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Citation: Arowoiya, V. A., Oke, A. E., Onososen, A. 2026. A Framework for Addressing Barriers to Digital Twin Adoption in the Construction Sector of Developing Countries. *Construction Economics and Building*, 26:3/4, 1–25. <https://doi.org/10.5130/e92c7616>

ISSN 2204-9029 | Published by UTS ePRESS | <https://epress.lib.uts.edu.au/journals/index.php/AJCEB>

ARTICLES (PEER REVIEWED)

A Framework for Addressing Barriers to Digital Twin Adoption in the Construction Sector of Developing Countries

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DOI: <https://doi.org/10.5130/e92c7616>

Article History: Received 10/08/2025; Revised 31/10/2025; Accepted 19/01/2026; Published 18/09/2026

Abstract

Despite the global advancement of digital technologies aimed at improving productivity and performance, several limiting factors hinder the adoption of digital technologies among construction professionals, especially digital twin technologies. This research investigates the barriers to the use of the digital twin (DT) among construction professionals. A survey approach was adopted, and questionnaires were distributed using random sampling techniques to digitally inclined professionals. The response rate for the data retrieved was 50.9%; descriptive and inferential statistics were used to analyze the data collected. It was found that lack of government support, lack of expertise, cost of implementation, unavailability of technological operators, and lack of standardized tools were the top-ranked barriers to using DT in a developing context. Factor analysis was conducted to group the barriers into five components: programming and simulation, mindset, policy and structure, economic, and knowledge barriers. The Kruskal–Wallis test revealed that the cost of implementation significantly differed among the professionals,

DECLARATION OF CONFLICTING INTEREST The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. **FUNDING** The author(s) received no financial support for the research, authorship, and/or publication of this article.

while other factors did not differ significantly among the respondents. Dunnett's and least significant difference (LSD) post-hoc tests revealed significant differences between architects and builders, builders and quantity surveyors, architects and engineers, and engineers and quantity surveyors. It was therefore concluded that government support and the availability of technological experts are critical in helping professionals embrace cutting-edge technology such as DT. It was recommended that the government and other stakeholders make efforts to improve awareness and technical capacity through training, workshops, and seminars. It was also recommended that user-friendly DT solutions be developed to facilitate broader implementation across construction firms and organizations.

Keywords

Barriers; Construction; Digital Twin; Professional; Technology

Introduction

Digital twins (DTs) are virtual models connected to physical systems through data links, enabling simulations, predictions, and real-time decision-making ([Kober et al., 2024](#)). Initially coined in the context of rocket development, the scope of DTs has expanded across various industries, leveraging advancements in the Industrial Internet of Things (IIoT), big data, artificial intelligence (AI), cyber-physical systems (CPS), cloud computing, and automation ([Bello et al., 2024](#)). These technologies eliminate the effort and delay in model parametrization by integrating live data, thanks to the proliferation of sensors and the miniaturization of computing hardware in the Industry 4.0 era ([Almatared et al., 2024](#)).

In recent years, enhancing cost-effectiveness, sustainability, and flexibility has become critical for maintaining competitiveness ([Ferlito et al., 2022](#)). Digitalization has emerged as a crucial enabler of these goals, leading to widespread digital transformation ([Adewale et al., 2024](#)). This refers to the integration of digital technology across all business areas, fundamentally changing how organizations operate and deliver value to customers ([Barrientos-Orellana et al., 2022](#)). The adoption of emerging technologies, such as DTs, is crucial for improving performance, particularly in industries facing significant challenges, including the construction sector.

The construction industry, globally and in Nigeria, struggles with low productivity, project delays, and cost overruns ([Oke et al., 2023](#)). To address these issues, the industry is increasingly turning to digital and innovative solutions such as Building Information Modeling (BIM), the Internet of Things (IoT), blockchain, immersive techniques, and DTs ([Garrido-Hidalgo et al., 2024](#)). Specifically, DTs have become highly relevant for the construction industry, offering the ability to create dynamic, real-time replicas of built assets, systems, or processes ([Torres et al., 2024](#)). These models allow construction professionals to test designs, monitor performance, and identify areas for improvement during the construction process. DTs have been shown to enhance decision-making, reduce risks, and optimize project performance, leading to better collaboration among stakeholders.

Despite the clear benefits, the adoption of DT in the construction industry remains slow, especially in Nigeria. The Nigerian construction industry (NCI) is notorious for lagging in digital technology uptake, exacerbating its performance issues ([Fagbenro et al., 2022](#)). Limited studies have explored the barriers to DT adoption in developing countries. Most existing research on these barriers has been conducted in regions such as Indonesia, the Middle East, Sri Lanka, Singapore, and several developed nations, revealing a clear geographical gap ([Waqar et al., 2023](#); [Indunil et al., 2025](#); [Barham et al., 2025](#)). This underscores the need for a more coordinated effort to advance digitalization, particularly within the NCI ([May & Rösner, 2022](#)). The slow adoption of DT is further compounded by the coronavirus pandemic, which has increased the pressure on the industry to improve productivity and efficiency ([Musonda et al., 2023](#)). High-value

industries like aerospace and automotive have already embraced DTs as part of their digital transformation strategies, benefiting from reduced costs, risks, and design time ([Kober et al., 2024](#)).

For the NCI, incorporating DT into its digital strategy could unlock similar benefits, improving the delivery and management of infrastructure projects ([Bonomi & Drobot, 2023](#)). The potential to visualize the final product, adjust before construction, and engage in accurate project planning underscores DT's capacity to transform construction practices. Nonetheless, broader acceptance and application of DT within the NCI are essential to realizing these advantages ([Winter & Chico, 2023](#)). The objective of this research was to examine the barriers to the adoption of DT technology (DTT) among construction professionals in Nigeria. This is highly significant to the developing context because identifying these key challenges will enable targeted strategies to accelerate digital transformation and improve project outcomes in the construction industry.

Literature review

TRENDS IN DIGITAL TWIN RESEARCH

DTs have significant potential to improve project planning, design, and construction in the NCI by enabling proactive risk management and enhancing efficiency ([Bonomi & Drobot, 2023](#)). However, adoption remains limited, reflecting a global trend of slow DT maturity ([Jahangir et al., 2024](#)).

While the Architecture, Engineering, Construction, and Operation (AECO) industry is moving toward digital transformation ([Kerrouchi et al., 2024](#)), technical challenges (e.g., interoperability, real-time capabilities, and data quality) and non-technical factors (e.g., resistance to change, skill gaps, and unclear objectives) hinder widespread use ([Klößner et al., 2023](#)).

There is no universal definition of DTs, contributing to conceptual ambiguity ([Mohandes et al., 2024](#)). The shift from BIM to DTs introduces real-time data integration, enabling better life cycle management of built assets ([Zhao et al., 2022](#)). DTs are increasingly applied in sectors such as smart manufacturing, healthcare, and facility management, demonstrating versatility and benefits that include improved decision-making, sustainability, and operational efficiency.

In developing countries, adoption is slowed by limited skilled personnel, project complexity, poor connectivity, and integration challenges ([Machado et al., 2023](#)). Overcoming these barriers requires clearer definitions, stronger stakeholder collaboration, targeted training, and strategic investment ([Rafsanjani & Ahn, 2016](#); [Opoku et al., 2023](#)). Overall, DTs are central to the future of data-driven, sustainable, and efficient construction, but their full potential will only be realized through coordinated innovation and implementation efforts ([Grasso et al., 2024](#)).

BARRIERS TO DIGITAL TWIN TECHNOLOGY FOR CONSTRUCTION PROJECT PERFORMANCE

The following challenges can be identified in the implementation of digital twins, although it enhances the Cyber-Physical Production System (CPPS) in functionality, predictive capabilities, and efficiency. The widespread use of manual motion data acquisition, despite its conflict with the need for real-time data availability, limits the potential of simulation, which requires a central information system ([Al-Bouwarthan et al., 2020](#)). In addition, the in-house implementation of Industry 4.0 is often insufficient; slow standardization of data acquisition in production hinders agile and adaptable system implementations, and standardization of data acquisition has not yet been achieved. Furthermore, high costs for new information technology (IT) environments prevent the application of Industry 4.0; coupling of simulation and optimization is not sufficiently ensured to fully benefit from near real-time models and raises data

Table 1. Summary of literature review of the barriers to the adoption of digital twin technology for construction project performance.

S/N	Variables	Al-Bouwarthan et al., 2020	Singh et al., 2021	Eleonu & Anebo, 2020	Mchirgui et al., 2024	West & Blackburn, 2017	Choi et al., 2019	Kshetri, 2021	Grieves, 2014	Sepasgozar, 2020	Radchenko et al., 2018	Kehoe et al., 2015	Deng et al., 2019
B1	Unavailability of technological operators												
B2	Slow standardization of data acquisition in productions						✓						
B3	Digital privacy and rights issues	✓	✓										✓
B4	Electrodermal activity (EDA)						✓						
B5	Lack of standardized tools												
B6	Technical knowledge of the operation									✓			
B7	Lack of trust											✓	
B8	Lack of finance		✓					✓					✓
B9	Economic situation of the nation										✓		
B10	Poor investment return/profit margin								✓				
B11	Unreliable power supply				✓								
B12	Complexity						✓						
B13	Cultural beliefs			✓									
B14	Lack of government support												
B15	Cost of implementation					✓			✓				
B16	Limitations in the simulation potential, combined with decentralized data acquisition and connectivity problems												
B17	Lack of awareness												
B18	Lack of experts												
B19	Low-speed Internet connection												

security concerns ([Uhlemann et al., 2017](#)). The hindering factors are discussed in the following section, and a summary of the literature review is shown in [Table 1](#).

Cultural beliefs

Culture is largely focused on why people are motivated and what their capabilities are. Research on the cultural and management barriers to implementing digital engineering in design, procurement, and manufacturing appears to be more mature than that in construction and facilities management ([Eleonu & Anebo, 2020](#)). Some cultures rely on traditional methods and human expertise for executing any construction project. In addition, there is reluctance or skepticism to replace traditional construction practices with digital twin systems; for instance, concerns regarding data privacy and security, and fear of losing their jobs due to automation of processes. When top leaders in an organization are unfamiliar due to cultural background, it can lead to resistance to digital twin adoption ([Barham et al., 2025](#)).

Shirowzhan et al., 2019	Thirumal et al., 2024	Rathore et al., 2021	Greif et al., 2020	Russell, 2020	Botin-Sanabria et al., 2022	Opoku et al., 2023	Agrawal et al., 2022	Yang et al., 2024	Zhu et al., 2024	Waqar et al., 2023	Barham et al., 2025	Indunil et al., 2025
	✓											
										✓		
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		✓									✓	
			✓									
						✓						
	✓											
											✓	
									✓			
					✓							
						✓						
				✓			✓	✓				

Cost of implementation

Factors affecting the cost of implementation include the need for new business models, a lack of a methodical approach for implementation, and high coordination effort ([Grieves, 2014](#)). According to [West and Blackburn \(2017\)](#), cost is a major consideration when deciding to implement digital twins in construction projects. In addition, the need for highly skilled operators who are proficient in digital technologies can lead to high labor costs and increase the overall cost of project execution, which makes DT adoption unappealing to stakeholders.

Slow standardization of data acquisition in production

This area is still being developed and lacks standards, such as a comprehensive and global standard for RFID technology, multi-protocol tags, and readers, and consistent BIM standards (to address software incompatibility). These reflect limited strategies and a lack of standardization of technical features. Additionally, an industry-specific reference architecture for Industry 4.0 is required ([Choi et al., 2019](#)).

Technical knowledge of operation

Digital twins involve the integration of different technologies, including sensors, cloud computing, data analytics, and visualization tools. Lack of standards, weak IT infrastructure, uncertainty about systems reliability, difficult interoperability/compatibility, and lack of technological maturity are challenges faced when setting up these components for digital twins ([Indunil et al., 2025](#)). Furthermore, the lack of standardized and shared project information is caused by the short-term nature of building projects and the disjointed nature of the construction value chain ([Sepasgozar, 2020](#)). Adoption is hindered when there is a lack of expertise in operating and using DT systems.

Economic situation of the nation

High cost of equipment, lack of business evaluation, unclear benefits, complexity of the construction site-based environment, financial risks, access to capital, and over-optimistic demand forecasts significantly influence DT implementation ([Radchenko et al., 2018](#)). Also, [Greif et al. \(2020\)](#) mentioned that hard economic challenges make it difficult to utilize DT. A country's economy impacts investment capabilities for these technologies and infrastructure development. These technologies have high initial investment costs, which constrain small and medium enterprises (SMEs) from investing in those technologies.

Lack of standardized tools

There is a growing need for customization while at the same time competing globally with rivals. As a result of increasing product diversity (high-volume to low-volume production), this trend, which is driving the transition from macro to micro markets, leads to smaller lot sizes. It is necessary to consider higher needs for computing equipment used in the environment of a building site, which is primarily outside, dusty, and damp. For instance, mobile gadgets ought to be built to withstand high humidity, big drops, and powerful vibrations ([Shirowzhan et al., 2019](#)).

Complexity of DT implementation

Site layouts, client modifications, insufficient time and resources, and progress measurement are quite challenging. Others include project ambiguity, piece-work contract, technological problems, the absence of standardized procedures, local variations, dynamic projects, and interdependencies. Design-related issues include uncontrolled environments, robot intelligence, inefficient algorithms, limited modularization, reusability of information technology and solutions, and immature functional integration ([Choi et al., 2019](#)).

Poor investment return/profit margin

Digital twin technology is associated with upfront costs, which include software, hardware, and training that deter companies from reaching their profit target. Most construction companies hesitate to invest in technology when the return on investment is unclear or long-term ([Opoku et al., 2023](#)). In addition, smaller companies also struggle for financial resources for digital transformation due to low profit margins and market position, additional innovation risks, costs associated with the protection of intellectual property (IP), academic collaboration, and start-up costs ([Grieves, 2014](#)).

Unreliable power supply

It takes enormous amounts of energy to perform proof-of-work processes. Demand management, grid capabilities, and emissions are all impacted by the built environment ([Mchirgui et al., 2024](#)). Ensuring a reliable supply of electricity will require making quick decisions, depending on the expert judgment of grid operators. The supply of power is a major factor in the successful implementation of digital twins in the construction industry, especially in developing countries where supply is unreliable because of power

interruptions. Digital twins depend on real-time data synchronization and cloud connectivity, and power interruptions disrupt data flow for digital twin platforms.

Digital privacy and rights issues

Concerns about privacy, security, and unethical use, and inefficient data processing that could provide biased results are only a few of the issues raised by big data ([Singh et al., 2021](#)). Supply chain experts expressed worries about data security and privacy, claiming that one of the main barriers to data sharing, particularly with consumers, is outdated legislation. Since transnational supply chains must adhere to various national laws when exchanging data, privacy, security, and data regulations may pose significant concerns ([Waqar et al., 2023](#)). However, by implementing efficient data governance activities within data integration and management, these difficulties could be resolved ([Arunachalam et al., 2017](#)).

Anyone involved in the computing business should be concerned about privacy and security, and data analytics is no exception. Because AI is still in its infancy, laws and regulations have not yet been properly developed ([Al-Bouwarthan et al., 2020](#)). As technology advances, the problem can be resolved by increased regulation, monitoring, and policies about AI. Future regulation could guarantee the creation of algorithms that take precautions to safeguard user data. A new law known as the General Data Protection Regulation (GDPR) establishes the protection and privacy of personal data in the UK and throughout Europe. Although it is a general rule for data and security, GDPR emphasizes the specific issues of handling data when creating AI algorithms ([Deng et al., 2019](#)).

Lack of trust

Another issue that affects a large part of the AI sector is trust. First, it is still relatively new, and second, using AI can be intimidating unless the developer is aware of its intricacy ([Kehoe et al., 2015](#)). Trust is hampered by the fear that AI and robots will overtake humans as the dominating force on Earth and seize control of vital infrastructure. AI is portrayed mostly in terms of its potential negative outcomes, and a lack of trust may pose a significant hurdle. Although there are increasingly good media articles about AI, there is still a clear problem, and more people need to be exposed to AI and its beneficial applications to overcome trust issues ([Shirowzhan et al., 2019](#)). These trust issues are exacerbated by privacy and security concerns but can be mitigated by more thorough privacy and security regulations governing AI.

Lack of financial resources

Digital twin creation has been expensive for a long time. Businesses have to invest in advanced software and recruit engineers and developers on a full-time basis ([Barham et al., 2025](#)). There has not been much testing or data visualization. In recent years, wearable technology and mixed reality have emerged, making the development of digital twins easier ([Deng et al., 2019](#)). However, access to financial resources for sensors and other computational resources remains limited ([Singh et al., 2021](#); [Rathore et al., 2021](#)), which is common in developing countries ([Kshetri, 2021](#)).

Lack of awareness

Most professionals are not aware of digital twins, and there is a misconception between BIM and digital twins, which indicates a low level of knowledge of this concept. This lack of knowledge has limited the acceptance and adoption of digital twin technology implementation in the construction industry ([Opoku et al., 2023](#)). A clear awareness and value proposition to the organization will enhance its adoption.

Lack of government support

Government plays a critical role in digital twin technology implementation. This technology is costly for small businesses, enterprises, and large organizations. The government should create incentives and give

subsidies for its adoption. Such initiatives and policies should be implemented to accelerate the adoption of DT technology ([Zhu et al., 2024](#)). However, few governments have incorporated digital twin technology in construction, such as the National Digital Twin Programme (NDTP) in the UK through the Centre for Digital Built Britain, and the Sydney Opera House, using centralized data sources for improving its operation and maintenance through DT concepts.

Lack of experts

Construction professionals have a limited understanding of what digital twins are made up of, what their capabilities and levels are, and how to utilize them effectively. Also, stakeholders are unwilling to change from traditional workflows to new technologies, such as digital twin systems for integrated workflows ([Agrawal et al., 2022](#)). This lack of knowledge due to inadequate expertise brings low productivity and causes underutilization of DT ([Yang et al., 2024](#)).

Unavailability of technological operators

The construction industry needs skilled operators to manage, analyze, gain insight, and maintain data from the digital twin system. Furthermore, operators must be capable of maintaining both the synchronized virtual and physical entities of a construction project. When there are no technological operators, projects may face the challenges of prolonged delays and high costs ([Thirumal et al., 2024](#)).

Low-speed Internet connection

Digital twins operate smoothly based on reliable and continuous Internet connectivity. Bidirectional transfer between the digital and physical models is needed. A lack of a high-speed Internet connection hinders the full maximization of the potential of digital twins. Real-time data exchange of physical entities requires high-speed Internet connections, such as 5G, for efficient communication interfaces ([Russell, 2020](#)). This will enable improved DT reliability and operational efficiency.

Limitations in the simulation potential, combined with decentralized data acquisition and connectivity problems

Real-time dynamic data are important tools for the creation of digital twins, and there are challenges in the proper integration of these data for the implementation of digital twins. For instance, sensor data come with complexity for data connectivity and processing, which poses challenges to implementation. Furthermore, proper simulation and modeling techniques are important to reduce computational complexity for DT ([Botin-Sanabria et al., 2022](#)).

Electrodermal activity

Electrodermal activity (EDA) is an indicator that measures the sweat gland activity associated with physiological and emotional responses and is controlled by the autonomic nervous system. EDA can be measured on the skin, particularly the palms, fingers, or soles of the feet, to assess stress and excitement ([Choi et al., 2019](#)). In the construction industry, incorporating these data into digital twin frameworks has technical challenges that require seamless integration to manage and monitor the stress and fatigue levels of construction workers for the purpose of enhancing safety.

Research methods

This section describes how this research was carried out. It focused on population, sampling frame, techniques, sample size, data collection, analytical tools, and Cronbach's alpha test. The study adopted a quantitative research approach using a survey of the selected population sample ([Kothari, 2014](#)).

POPULATION

The target population for the study was construction professionals in the built environment in Lagos State. These professionals are registered professionals in each professional body. These were limited to architects, quantity surveyors, builders, and engineers. The basis for selecting Lagos was the level of development in the use of emerging technologies compared to other states in the federation. Also, the level of urbanization in the state and the high volume of construction projects made it the right choice for the study ([Bryman, 2016](#)).

SAMPLING FRAME AND TECHNIQUES

The sampling frame represents the number of respondents within the whole population ([Creswell & Creswell, 2018](#)). The total number of construction professionals was 5,330, i.e., architects, engineers, builders, and quantity surveyors. The breakdown of each profession was 1,850 engineers; 1,080 quantity surveyors; 1,700 architects; and 700 builders. Random sampling techniques were adopted to support generalizability and minimize sampling bias, where each member of the population has an equal chance of being selected ([Saunders et al., 2019](#)). These professionals work in consulting, contracting firms, private and public institutions, and government agencies.

SAMPLE SIZE

To determine the sample size of the study, the formula by [Yamane \(1967\)](#) was used to determine the number of respondents to be chosen from the whole population, as shown in equation 1. The approach aligns with [Creswell and Creswell \(2018\)](#) and [Saunders et al. \(2019\)](#) for quantitative studies. The formula was used to get a sample size of 369 professionals. This was made up of 92 quantity surveyors, 88 builders, 95 engineers, and 94 architects.

$$S = \frac{N}{1 + N(e)^2} \quad (1)$$

where S, N, and e represent sample size, total population, and level of precision or standard of accuracy, respectively. The level of precision used was 10%.

DATA COLLECTION

The questionnaire was developed with two sections; the first section was the general background of the respondents, including academic qualifications, the respondents' professions, professional qualifications, years of working experience, and their organizations' years in operation. The second section 2 was concerned with the barriers or limitations of digital twin technology in construction. This was structured on a 5-point Likert scale based on the level of hindrances. The questionnaires were distributed to the limited sample size of 369 by hand and through the mail. Within 3 months, i.e., March–May, 225 were retrieved, and 188 were deemed fit for further analysis after proper scrutiny. The other 37 questionnaires were excluded and discarded because they were incomplete and contained errors. This response rate of 50.9% was sufficient and reliable, as supported by [Fosnacht et al. \(2017\)](#).

ANALYTICAL TOOLS/DATA ANALYSIS

The collected data were analyzed using SPSS and Excel. Frequencies, percentages, bar charts, and pie charts were employed to present the demographic information of the respondents. Information included the type of organization, field of specialization, years of working experience, and highest academic qualification.

These methods were employed to analyze the variables according to their frequency and percentage distributions and to identify patterns and differences among the variables.

Mean item score (MIS), which is a measure of the distribution of assigned scores within a collection of specified variables, was used to analyze the data. When two or more variables had the same MIS, standard deviation (SD) was used as a basis for ranking. A variable with a larger SD was ranked lower than an item with a smaller SD when their mean scores were the same.

Researchers utilized factor analysis, a flexible statistical technique, to identify underlying factors that may explain the correlations among variables in the dataset. Its main objective was to derive a more parsimonious set of variables, that is, fewer variables than the original set, to facilitate the interpretation of the underlying constructs.

The Kruskal–Wallis test was used to determine whether there were significant differences in the opinions of the four respondent groups regarding barriers to digital twin technology, while Dunnett’s test and the LSD post hoc test were used to identify where significant differences occurred. [Figure 1](#) shows the overall research framework.

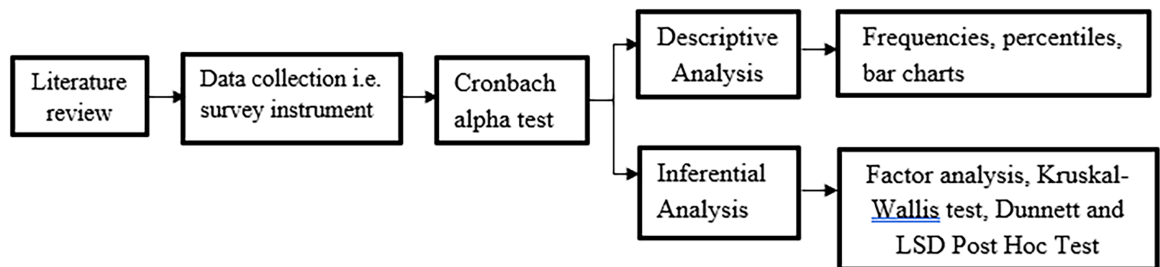


Figure 1. Research framework.

These methods were employed to analyze the variables according to their frequency and percentage distributions and to identify patterns and differences among the variables.

CRONBACH’S ALPHA TEST

The questionnaire was validated, and the test of reliability was conducted using Cronbach’s alpha. This was used to check the internal consistency of the items in the questionnaire survey and verify its reliability, as shown in equation 2.

$$\alpha = \left[\frac{K}{K-1} \right] \times \left[1 - \frac{\sum s^2_i}{s^2_{sum}} \right] \quad (2)$$

where K denotes the total number of barriers to digital twin technology, s^2_i denotes the variance of the respondent’s current sample, and s^2_{sum} is the variance of the sum of the respondents. This study used SPSS to determine Cronbach’s alpha coefficient (α) for the variables ([Taber, 2018](#)). [Table 2](#) presents the test findings indicating that the designed questionnaire is reliable, as its value exceeds 0.50.

Table 2. Cronbach’s alpha test for barriers to the adoption of digital twin technology.

Cronbach’s alpha test	Alpha value
Barriers to digital twin technology	0.845

Findings and discussions

RESPONDENTS' DEMOGRAPHICS

This section reveals the attributes of the respondents. It shows their profession, highest academic qualification, membership status, years of working experience, professional qualification, and years of operation of the organizations of the respondents who have been asked to provide information on their professional backgrounds.

The professionals registered with the Council of Registered Builders of Nigeria (CORBON) were 6.4%, those registered with the Quantity Surveyor Registered Board of Nigeria (QSRBN) were 21%, respondents registered with the Architects Registration Council of Nigeria (ARCON) were 28.7%, and those registered with the Council for the Regulation of Engineering in Nigeria (COREN) were 43.6%. Also, [Figure 2](#) shows the respondents' professions, where quantity surveyors comprise 23.4%, builders comprise 6.4%, architects represent 27.57%, and engineers represent 42.6%.

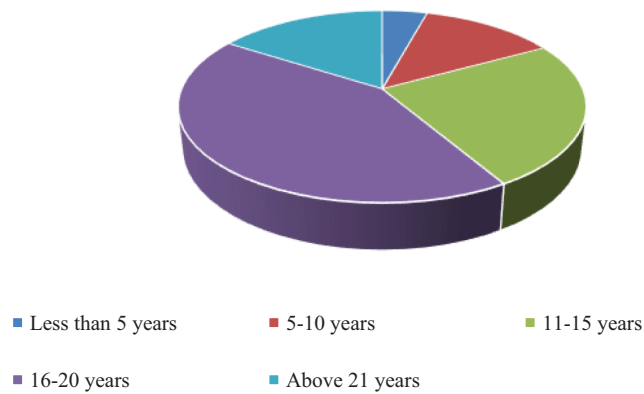


Figure 2. Years of organizational operations.

Furthermore, [Figure 3](#) reveals the years of operation of the respondents' organizations. Organizations with less than 5 years of establishment were 4.3%, while those with 5–10 years of operation were 12.8%. Organizations with 11–15 years of establishment were 24.5%; organizations with 16–20 years of operation were 42.6%; and those with ≥21 years of operation were 16%. Also, the professional qualifications of the respondents showed that Bachelor of Science or Technology (B.Sc/B. Tech) holders were 6.4%, Master

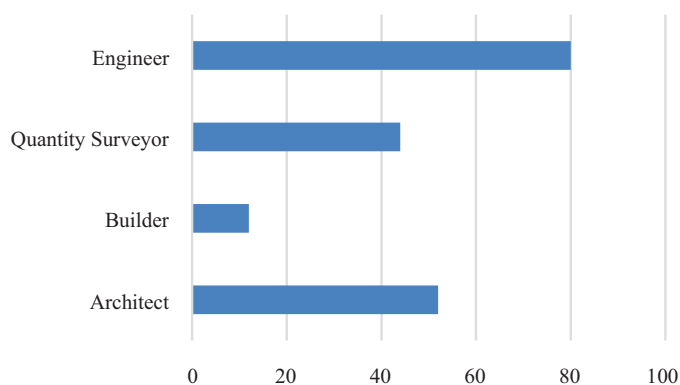


Figure 3. Profession of respondents.

of Science or Technology (M.Sc./MTech) holders represented 24.5%, Higher National Diploma (HND) holders represented 53.2%, and Doctor of Philosophy (Ph.D.) holders made up 11.7%. Moreover, for working experience, 28.7% of the respondents had less than 5 years, 37.2% had 6–10 years, 18.1% had 11–15 years, and 6.4% had 16–20 years. On this basis, it can be concluded that the data provided by the professionals are reliable for the analysis.

DESCRIPTIVE ANALYSIS

[Table 3](#) shows the barriers to adopting digital twins for construction projects. The result reveals that the lack of government support was the major barrier, with a mean of 3.90, followed by the lack of experts with a mean of 3.87. The cost of implementation had a mean of 3.85, next to the unavailability of technological operators with a mean of 3.79. The lack of standardized tools was ranked fifth with a mean of 3.78, followed by the lack of financial resources with a mean of 3.76, while unreliable power supply was ranked seventh. The economic situation of the nation and lack of awareness were both ranked eighth; however, the economic situation of the nation was ranked higher than lack of awareness because it had a lower standard deviation. Finally, the least of the barriers were digital privacy and rights issues, with a mean of 3.53.

Table 3. Barriers to the adoption of digital twin technology for construction project performance.

Factors	Mean	Standard deviation	Rank
B14	3.90	0.942	1
B18	3.87	0.894	2
B15	3.85	0.911	3
B1	3.79	0.898	4
B5	3.78	0.850	5
B8	3.76	0.892	6
B11	3.72	0.988	7
B9	3.70	0.958	8
B17	3.70	1.027	9
B16	3.69	0.924	10
B10	3.69	0.937	11
B13	3.69	0.984	12
B19	3.67	0.986	13
B2	3.66	0.941	14
B12	3.64	0.908	15
B6	3.64	1.047	16
B7	3.63	0.958	17
B4	3.62	0.994	18
B3	3.53	0.893	19

INFERENTIAL ANALYSIS

In terms of the quantity of data and the size of the population, [Table 4](#) illustrates how adequate the sampling strategy was. [Tabachnick and Fidell \(2007\)](#) stated that for component analysis to be appropriate,

Table 4. KMO and Bartlett's test for barriers to the adoption of digital twin technology for construction project performance.

Kaiser–Meyer–Olkin measure of sampling adequacy		0.739
Bartlett's test of sphericity	Approximate chi-square	605.033
	df	171
	Sig.	0.000

Table 5. Total variance explained on the barriers to the adoption of digital twin technology for construction project performance.

Component	Initial eigenvalues			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.168	27.201	27.201	5.168	27.201	27.201
2	2.456	12.926	40.127	2.456	12.926	40.127
3	1.862	9.800	49.928	1.862	9.800	49.928
4	1.234	6.497	56.424	1.234	6.497	56.424
5	1.059	5.572	61.997	1.059	5.572	61.997
6	0.980	5.157	67.154			
7	0.877	4.617	71.770			
8	0.808	4.255	76.026			
9	0.694	3.653	79.679			
10	0.587	3.087	82.766			
11	0.552	2.907	85.673			
12	0.524	2.760	88.433			
13	0.425	2.237	90.669			
14	0.395	2.077	92.746			
15	0.375	1.974	94.721			
16	0.304	1.601	96.321			
17	0.277	1.459	97.780			
18	0.262	1.380	99.160			
19	0.160	0.840	100.000			

Extraction method: principal component analysis.

Bartlett's test of sphericity must be significant ($p < 0.05$). Additionally, they proposed that the Kaiser–Meyer–Olkin (KMO) index had a range of 0 to 1, with 0.50 being deemed appropriate for factor analysis. Factor analysis was appropriate in both situations since the KMO index in this instance was 0.739, and the test of sphericity was significant with a value of 0.000.

The initial matrix and the extracted squared loading results for the barriers to the adoption of digital twin for construction project performance are given in [Table 5](#). Initial matrices are in the second, third, and fourth columns (Total, % Variance, and Cumulative %, respectively); the next three columns to the right of the rotated matrix shown are when the eigenvalue was greater than 1. The second column of total/initial eigenvalue shows the total variance explained by each factor. The factors listed in the third column are in decreasing order of the variance. The total variance of the first five items in the third column was 61.99%, meaning that the remaining 19 items only contributed 38.30% of the variance.

[Figure 4](#) shows the scree plot, which is a graphical representation of the eigenvalues on the y-axis against the factors represented as components on the x-axis. The scree plot displays a downward curve, a graphical explanation of the total variance as explained in [Table 6](#). A reduced set of components for barriers to the adoption of digital twins for construction project performance is shown in [Table 7](#).

[Table 8](#) shows the Kruskal–Wallis test to understand the differences in the opinions of professionals regarding barriers to the adoption of DT. Among the factors, professionals had diverging opinions regarding the cost of implementation, whereas construction professionals had a converging view of other factors, which include lack of government support, lack of experts, unavailability of technological operators, lack of standardized tools, lack of financial resources, and unreliable power supply.

A further test was conducted to understand where the significance lies among the professionals. A post-hoc test was conducted to determine where significant differences existed among the variables. Only the cost of implementation showed a significant difference among all the variables. The further test revealed significant differences between architects and builders, architects and engineers, builders and quantity surveyors, and engineers and quantity surveyors, as shown in [Table 9](#).

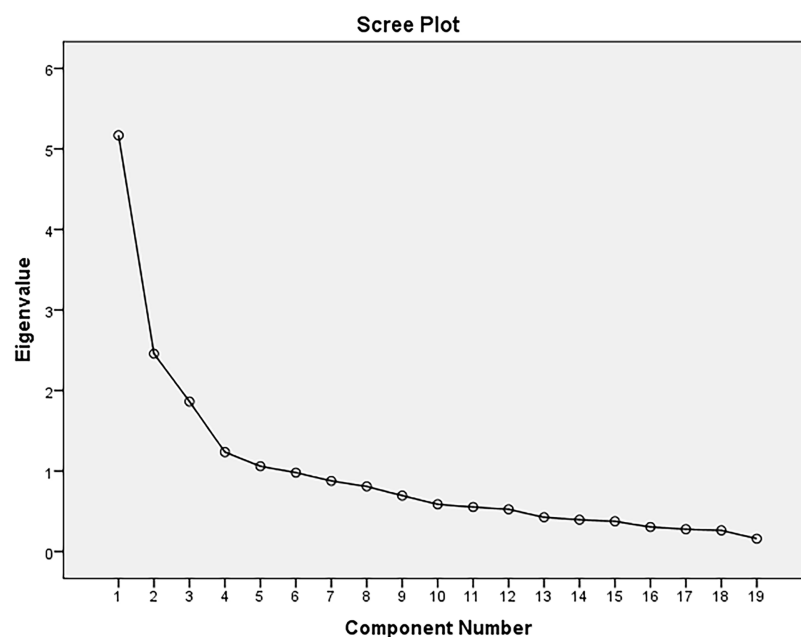


Figure 4. Graphical representation of eigenvalues.

Table 6. Rotated component matrix barriers to the adoption of digital twin technology for construction project performance.

Variables	Component				
	1	2	3	4	5
B2	0.844				
B4	0.762				
B16	0.750				
B3	0.720				
B19	0.631				
B7		0.753			
B8		0.751			
B9		0.654			
B6		0.605			
B11			0.731		
B14			0.725		
B13			0.638		
B10			0.608		
B17				0.788	
B15				0.752	
B1				0.577	
B5					0.772
B18					0.715
B12					0.384

Extraction method: principal component analysis.

Rotation method: Varimax with Kaiser normalization.

a. Rotation converged in six iterations.

Discussion of findings

The barriers to the use of digital twins for construction project performance were represented by a model consisting of five components, as shown in [Table 7](#). Factor analysis yielded only five reduced components. The varimax rotation is given in [Table 6](#); each variable has a significant impact on one of the components, and the loading on each factor is greater than 0.30. [Yap \(2013\)](#) suggested that it is preferable to interpret only factor loadings that are greater than 0.30 (>0.30). Consequently, factor loadings below 0.30 were not shown. The strong communalities indicate that the variables are well represented by the retrieved components. Certain elements were heavily loaded under two components, but the highest loadings were selected for this research.

Table 7. Reduced components for the barriers to the adoption of digital twin technology for construction project performance.

S/N	Factor components	Variables	Factor loading
1	Programming and simulation barriers	B2	0.844
		B4	0.762
		B16	0.750
		B3	0.720
		B19	0.631
2	Mindset barriers	B7	0.753
		B8	0.751
		B9	0.654
		B6	0.605
3	Policy and structure barriers	B11	0.731
		B14	0.725
		B13	0.638
		B10	0.608
4	Economic barriers	B17	0.788
		B15	0.752
		B1	0.577
5	Knowledge barriers	B5	0.772
		B18	0.715
		B12	0.384

Before an accurate and succinct interpretation could be made, it was necessary to name the five extracted components. There was little to no established principle for identifying the extracted components of factor analysis, which was consistent with the first-factor analysis used in this study. The aforementioned remark implied that identifying these elements may have been arbitrary and dependent on the observer's, researcher's, or analyst's perspectives, experiences, and education. Following thorough deliberation on the proper naming procedure, these names were given to each component: (i) programming and simulation barriers, (ii) mindset barriers, (iii) policy and structure barriers, (iv) economic barriers, and (v) knowledge barriers.

PROGRAMMING AND SIMULATION BARRIERS

This component has five items, namely, slow standardization of data acquisition in production with a factor loading of 0.844; electrodermal activity (EDA) with a factor loading of 0.762; limitation in the simulation potential, combined with decentralized data acquisition connectivity problems with a factor loading of 0.750; digital privacy and rights issues with a factor loading of 0.720; and low-speed Internet connection

Table 8. Kruskal–Wallis test on the barriers to the adoption of digital twins in the construction industry.

	S-W	Architect		Builder		Quantity Surveyor		Engineer		Overall		Kruskal–Wallis	
Code		MIS	RK	MIS	RK	MIS	RK	MIS	RK	MIS	SD	Chi-square	Asymp. sig.
B14	0	3.92	6	3.47	12	4.07	2	3.89	1	3.9	0.942	4.589	0.204
B18	0	3.85	9	3.94	2	3.98	3	3.58	4	3.87	0.894	3.547	0.315
B15	0	4.15	1	3.47	13	4.15	1	3.37	15	3.85	0.911	12.49	0.006*
B1	0	4	3	4	1	3.83	11	3.37	14	3.79	0.898	5.408	0.144
B5	0	3.69	14	3.71	7	3.98	4	3.47	9	3.78	0.85	5.386	0.146
B8	0	3.69	16	3.76	3	3.9	7	3.53	5	3.76	0.892	0.974	0.807
B11	0	4	2	3.18	19	3.85	10	3.74	2	3.72	0.988	7.753	0.051
B17	0	3.77	13	3.47	14	3.97	5	3.26	18	3.7	1.027	7.834	0.05
B9	0	3.85	10	3.35	18	3.93	6	3.42	13	3.7	0.958	7.446	0.059
B10	0	4	4	3.47	11	3.85	9	3.32	16	3.69	0.937	6.777	0.079
B16	0	3.77	12	3.76	5	3.75	14	3.42	11	3.69	0.924	1.75	0.626
B13	0	3.92	5	3.41	16	3.9	8	3.32	17	3.69	0.984	5.35	0.148
B19	0	3.92	7	3.71	8	3.7	15	3.42	12	3.67	0.986	2.622	0.454
B2	0	3.69	17	3.76	4	3.6	19	3.68	3	3.66	0.941	0.362	0.948
B12	0	3.77	11	3.65	9	3.68	16	3.47	8	3.64	0.908	1.837	0.607
B6	0	3.38	19	3.65	10	3.78	12	3.53	6	3.64	1.047	1.633	0.652
B7	0	3.69	15	3.76	6	3.63	18	3.47	10	3.63	0.958	0.974	0.807
B4	0	3.85	8	3.47	15	3.65	17	3.53	7	3.62	0.994	1.016	0.797
B3	0	3.46	18	3.41	17	3.75	13	3.21	19	3.53	0.893	5.709	0.127

Notes: S–W, Shapiro–Wilk value; MIS, mean item score; RK, rank; SD, standard deviation; Asymp. sig., asymptotic significant values; and *p-values less than 0.05.

with a factor loading of 0.631. Note that different simulation models have limitations in data integration due to varied features and criteria that limit the full potential, accuracy, efficiency, and effectiveness of digital twin systems ([Jahangir et al., 2024](#)).

Data integration and compatibility issues have hindered seamless integration and accurate digital twin simulations ([Yang et al., 2024](#)). Without this issue being resolved, accurate and valuable insights into the project life cycle cannot be obtained, creating biased results. This poses a challenge to the clear benefits of incorporating these digital technologies in construction. Furthermore, digital privacy and security challenges contribute to trust issues, which imply that for organizations to have access to data throughout a project life cycle, it is vital that comprehensive privacy and security regulations are ensured to build trust in many

Table 9. Dunnett's test and LSD post-hoc test of barriers with significant difference.

Barriers	I-J	Mean difference (I-J)	SE	Sig.	Lower bound	Upper bound
B15	Architects-builders	0.683*	0.313	0.032	0.06	1.31
	Architects-quantity surveyors	0.004	0.271	0.989	-0.54	0.54
	Architects-engineers	0.785*	0.306	0.012	0.18	1.39
	Builders-architects	-0.683*	0.313	0.032	-1.31	-0.06
	Builders-quantity surveyors	-0.679*	0.246	0.007	-1.17	-0.19
	Builders-engineers	0.102	0.284	0.720	-0.46	0.67
	Engineers-architects	-0.785*	0.306	0.012	-1.39	-0.18
	Engineers-builders	-0.102	0.284	0.720	-0.67	0.46
	Engineers-quantity surveyors	-0.782*	0.237	0.001	-1.25	-0.31
Dunnett's (two-sided)	Architect-engineers	0.785*	0.306	0.032	0.05	1.52
	Builders-engineers	0.102	0.284	0.969	-0.58	0.78
	Quantity surveyors-engineers	0.782*	0.237	0.004	0.22	1.35

Note: SE, standard error.

* Significant (Sig.) at 0.05.

organizations. These findings support research conducted in Malaysia, which identified privacy and security as negative effects of digital twin implementation for smart city development ([Waqar et al., 2023](#)).

MINDSET BARRIERS

This component involves four items: lack of trust with a factor loading of 0.753, lack of financial resources with a factor loading of 0.751, economic situation of the nation with a factor loading of 0.654, and technical knowledge of operation with a factor loading of 0.605. The adoption of more efficient and innovative practices is hindered because most professionals are reluctant to change the conventional methods of practice. Also, the upfront cost of implementing digital twin technology, which includes sensors, training, and software, is perceived as expensive by employers. These deter organizations from utilizing this technology because it does not seem to have quick benefits for and return for the organization.

There is also a limited understanding of digital twin technology in the construction industry. Many organizations in some developing countries underestimate its value, resulting to missed opportunities to improve project performance ([Waqar et al., 2023](#); [Oke et al., 2024](#)). This mindset challenge from employers and employees must be addressed through education and training; clear demonstration of their usage and benefits in case studies will change the orientation of stakeholders in the construction industry ([Arowoiya et al., 2024](#)). It is important to highlight that the long-term benefits of using these technologies can go a long way in changing mindsets. Therefore, building trust and changing mindsets in the field of digital

technologies are vital because these technologies may seem new, complex, and daunting to stakeholders and developers.

POLICY AND STRUCTURE BARRIERS

This component has four items, namely, unreliable power supply with a factor loading of 0.731, lack of government support with a factor loading of 0.625, cultural beliefs with a factor loading of 0.638, and poor investment return/profit margin with a factor loading of 0.608. The construction industry is reluctant to change and slow to adopt new technologies because there are no clear benefits and returns on investment. This makes stakeholders skeptical about adopting, despite some professionals being aware of the Industry 4.0 revolution and related technologies (Zhu et al., 2024). Therefore, the government plays a significant role in enacting policies to stabilize the economy and encourage investments in these digital technologies. When there are no clear policies that promote the use of these technologies, companies may hesitate to use them because of the cost and risks involved (Ojo et al., 2022).

When there is a lack of legal frameworks that address the privacy, ownership, and security of data, this undermines the belief and trust in adopting those technologies and indirectly affects other barriers, as shown in Figure 5. This leads to stakeholders' reluctance to share data for digital twin solutions. A study from the Middle Eastern construction industry highlighted that organizational culture, entrenched beliefs, and resistance to change significantly impede the implementation of digital twin technologies (Barham et al., 2025). Also, subsidies or tax incentives should be offered to ameliorate financial burdens for organizations (Opoku et al., 2023). Finally, it is essential that the issue of interrupted power is resolved by relying on more renewable energy and energy storage solutions that can be implemented by the government.

ECONOMIC BARRIERS

This component has three items: lack of awareness with a factor loading of 0.788, cost of implementation with a factor loading of 0.752, and unavailability of technological operators with a factor loading of 0.577. Cost of implementation is a major challenge in adopting digital twin technologies; however, there is a need for new business models. Smaller firms do not employ technological operators due to the high costs of using

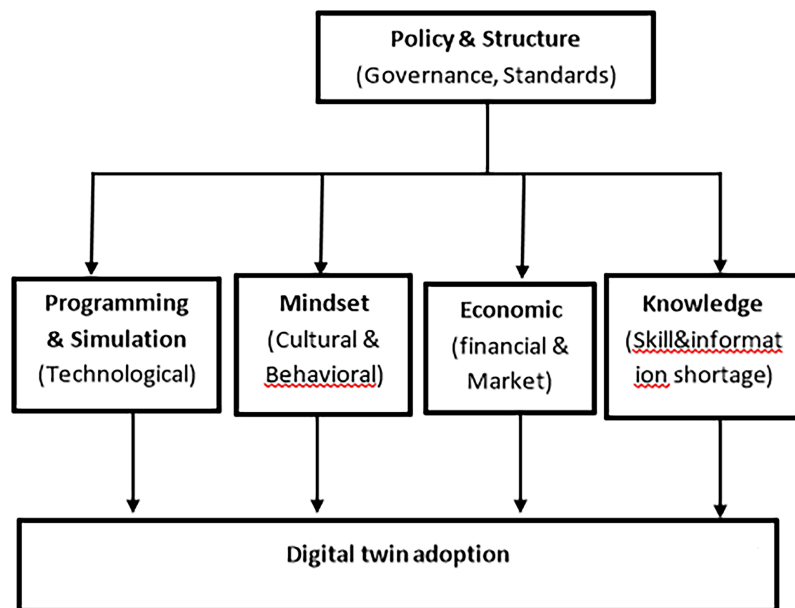


Figure 5. Framework for barriers to the adoption of digital twin technology.

their expertise to set up and operate the DT system. These financial resources include skilled personnel, hardware, and software. The cost of investment can discourage construction firms and small and medium enterprises from adopting digital twin solutions when there are no obvious value propositions, benefits, and return on investment (ROI) ([Zhu et al., 2024](#)).

Most organizations' way of operation focuses on cost minimization and short-term financial outcomes, i.e., profit, which impedes innovation and investment in new technologies. This aligns with findings from studies conducted in the Middle East, which reported that financial uncertainties hinder the adoption of digital twin technologies. Many organizations and businesses remain uncertain about ROI and face challenges in identifying cost-effective software and hardware solutions that best meet their operational needs ([Barham et al., 2025](#)). However, the promotion of low-interest loans or grants for small firms interested in adopting these technologies in their business workflows could improve the awareness of construction professionals working in those firms. Overall, there is a lack of a methodical approach to implementation, lack of effective coordination among diverse stakeholders, and limited collaboration among technological providers, affecting digital twin adoption ([Grieves, 2014](#)).

KNOWLEDGE BARRIERS

This component involves three items, namely, lack of standardized tools with a factor loading of 0.772, lack of experts with a factor loading of 0.715, and technical complexity with a factor loading of 0.384. Many professionals still have unclear understanding of what a digital twin entails, causing misconceptions and resistance to its use or investment in it. There is insufficient understanding of how to incorporate these new technologies into existing workflows, systems, and processes, which creates technical and operational hindrances to their adoption. A review and interview-based study conducted in Sri Lanka confirmed that technical complexity is one of the major barriers to digital twin implementation ([Indunil et al., 2025](#)). Developing, implementing, and managing digital twin solutions in the construction sector, therefore, require specialized technical skills and expertise ([Daniel et al., 2024](#)).

Knowledge barriers can be addressed through programs and certifications for using these digital twin components. Similarly, existing construction professionals need to upskill through training to be more aware of utilizing these components. A proper understanding of integration and how to resolve interoperability issues must be well-practiced by professionals. Finally, the temporary nature of construction projects and the fragmented characteristics of the construction value chain are reasons for the lack of codified and shared project knowledge ([Sepasgozar, 2020](#)).

Conclusion, recommendations, and further studies

CONCLUSION

This study has explored the barriers to the adoption of digital twins in the construction industry from a construction-professional perspective. The following variables were ranked highest among the barriers to digital twin adoption. These include lack of government support, lack of expertise, cost of implementation, unavailability of technological operators, lack of standardized tools, lack of financial resources, unreliable power supply, and lack of awareness. The results can assist policymakers, technology developers, and construction firms in fine-tuning interventions to address these barriers. The Kruskal–Wallis test also shows that respondents had diverging opinions regarding only the cost of implementation, while professionals had converging views regarding other variables.

Factor analysis was conducted to classify variables related to barriers to DT adoption into five components, namely, programming and simulation, mindset, policy and structure, economic, and knowledge

barriers. Policy and incentive schemes are needed to alleviate the economic burden of DT implementation. Also, professional bodies and training institutions should invest in digital literacy programs and continuous professional development to strengthen their capabilities in the use of DT tools and processes.

Understanding and addressing these barriers will assist construction professionals and academia in improving digital twin implementation in business and organizational contexts. Insights from the study could enable technology providers to create simplified, low-cost, and user-friendly DT solutions. By highlighting the limitations in a developing-country context, the study provides a roadmap for increasing the adoption of DT. Beyond the construction context, the findings contribute more broadly to digital transformation and innovation across different sectors in developing countries.

RECOMMENDATIONS

The following are recommendations from the study to enable digital twin implementations in the construction industry:

1. Since the study has revealed that lack of government support, lack of experts, and unavailability of technological operations are highly crucial to professional adoption, the government should be willing and ready to sponsor start-up technological firms and incorporate this into public construction projects. This will encourage private firms to follow suit.
2. Companies should prepare their staff for digital technologies such as digital twins by hiring technological firms to train them to improve their digital skills.
3. There should be more platforms to share knowledge about digital twins, their uses, and how they can be applied in the construction industry and business context.
4. All professionals involved in digital twins for the construction industry should ensure that they play their roles properly and efficiently so that project goals are achieved in terms of cost, time, and quality while adopting digital twins.

LIMITATIONS AND AREAS OF FURTHER STUDY

Despite the findings of this research, some limitations need further exploration to confirm the results:

1. The study focused on Nigeria's most industrialized state, i.e., Lagos State; other researchers can investigate other states or locations in the federation. Also, this study can be extended to other developing countries.
2. A firm-specific approach can also be adopted to properly and deeply investigate some uses of the digital twin system.
3. This study examined four types of professionals; further research can be conducted to include project managers and clients to assess their potential roles in addressing barriers to DT adoption.
4. A Delphi survey of international experts or a focus group of experts through interviews can give deeper insights into other barriers not covered in this study.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to information that could compromise the privacy of research participants.

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