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Construction 4.0 technologies in a developing economy: awareness, adoption readiness and challenges

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Abstract

Purpose – Construction 4.0 technology is a novel innovative technology that has been proved to enhance project performance. However, information on the concept's awareness, adoption readiness and challenges in developing economies is still scanty. The purpose of the study is to appraise awareness, adoption readiness and challenges of Construction 4.0 technologies in Nigeria to bring to the fore the state of art of these innovative technologies in the study area.

Design/methodology/approach – The study used a convenient sampling technique to select 129 construction professionals (architects, engineers and quantity surveyors) in Osun State, Nigeria, who provided data for the study through a closed-ended structure questionnaire survey. The quantitative data supplied were analysed using frequency, percentile, Cronbach's alpha, mean score (MS) analysis and analysis of variance (ANOVA).

Findings – The overall awareness level of construction professionals in the study area about Construction 4.0 technologies is at a moderate level (MS = 3.03). The analysis of each component of the Construction 4.0 technologies shows that BIM (MS = 3.69) has the highest level of awareness, while augmented reality (MS = 2.51) has the least awareness level. More results show a significant difference in the opinion of the respondents, a significant difference in the respondents on 36% of the components of Construction 4.0 technologies. The adoption readiness of the Nigerian construction industry (NCI) to Construction 4.0 technologies is at an initial level (MS = 2.86). However, the 3D printing (MS = 3.36) and augmented reality (MS = 2.49) have the highest and lowest adoption readiness ratings, respectively. There is no significant difference in how respondents ranked the NCI adoption readiness on 73% of the components of Construction 4.0 technologies. The main challenges of Construction 4.0 technologies in the study area are lack of standardisation (MS = 4.02), lack of investment in research and development and cost of implementation (MS = 3.87) each. The result shows that there is perfect unanimity in the way respondents ranked the challenges of Construction 4.0.

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Practical implications – The study provided information on the status quo of Construction 4.0 technologies in the NCI to enhance improvement in practice and the attendant project delivery.
Originality/value – The study attempted to bring to the fore the state of the art on awareness, adoption readiness and challenges of Construction 4.0 technologies in Nigeria. The study's information will be valuable to improve project delivery.
Keywords Adoption readiness, Awareness, Challenges, Construction 4.0, Nigeria
Paper type Research paper

Introduction

The construction industry, like other industries, is dynamic, and as such, it is revolutionary (Osunsanmi *et al.*, 2020). The construction industry metamorphosed from the crude system of the earliest construction activities with the use of implements such as shovels, diggers and hoes to the heavily mechanised industry most especially in developed countries (Osunsanmi *et al.*, 2020) The Third Industrial Revolution came to the fore in the mid-1990s, and the growth of the Internet and renewable energy created the necessary infrastructure for the third industrial revolution (Rifkin, 2011). This revolution was software-driven; the stage developed after the rise of information technology that supports the creation of software such as building information modelling (Osunsanmi *et al.*, 2020). The 21st-century construction industry, however, is no longer hardware-driven but an integration of hardware, software and human, which is made possible with the complex advancement in information and communication technology and Internet connectivity (Schwab, 2017).The uniqueness of the Fourth Industrial Revolution could be that it completed the integration of people and digitally controlled machines.

Researchers in the construction sector have used different nomenclature to describe the 21st-century revolution in the construction industry. The term includes smart production, smart factory, smart manufacturing (Drath and Horch, 2014; Oesterreich and Teuteberg, 2016), the Fourth Industrial Revolution, Industry 4.0 (Xu and Duan, 2019), I4 (Newman *et al.*, 2021; Demirkesen and Tezel, 2021), Construction Industry 4.0 (CI 4.0) (Sepasgozar, 2021) and Construction 4.0 (Osunsanmi *et al.*, 2020). Therefore, this study adopts the use of Construction 4.0 for the digitalisation of the construction process (FIEC, 2015), which is referred to as Industry 4.0 by some other studies. According to Bhatkar (2017), the birth of Industry 4.0 concept could be traced to the year 2011 when the German government sought to computerise production processes using the latest advancements in the German manufacturing sector. Jules (2016) traced its origins to the digital age that evolved out of the Third Industrial Revolution. Newman *et al.* (2021) opined that the Construction 4.0 technology is an integration of complex technologies such as big data, artificial intelligence, Internet of things, sensor-based technologies, cloud computing, 3D printing, building information modelling (BIM) and cyber security (Trappey *et al.*, 2017; Trotta and Garengo, 2018; Sony and Naik, 2020; Craveiro *et al.*, 2019; Heynitz and Bremicker, 2017; Bensalah *et al.*, 2019; Fisher *et al.*, 2018; Parn and Edwards, 2019).

One major benefit of adopting Construction 4.0 technologies from the human perspective lies in the fact that the technologies help alleviate human managerial burdens associated with pre-Industry 4.0 revolutions (Newman *et al.*, 2021). Research has shown that workers were overburdened with work and are required to endure late-night shifts or take work homes (Bauer *et al.*, 2015). These burdens' effects are seen to affect workers' work-life balance, reducing labour productivity negatively and eroding workplace safety (Solis, 2018; Sommer, 2018; Thompson, 2018). The complete automation of manufacturing processes through advanced smart manufacturing practices inherent in Industry 4.0 has the potential to automate the whole organisation and help to solve pre-Industry 4.0 challenges (Sony and Naik, 2020). The study by Moon *et al.* (2020) showed how application of Construction 4.0 technologies improved productivity and efficiency during construction.

In recent times, research efforts in developed nations have focused on Construction 4.0 technologies and its application in construction management (Moon *et al.*, 2020; Newman *et al.*, 2021; Demirkesen and Tezel, 2021). Moon *et al.* (2020) opined that a paradigm shift has begun on construction sites, as individuals in the construction value chain have moved to embrace the Construction 4.0 technologies. However, there appears to be a dearth of research in developing countries. The few research endeavours in developing countries, most notably South Africa, on the concept of Construction 4.0 have been largely on willingness to adopt Construction 4.0 technologies for construction projects (Osunsanmi *et al.*, 2020). Although Osunsanmi *et al.* (2021) modelled Construction 4.0 as a vaccine for ensuring construction supply chain resilience amid COVID-19 pandemic, there are still much research gap that has not been explored in other developing countries such as Nigeria. The economy of Nigeria is a middle-income, mixed economy and emerging market with a debt-to-GDP ratio of 16.08% as of 2019 USAID (2017).

In the opinion of KPMG (2020), many business organisations are contemplating Industry 4.0 technologies, even though they seem not to have developed the requisite knowledge as business leaders are not ready for associated changes. This is contrary to the view of Moon *et al.* (2015) and Bouras *et al.* (2016) who have labelled the construction industry as one of the slower industries to adopt technological transformation. Bhattacharya and Momaya (2021), in corroborating the view expressed by Moon *et al.* (2015), asserted that many organisations across the architectural, engineering and construction operation value chain are still struggling to evolve a successful strategy for digital transformation to adopt Construction 4.0 technologies, notwithstanding the benefits inherent in their adoption. Newman *et al.* (2021) asserted that the construction industry is known to lag in the adoption of Construction 4.0 technology unlike the manufacturing industry that has made significant progress in implementing digitalisation of manufacturing processes (Zhong *et al.*, 2017). The evidence of the adoption of Construction 4.0 technologies is seen in digital construction, virtual construction, BIM and augmented reality (Moon *et al.*, 2017). Oke and Arowoiya (2021) analysed the application areas of augmented reality technology in the Nigerian construction industry (NCI), which is an application area of Construction 4.0 technologies. However, no known research has examined the awareness, adoption readiness and challenges of Construction 4.0 in the NCI. Therefore, this study intends to examine the awareness, adoption readiness and challenges of Construction 4.0 technologies in the NCI. The motivation for the study stems from the need to unearth the extent of awareness of construction professionals in the study area about Construction 4.0 technologies, adoption readiness, as well as the challenges of the application of the technologies in the NCI considering its population and the economic relevancy in the African continent as the largest economy with US$480.48 billion gross domestic product in the year 2021 (World Bank, 2021). The information provided by the study would be of benefit to stakeholders in the NCI to enhance performance of construction projects.

Literature review

Generically, Construction 4.0 is an adaptive of the construction industry for Industrial revolution 4.0 as it evolved from the manufacturing industry publicised by the German government. The European Construction Industry Federation (FIEC, 2015) mentioned Construction 4.0 in their manifesto: “Construction 4.0 is our branch of Industry 4.0”. The technology focuses on machine learning, interconnectivity, automation, real-time data and smart digital technologies (EPICOR, 2019; MacDougall, 2014). Osunsanmi *et al.* (2020) have proposed the adoption of Industry 4.0 technologies in the construction industry and referred to it as Construction 4.0. Oesterreich and Teuteberg (2016) opined that Construction 4.0 consists of technologies such as blockchain, 3D printing, Internet of things, cyber-physical systems and robotics with integration of BIM (Lee *et al.*, 2020). Guoping *et al.* (2017) posited that Industry 4.0 is a convergence of technologies found on the digitisation and interconnectivity of all production units present within an economic system. The technological innovations embedded in the Construction 4.0 technologies have been found to lead to rapid growth and enhance the performance of construction firms (Maskuriy *et al.*, 2019). Demirkesen and Tezel (2021) asserted that the major benefit of Construction 4.0 to the construction industry lies in its ability to create more efficient production processes and business models and enhance the construction value chains. To Fargnoli and Lombardi (2020), the adoption of Construction 4.0 in the industry is essential considering its impact on competitiveness in relation to financial performance, workforce empowerment and production technologies. The construction industry will benefit with a faster delivery and high-quality projects at a reduced cost when Construction 4.0 technologies are fully adapted into the construction industry (Oesterreich and Teuteberg, 2016).

Cambridge Advanced Learner's Dictionary (McIntosh, 2015) defines awareness as "knowledge or perception of a situation or fact". Construction professionals in the developed countries have up their game in technological innovation like their counterparts in the manufacturing and health sectors in terms of awareness of new technologies, readiness for adoption and the eventual usage of such innovations (Moon *et al.*, 2020; Newman *et al.*, 2021). On the contrary, the rate of awareness of construction professionals in the developing countries to technological innovations has been considered to be poor in comparison to their counterparts from the advanced economies (Sepasgozar, 2021; Olatunde and Okorie, 2016). The construction industry will benefit tremendously from the adoption of Construction 4.0 technologies when fully deployed for construction works (Oke and Arowoiya, 2021). As the Construction 4.0 technology progresses to be mature and adopted, it will become a viable tool that can change the future of building (Zitzman, 2019). Pacchini *et al.* (2019), in investigating the degree of readiness for implementing Industry 4.0, differentiate between Industry 4.0 readiness and maturity for Industry 4.0 adoption and posited that readiness indicates whether an organisation is prepared to start a development process.

On the contrary, maturity indicates a level of an organisation in comparison to analysed process (Schumacher *et al.*, 2016). Extant literature has proposed some adoption readiness models for Industry 4.0. These models included the three-stage maturity model in small and medium enterprises towards Industry 4.0 proposed by Ganzarain and Errasti (2016), and concept for an evolutionary maturity-based Industry 4.0 migration approach proposed by Stefan *et al.* (2018). Ahuett-Garza and Kurfess (2018) found that the enabling technologies for adoption readiness of Construction 4.0 are big data, autonomous robot, the Internet of things, additive manufacturing, cyber-physical system and artificial intelligence. The enabling technologies for the adoption of Construction 4.0, according to Guoping *et al.* (2017), are big data, vertical/horizontal integration, autonomous robot, Internet of things, cyber security, cloud computing, additive manufacturing, augmented reality and radio-frequency identification. Literature has opined that BIM and cloud computing are the Construction 4.0 technologies that are mostly adopted by the construction industry (Oesterreich and Teuteberg, 2016).

Previous studies (Demirkesen and Tezel, 2021; Alaloul *et al.*, 2020; Woodhead *et al.*, 2018; Schneider, 2018; Hemström *et al.*, 2017) have mentioned different challenges of Construction 4.0. Demirkesen and Tezel (2021) did an extensive literature review on the challenges of Construction 4.0 and found 17 factors inhibiting the adoption of Construction 4.0 technology. The study summarised the challenges into 9 major factors: cost of implementation, resistance to change, lack of labour force, unclear benefits and gains, lack of investment in research and development, fragmented and project-based nature of the industry, lack of standardisation, data protection and cyber security and legal and contractual issues. The high cost of implementation of new technology has been a significant challenge of Construction 4.0 (Alaloul *et al.*, 2020;

Demirkesen and Tezel, 2021). This cost ranges from the initial cost of procurement and installation of new technology, cost of recruitment, training and retraining of personnel as well cost of maintenance of such technologies (Costin and Teizer, 2015; Hosseini *et al.*, 2016). Hemström *et al.* (2017) as well as Chan *et al.* (2019) found resistance to change as an important factor inhibiting the adoption of Construction 4.0. This resistance to change manifested in the unwillingness of major stakeholders to adopt innovative technologies. According to Osunsanmi *et al.* (2018), the challenges of adoption of Construction 4.0 technologies are essentially due to the complex nature of construction projects, uncertainty of construction projects and fragmented nature of construction activities. In order to examine the challenges of Construction 4.0 in the NCI, some of the challenges of construction4.0, as identified from literature, were synthesised in the questionnaire and posted to the respondents.

Research methodology

The study appraised the awareness, adoption readiness and challenges of Construction 4.0 in a developing economy. To achieve the study's objectives, the study used a quantitative research approach with the aid of structured questionnaire to elicit information from construction professionals (architects, engineers and quantity surveyors) based in Osun State, Nigeria. The choice of quantitative research approach using a structured questionnaire was considered appropriate for this study because, according to Tan (2011), the questionnaire would cover large audience in a lesser time, and it is simple to use. A random sampling of construction professionals both in the academics and the main stream industry was sampled for data collection. Osun State was selected as the study area for the research based on the fact that the Osun State is one of the states in Nigeria with the highest number of tertiary institutions, second to Ogun State, and this facilitatse easy of comparison of opinion between the construction professionals in the academics and industry. The structured questionnaire designed was segmented into two sections. The first section asked questions relating to the respondents' background, while the second section dealt with the study's objectives. Questions were asked on a 5-point Likert as used in previous studies (Pacchini *et al.*, 2019; Olatunde *et al.*, 2021). The questionnaire was self-administered to architects and engineers at their respective professional association's ordinary general meeting days, while the quantity surveyors were captured at a workshop organised by the Osun State branch of the Nigerian Institute of Quantity Surveyors (NIQS) in the state capital, Osogbo. This approach helps in achieving a high return rate rather than meeting the respondents in their individual office or site. The choice of professionals across the construction industry (architects, engineers and quantity surveyors) was to ensure ease of comparison and holistic opinion of built environment professionals on the concept. The questionnaire administration took place between March and June 2022, and it took between 10 and 15 min for each respondent to complete the questionnaire. The sample frame for the study for each sampled profession was taken from the secretary of the respective professional associations, including 1,050 engineers, 320 architects and 142 quantity surveyors. The sample size was estimated to be 156 from a total sample frame of 1,512, using the Yamane formula with the level of precision to be 10%. From the 156 questionnaires distributed, 136 (87%) were returned. However, only 129 (82%) were scrutinised to be correctly filled and were used for analysis. The high return rate could be attributed to the methodology adopted in capturing the respondents in workshop or ordinary general meetings. The sample size was justified to be adequate when compared with the 20 and 30% response rate benchmark stated by Akintoye (2000). To ensure the reliability of the data collected, the data were subjected to Cronbach's alpha reliability and validity tests. Both descriptive and inferential data analysis methods were employed for data analysis. The Cronbach's alpha coefficient for awareness and adoption readiness was 0.900, while that of challenges of Construction 4.0 was 0.845 (Table 1).

As evident from the values, each of the figures was higher than 0.70 recommended by DeVellis (2003), which implied that the data supplied are adequate and the responses are reliable. The descriptive data analysis method used included frequency, percentile and mean score (MS), while the inferential analysis method was analysis of variance (ANOVA). The Construction 4.0 technologies measured in this study were limited to BIM, 3D printing, Internet of things, artificial intelligence, cyber security, cloud computing, automated and robotic equipment, big data, cyber-physical system, block chain and augmented reality. This delimitation is premised on the authors' consideration of the most important Construction 4.0 technologies, as it may be impracticable to consider all the technologies opined to be Construction 4.0 technologies by different studies on the concept; this followed the approach used by Osunsanmi *et al.* (2020).

Research hypothesis

The study's objective was to appraise the awareness, adoption readiness and challenges of Construction 4.0 in a developing economy. One null hypothesis was formulated further to examine this research's objective in quantitative terms.

H1. There is no significant difference in the opinion of architects, engineers and quantity surveyors on awareness, adoption readiness and challenges of Construction 4.0 technologies in the study area.

Results

Characteristics of respondents to questionnaire survey

Table 2 shows the characteristics of respondents. The main professionals sampled for data collection were architects (31.8%), quantity surveyors (24.0%) and engineers (44.2%). The main areas of work of the respondents are in academics and industries. From the respondents who are academics, 18.6% work in polytechnics and 12.4% work in the universities. The industrial practitioners consist of 30.2% from the contracting organisations, 24.8% from consulting firms and 14.0% work with public works organisations. The years of work experience of the respondents indicate that the highest number (28.7%) of respondents have worked for 11–15 years, 27.1% of the respondents have a work experience of 11–15 years and only 14.7% have worked for more than 21 years. The result of the academic qualification of the respondents shows that the majority (38.0%) of the respondents have a master's degree, 23.3% have bachelor of science or bachelor of technology and only 14.7% are PhD holders. All the respondents are members of their respective professional association. While the majority (44.2%) are member of the Nigerian Society of Engineers (NSE), 31.8% are members of the Nigerian Institute of Architects (NIA) and only 24.0% are members of the Nigerian Institute of Quantity Surveyors (NIQS). The analysis of the membership type of the respondents indicates that majority (75.2%) are associate members of their respective association. The result of the characteristics of the respondents shows that they are eminently qualified to supply the information required of them as they have the required academic qualifications, sufficient experience and professional certification.

Table 1. Reliability statistics for awareness, adoption readiness and challenges of Construction 4.0

Awareness and adoption readiness		Challenges	
Cronbach's alpha	No. of items	Cronbach's alpha	No. of items
0.900	11	0.845	9

Category	Classification		Frequency	Percentage
Profession of respondents	Architects		41	31.8
	Quantity surveyors		31	24.0
	Engineers		57	44.2
	Total		*129*	*100.0*
Area of work	Academics	Polytechnic	24	18.6
		University	16	12.4
	Industrial practitioner	Contracting	39	30.2
		Consulting	32	24.8
		Public works	18	14.0
	Total		*129*	*100*
Years of experience	1–5		10	7.8
	6–10		28	21.7
	11–15		35	27.1
	16–20		37	28.7
	≥21		19	14.7
	Total		*129*	*100.0*
Highest academic qualification	HND		8	6.2
	PGD		23	17.8
	B.Sc/B.Tech		30	23.3
	M.Sc/M.Tech/MBA		49	38.0
	PhD		19	14.7
	Total		*129*	*100.0*
Membership of professional bodies	NIA		41	31.8
	NIQS		31	24.0
	NSE		57	44.2
	Total		*129*	*100.0*
Type of membership	Graduate		17	13.2
	Probationer		13	10.1
	Associate member		97	75.2
	Fellow		2	1.6
	Total		*129*	*100.0*

Table 2. Background information of respondents to questionnaire

Awareness of Construction 4.0 technologies

From the result shown in Table 3, it was evident that the overall awareness level of construction professionals in the study area about Construction 4.0 technologies is at a moderate level (MS = 3.03). However, the analysis of each component of the Construction 4.0 technologies indicated that the awareness level of the respondents on 55% components of Construction 4.0 technologies was below average (MS ranges between 2.51 and 2.93). Respondents in the study area have a comparative higher awareness level (MS = 3.69) about BIM than other components. Other components that respondents have a high awareness level are 3D printing (MS = 3.66), Internet of things (MS = 3.47), artificial intelligence (MS = 3.21) and cyber security (MS = 3.14). On the contrary, respondents in the study area have the least awareness level about augmented reality (MS = 2.51). Other components of Construction 4.0 technologies with comparative low awareness level were block chain (MS = 2.61), cyber-physical system (MS = 2.62), big data (MS = 2.71), automated and robotic equipment (MS = 2.75) and cloud computing (MS = 2.93). The result of the ANOVA shows a significant difference in the respondents' opinion (*p*-value less than 0.05) on 36% of the components of Construction 4.0 technologies in the study area. This result implies that the way architect, quantity surveyors and engineers ranked their awareness level on BIM, 3D printing, cyber security and automated and robotic equipment is different.

Constituent of Construction 4.0 technologies	Overall mean	Rank	F-stat	p-value
Building information modelling	3.69	1	25.004	0.000
3D printing	3.66	2	7.424	0.001
Internet of thing	3.47	3	1.086	0.341
Artificial intelligence	3.21	4	0.993	0.373
Cyber security	3.14	5	7.843	0.001
Cloud computing	2.93	6	0.187	0.830
Automated and robotic equipment	2.75	7	4.023	0.020
Big data	2.71	8	0.020	0.980
Cyber-physical system	2.62	9	1.104	0.335
Block chain	2.61	10	0.667	0.515
Augmented reality	2.51	11	0.708	0.494
Overall mean	*3.03*			

Table 3. Stakeholders' awareness of Construction 4.0 technologies

Table 4 shows the adoption readiness of Construction 4.0 technologies. The result indicates that in the overall opinion of stakeholders in the study area, the adoption readiness of the NCI to Construction 4.0 technologies was at an initial level (MS = 2.86). However, the analysis of the individual component of the Construction 4.0 technologies shows that 3D printing has the highest adoption readiness rating (MS = 3.36). The other components with high rating were BIM (MS = 3.24) and Internet of things (MS = 3.16). This implies that in the opinion of the respondents, the adoption readiness of the NCI to these components of Construction 4.0 technology was at the intermediate level. On the contrary, big data (MS = 2.60), automated and robotic equipment (MS = 2.57) and augmented reality (MS = 2.49) has the lowest adoption readiness rating.

The result of the ANOVA shows that there was 27% significant difference in the opinion of stakeholders on the adoption readiness of all the components of the Construction 4.0 technologies in the study area. This result indicates that respondents to the questionnaire ranked 73% of the components of Construction 4.0 similarly, while the way they rank 27% is significantly different.

Table 5 shows the opinion of the respondents on the challenges of Construction 4.0 technologies. The result shows that the most pronounced challenge of Construction 4.0 in the study area was lack of standardisation (MS = 4.02). Other important challenges of Construction 4.0, as indicated in the result, were lack of investment in research and development, cost of implementation (MS = 3.87) in each and resistance to change (MS = 3.61). Other challenges of

Constituent of Construction 4.0 technology	Overall mean	Rank	F-stat	p-value
3D printing	3.36	1	4.224	0.017
Building information modelling	3.24	2	16.477	0.000
Internet of thing	3.16	3	1.636	0.199
Cyber security	2.91	4	2.680	0.072
Artificial intelligence	2.89	5	0.993	0.373
Block chain	2.77	6	0.097	0.907
Cloud computing	2.74	7	1.383	0.255
Cyber-physical system	2.69	8	0.321	0.726
Big data	2.60	9	5.301	0.006
Automated and robotic equipment	2.57	10	0.328	0.721
Augmented reality	2.49	11	0.394	0.675
Overall mean	*2.86*			

Table 4. Adoption readiness of Construction 4.0 technology

Construction 4.0 technologies that have low rating are fragmented and project-based nature of the industry (MS = 3.30), lack of labour force (MS = 3.27) and legal and contractual problem (MS = 3.21). In the overall opinion of the stakeholders in the NCI, the challenges of Construction 4.0 technologies are moderately important. The analysis of the variance of respondents' opinion shows that there was no significant difference (*p*-value greater than 0.05) in the way respondents ranked the challenges of 4.0 technologies in the study area. A unanimous agreement in the rating of stakeholders on the challenges of Construction 4.0 technologies implies that the architects, engineers and quantity surveyors see the challenges of Construction 4.0 technologies the same way in the study area.

Discussion

The finding of the study that the awareness level of construction professionals in the study area about Construction 4.0 technologies was at moderate level is in consonance with attribute of developing countries as known to comparatively lag in awareness and adoption of innovative technologies as their counterparts in developed countries (Osunsanmi *et al.*, 2020). Aside from this, the construction industry in comparison with other sisters sectors such as manufacturing and health has been slower in adopting contemporary technologies in delivering their services (Zhong *et al.*, 2017; Bouras *et al.*, 2016). The moderate awareness level about Construction 4.0 technologies in the NCI found by this study is in agreement with the study of Oke and Arowoiya (2021), which found that the awareness level in the NCI about augmented reality technology was average. However, this finding could be compared to be in contrast with the study of Osunsanmi *et al.* (2020), which found a little awareness level of the concept in the South African construction industry.

The revelation by this study that the adoption readiness of the NCI to Construction 4.0 technologies is at an initial level is supported by extant literature. In the opinion expressed by Moon *et al.* (2015), and supported by Bhattacharya and Momaya (2021), the construction operation value chains are still struggling to come up with a successful strategy for digital transformation to adopt Construction 4.0 technologies, in spite of the benefits therein. As such, the adoption readiness of the initial level in the NCI could be said to be in tandem with previous studies. Furthermore, the initial level of adoption readiness in the NCI found by this study could be compared to be in consonance with the study of Osunsanmi *et al.* (2020), which found that construction stakeholders are willing to adopt Construction 4.0 technologies for construction projects in the South African construction industry, but the possibility of fully integrating the technologies into the construction industry is low. However, in mild variance with Oke and Arowoiya's (2021) findings which found that the usage level of the emerging technologies in the NCI is on average, this study did not find sufficient evidence to reach such

Challenges of Construction 4.0 technology	Mean score	Rank	*F*-stat	*p*-value
Lack of standardisation	4.02	1	2.104	0.126
Lack of investment in research and development	3.87	2	0.644	0.527
Cost of implementation	3.87	3	2.234	0.111
Resistance to change	3.61	4	0.279	0.757
Data protection and cyber security	3.49	5	1.461	0.236
Unclear benefits and gains	3.39	6	0.322	0.725
Fragmented and project-based nature of the industry	3.30	7	0.239	0.788
Lack of labour force	3.27	8	1.149	0.320
Legal and contractual problem	3.21	9	2.635	0.076
Overall mean	*3.56*			

Table 5. Challenges of Construction 4.0 technology

conclusion within the study area. In a mild variation with the finding of Oesterreich and Teuteberg (2016) that BIM and cloud computing are the Construction 4.0 technologies that are mostly adopted by the construction industry, this study found that 3D printing and BIM have the highest adoption readiness.

Lack of standardisation is the most important challenge of Construction 4.0 in the study area. This implies that government agency saddled with the responsibility of formulating and regulating standards for usage of digital inventions has not been proactive enough to ensure standards for adoption and usage of Construction 4.0 technologies. Unlike Demirkesen and Tezel's (2021) study which found resistance to change, unclear benefits and gains and cost of implementation as the major challenges of adopting 4.0 technologies on construction projects in the United States, this study found that lack of standardisation, lack of investment in research and development and cost of implementation are the most important challenges of Construction 4.0 technologies in Nigeria. This implies that stakeholders' perception of challenges of Construction 4.0 in developed and developing economies is different except on the cost of implementation. The implication of the finding in the construction industry is that, though to a large extent, the developed countries could afford these technologies as evident in the level of usage compared to the developing countries, where the cost of implementation could be said to impede its usage, hence making it a major barrier (Osunsanmi *et al.*, 2020).

Conclusion

The study appraised the NCI's awareness, adoption readiness and challenges of Construction 4.0 technologies. A quantitative research approach was used to collect the required data from the selected construction professionals in Osun State, Nigeria. Inferring from the results, the study concluded that construction professionals in the study area are moderately aware of the Construction 4.0 technologies. It was further concluded that the adoption readiness of the NCI to the Construction 4.0 technologies is at the initial level. More conclusions were that the main challenges of Construction 4.0 technologies in the NCI included lack of standardisation, lack of investment in research and development and cost of implementation.

Arising from these conclusions, the study recommended that the academic community and researchers intensify efforts to disseminate awareness of new technologies to professional colleagues. It was also recommended that professional associations should always and periodically organise conferences, seminars, workshops and refresher courses to their members where new technologies and innovation can be taught to increase awareness. It was further recommended that government at various levels should be more proactive in providing an enabling environment that enhances adoption readiness of innovative technologies such as Construction 4.0 technologies. It is also advocated that the National Information Technology Development Agency (NITDA) provide a technological template for adoption and usage of Construction 4.0 technologies in Nigeria. The study finally recommended an increase in government and corporate spending on research and development.

The findings and conclusion of the study are limited to data collected within Osun State, Nigeria; as such, generalisation to the whole country should be done with caution. In the same vein, generalisation and adaptation of the findings to other developing countries may be done with extreme caution, as each country and region has peculiar characteristics that could account for variation in results. Furthermore, the finding of the study was limited to the Construction technologies measured by this study; adoption of the findings to digital technologies not cover by this study should be with caution. The study advocated for further studies in other regions of Nigeria as well as other developing countries to engender comparison. Further study could also assess factors responsible for this study's level of awareness and adoption readiness.

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