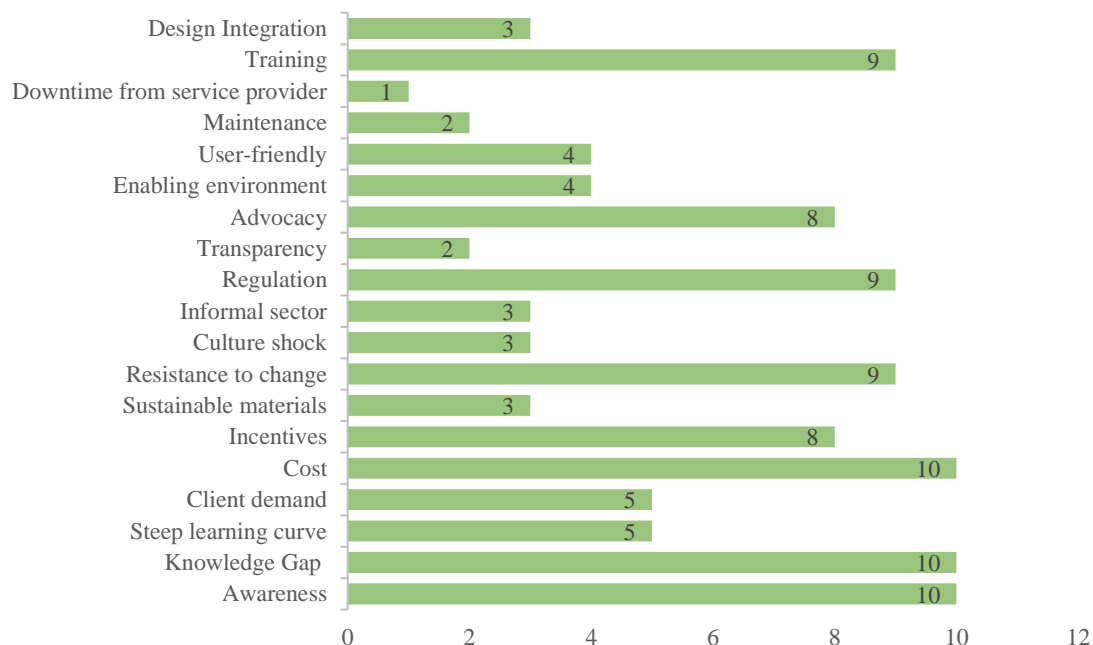


Figure 3: Frequency of factors influencing adoption of construction 4.0 for circularity

The analysis of the data reveals several significant barriers to the adoption of Construction 4.0 in advancing a circular economy within the construction industry. From Figure 3 above, among the most prominent challenges are awareness, knowledge gaps, and cost, each cited by all respondents (100%). The lack of awareness and knowledge is particularly detrimental in a sector where advanced technologies such as digital twins, automation, and the Internet of Things (IoT) are essential for enabling resource efficiency and sustainable practices inherent to a circular economy. Without adequate understanding of these innovations, industry players are unable to harness the potential benefits they offer, leaving traditional linear models in place. Additionally, the high cost of implementing these technologies creates a financial barrier that prevents wider adoption, especially in a resource-constrained environment like Nigeria's construction sector. Another major barrier is resistance to change, identified by 9 respondents (90%). Resistance to new technologies reflects a broader challenge within the construction industry, where entrenched practices are difficult to shift. This reluctance to embrace innovation slows down the transition towards more circular approaches, such as recycling construction materials and minimizing waste. Alongside this, regulatory challenges and the lack of sufficient training, also cited by 9 respondents (90%), Weak regulatory environments and insufficient policy incentives hinder the development of standards that encourage the adoption of sustainable practices and technologies that are key to Construction 4.0. Incentives, mentioned by 8 respondents (80%), further highlight the challenge of motivating industry stakeholders to invest in circular economy models. In the absence of strong governmental or market-based incentives, there is limited motivation to adopt Construction 4.0 technologies, which could otherwise streamline processes, reduce waste, and promote resource reuse all core elements of the circular economy. Moderate barriers include the steep learning curve and client demand, with 5 respondents (50%) mentioning these issues. The steep learning curve reflects the complexities involved in adopting Construction 4.0 technologies, which require both technical expertise and a willingness to overhaul traditional methods. The lack of sufficient client demand for circular economy practices further compounds the challenge.

Other less frequently mentioned barriers, such as sustainable materials and design integration, each cited by 3 respondents (30%), highlight specific obstacles that are still relevant to the shift toward a circular economy. The scarcity of sustainable materials makes it difficult to implement circular principles, which depend on the availability of materials that can be reused or recycled. Similarly, the challenge of design integration suggests that incorporating circular economy principles into the early design phases of construction projects remains a niche concern rather than a widespread practice. On the lower end of the barrier spectrum, issues such as transparency, maintenance, and downtime from service providers were cited the least, with 2 respondents (20%) mentioning transparency and maintenance, and only 1 respondent (10%) citing downtime. While these challenges may not be widespread, they still indicate specific technical and operational hurdles that could impede the smooth adoption of Construction 4.0 technologies.

“People are very, very adamant to change in this part of the world. There are people who are afraid of making mistakes.” (Respondent 3, Male, Registered Builder)

“The major thing is being on the same page with other stakeholders. The BIM is meant to bring every one of us to a platform where we can all collaborate and identify gaps in our designs and costs. But in a situation where there are 3 or 4 major stakeholders on a particular project and only 2 are able to deploy BIM effectively, there is no how you won't struggle. The number of those yet to deploy outweighs those that have. Other apps that are deployed strictly within the organization and don't need a third party, it will be fine, but in construction, it's not all about your organization, it's more of the involvement of stakeholders.” (Respondent 5, Female, Construction Manager and Chief Operating Officer)

“The cost of implementation is always a major challenge. And because of Nigeria, the way it is right now with the issue of inflation, there is no stability in the open markets and all of that. So, yes, the initial cost of Implementation is the major factor for a lot of organizations to embrace this.” (Respondent 8, Female, Green Building and Sustainability expert)

“For us private individuals, we are willing to, you know, take the bull by the horns and ensure that we create sustainable green building measures in every of our construction. However, the government, what are they doing? Are there any government buildings that is being registered at the moment as a green building? No. So government is not even encouraging its citizens to adopt these measures.” (Respondent 8, Female, Green Building and Sustainability expert)

“Well, I would say there's low client demand because many clienteles still do not understand what it is. And so, there's no client push for contractors and consultants to deploy it.” (Respondent 9, Male, Construction Manager)

“Awareness is the major issue. If we are aware, we would not be doing destructive construction, that is, construct a building then destroying some part of it to patch it up. If you're doing this for the first time, you have to learn from people doing it. You don't assume. Oh, and majority of those in the ecosystem who are new students don't know these things as well.” (Respondent 3, Male, Registered Builder)

“The technical know-how is still lacking. We have people afraid or unaware of the ability to use these technologies and afraid of the cost of investing in it, people think that these technologies are not affordable or are not easily accessible to them, it becomes a barrier for them to utilize it. We have quite a lot of issues too, in terms of the market inhibiting new innovations. They are used to traditional process. And so, the new innovation like this is sort of like a competitor or is regarded as a barrier to their own current process work processes.” (Respondent 9, Male, Construction Manager)

“There is an awareness issues, people don't know enough. Also, there is resistance to change and no proper regulatory framework to back it up. And looking at some short-term construction, it may be more costly to engage technologies like that, there is also the fear of mistakes especially on big projects. Experimenting can leave people in debt.” (Respondent 6, Project Manager)

These identified barriers were further grouped into categories. Table 3 presents a categorized summary of the barriers to the adoption of Construction 4.0 technologies for circularity, as identified through the thematic analysis. The barriers were grouped into five overarching categories: Knowledge and Awareness, Economic and Financial, Cultural and Behavioral, Institutional and Environmental, and Technical and Operational. Barriers under Knowledge and Awareness, such as limited awareness, knowledge gaps, and steep learning curves highlight the lack of exposure and training in Construction 4.0 technologies among professionals. The Economic and Financial category, which includes cost-related concerns, lack of incentives, and access to sustainable materials, reflects the affordability challenges of implementing new technologies in a resource-constrained environment. The Cultural and Behavioral category, comprising resistance to change and culture shock, points to entrenched habits and skepticism toward digital transformation in Nigeria. Meanwhile, Institutional and Environmental barriers such as regulation gaps, lack of advocacy, and dominance of the informal sector underscore systemic issues in Nigeria's construction ecosystem that hinder standardization and innovation. Finally, the Technical and Operational category addresses practical challenges like downtime from service providers, lack of user-friendly interfaces, insufficient maintenance systems, and poor integration of technologies into design workflows.

Table 3: Category of barriers to the adoption of construction 4.0 technologies for circularity

Challenge	Category
Awareness	Knowledge and Awareness
Knowledge Gap	
Steep learning curve	
Client demand	
Cost	Economic and Financial
Incentives	
Sustainable materials	
Resistance to change	Cultural and Behavioral
Culture shock	
Informal sector	Institutional and Environmental
Regulation	
Transparency	
Advocacy	Technical and Operational.
Enabling environment	
User-friendly	
Maintenance	
Downtime from service provider	
Training	
Design Integration	

This classification helps structure the complexity of challenges into actionable domains, offering a clearer roadmap for targeted interventions.



Figure 3: Barriers to the adoption of construction 4.0 technology for circularity in word cloud

Figure 3. presents a word cloud of the most frequently mentioned terms extracted from the interview transcripts. Commonly cited barriers include market resistance, high cost, limited awareness, regulatory challenges, and economic constraints. The size of each term reflects its frequency and emphasis among participants

Findings from the theme indicate that stumbling blocks await stakeholders attempting to adopt these technologies at every stage of the construction process. These challenges can be broadly categorized into five key areas: Knowledge and Awareness, Economic and Financial, Cultural and Behavioral, Institutional and

Environmental and Technical and Operational. Widespread ignorance from both sides of the construction divide presents the major impediment to the adoption of construction 4.0 technology in the Nigerian construction industry as does cost of acquisition and training. The awareness gap often leads stakeholders to avoid adopting these advanced technologies, preferring instead to play it safe with tried and trusted traditional methods. This aligns with findings by Amadi *et al.*, (2023) who highlighted risk aversion as a major hindrance to innovation adoption. In the Nigerian political climate were getting any particular group to work in sync may be harder than it sounds, an endeavor such as construction 4.0 that requires heightened levels of collaboration among parties proves a real headache. Moreover, the informal sector, which plays a crucial role in Nigeria's construction industry, is often overlooked, this indicates a significant gap in understanding the full scope of the construction workforce in Nigeria. Furthermore, the technicality of operating and maintaining construction 4.0 technology remains a major issue. Much of the workforce simply lacks the high levels of skills required for such tasks. As a result, the learning curve for workers is steep and often discouraging. Governmental inertia adds to stakeholders' discouragement in embracing these practices. According to Yuan *et al.*, (2011) the lack of updated regulations and policies to mandate and support the adoption of Construction 4.0 technologies and a circular economy is to blame. Few building regulations emphasize energy conservation and recycling. Those that do are woefully outdated in an era of alarming climate changes. Additionally, the scarcity of locally sourced sustainable materials, often due to quality concerns forces contractors and clients to rely on more expensive and harder-to-source foreign products (Pacheco-Torgal *et al.*, 2013). These findings highlight the multifaceted challenges that must be addressed to facilitate the adoption of Construction 4.0 technologies in Nigeria's construction industry, particularly in advancing a circular economy.

4. Conclusion

Following the results of the analysis, the study concludes that the adoption of Construction 4.0 technologies for a circular economy in Nigeria's construction industry is significantly hindered by several barriers. The most prominent barriers identified were high implementation costs, limited awareness, knowledge gaps, and resistance to change. Additionally, the lack of regulatory frameworks and insufficient incentives further impede the industry's ability to transition to circular construction practices. The findings indicate that the reluctance of stakeholders to embrace digital technologies like BIM, IoT, and 3D printing stems largely from cultural, financial, and institutional challenges. These barriers collectively slow the industry's shift towards a circular economy, which is crucial for improving resource efficiency, minimizing waste, and promoting sustainability. Without addressing these challenges, the widespread adoption of Construction 4.0 technologies in Nigeria will remain limited, hindering the overall progress towards circularity in the sector.

The study recommends that the identified barriers should be given careful consideration during policy formulation and industry reform. There are currently no statutory mandates promoting the integration of these technologies in Nigeria's construction regulations. Addressing this gap would enhance the industry's sustainability and resource efficiency. Furthermore, construction stakeholders must prioritize the selection and implementation of digital tools to foster circular economy practices. Collaborative efforts should be made to ensure that these technologies are adopted across all stages of construction, particularly in the design and planning phases. By doing so, the industry can significantly reduce waste, improve material reuse, and enhance project efficiency. Lastly, both the government and private sector should focus on creating financial incentives and training programs that will help reduce the high cost of adoption and bridge the existing skills gap. These initiatives would strengthen the industry's capacity to embrace circular economy principles, ensuring a more sustainable and resilient future for Nigeria's construction sector.

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