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Appraisal of awareness and usage of digital technologies for sustainable wellbeing among construction workers in a developing economy

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ABSTRACT

Several sectors across the world have begun to leverage the technologies accompanying the Fourth Industrial Revolution in their activities, operations, and processes to acquire a competitive advantage in their respective business models. Despite the benefits of these digital technologies (DT), the construction industry has been sluggish in embracing and implementing the concept. Therefore, this article examines the level of awareness and usage of DT in the construction industry. A quantitative research approach was conducted with close-ended questionnaires developed and administered to construction professionals based in Lagos State, Nigeria. Data obtained was analyzed using percentages, frequency, and mean item score (MIS). The Kruskal-Wallis H-test was used to examine the significant difference in opinions of the respondents for this study. Findings from this study revealed that although construction professionals had very good knowledge of certain DT, the implementation of these innovative tools in the construction industry remains very low which is a major cause for concern. Based on these findings, this article detailed a comprehensive roadmap for developing economies such as Nigeria, on how digital transformation can be achieved by the interrelated efforts of key players such as higher education institutions (HEIs), financial institutions, government, policymakers, lawmakers, and even professional bodies.

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Introduction

The technologies accompanying the Fourth Industrial Revolution (4IR) have the capabilities of transforming the operational efficiencies of industries across the globe (Hwang et al. 2022). First mentioned at the 2011 Hannover Fair in Germany, the 4IR concept is viewed as the extension of the third industrial revolution which paves the way for technologies that are merging the biological, digital, and physical spheres into a singular dimension never before imagined (Schwab 2017). Due to increasing interconnectivity and smart automation of processes, the era of the 4IR has triggered a disruptive change in technological advancement when compared to the earlier revolutions that were characterized by the emergence of water and steam power for mechanical production (First Industrial Revolution), electrical energy for mass production (Second Industrial Revolution) and the advent of the internet (Third Industrial Revolution) (Alaloul, 2019). The technologies accompanying the 4IR offer a plethora of new and emerging disruptive technologies such as the Internet of Things (IoT), Big Data analytics, 3D printing, autonomous robots, artificial intelligence (AI), augmented reality technology (ART), building information modelling (BIM), virtual reality (VR), Cyber-Physical Systems (CPS) and several others (Aliu et al. 2021; Rivera et al. 2021; Aghimien et al. 2022). The adoption of these innovative digital technologies (DT) is poised to improve the delivery of tangible and intangible services within sectors, enabling them to gain a competitive advantage over other competitors and provide better service deliveries. Sectors such as automotive, banking, education, finance, healthcare, logistics, manufacturing, telecommunications, transportation, and several others have begun the adoption of DT in their activities and process to acquire a competitive advantage in their respective business models (Arowoiya et al. 2020; Hwang et al. 2022).

Despite the progress made by other sectors in the quest to attain digital transformation, the construction sector has continued to persist with its traditional framework and as a result, the sector has struggled to improve the quality of its operations and project delivery (Mbala et al. 2018; Ebekozien et al. 2021). This slow pace of adopting DT is more visible in developing economies than in developed ones (Ikuabe et al. 2022). In most developing nations, the construction sectors are still operating based on the traditional mindset and are burdened with several challenges which are hindering the adoption and implementation of DT in their activities, processes, and operations (Bajpai and Misra 2022). Despite the sluggish adoption of DT in developing countries, the level of awareness around the use of smart technologies is gradually gaining momentum. In recent times, some DT such as BIM, 3D printing, artificial intelligence, social media, cloud computing, and cloud-based technologies have found their way into the construction industry, indicating that the sector is not left out from these widespread technological disruptions (Ahad et al. 2020; Rivera et al. 2021; Adekunle et al. 2022; Oke et al. 2022). Although existing studies have explored the adoption, drivers, and challenges of DT (Delgado et al. 2017),

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readiness to adopt DT (Maskuriy et al. 2019) and the impact of DT on the future workforce of the construction sector (García de Soto et al. 2022), very few studies have been conducted to examine the level of awareness and usage of DT in the context of developing nations such as Nigeria. Therefore, the objective of this study is to investigate the level of awareness and usage of digital technologies in the construction sector of developing countries such as Nigeria.

As a significant contribution, this study provides a better understanding of how construction professionals in Nigeria currently perceive the emerging technologies accompanying the 4IR era and whether they are currently being implemented in the day-to-day activities of the construction industry. The findings of this study can serve as a foundation for future researchers, the construction industry, and even the government on the various areas that need to be factored in when designing a roadmap to drive the adoption of DT in the construction sector. Based on the findings of this study, the researchers go ahead to detail a roadmap for developing economies such as Nigeria, on how digital transformation can be achieved by the interconnected efforts of key players such as higher education institutions (HEIs), financial institutions, government, policymakers, lawmakers, and even professional bodies. Another valuable contribution of this study is that it highlights how DT can trigger a monumental paradigm shift in the execution of construction projects in Nigeria. The findings of this study will serve as a theoretical background for future studies that are seeking valuable knowledge on how the construction industry can embrace digital transformation.

Digital technologies (DT) and the construction industry

Understanding the digital technologies (DT) concept

The Fourth Industrial Revolution also known as 4IR is considered the next phase in the digitalisation of industries around the globe and is characterised by increased automation and optimization across various sectors (Rivera et al. 2021; Hwang et al. 2022). More so, the emergence of digital technologies (DT) is poised to transform the way businesses are conducted and will enhance the decision-making process as well as increase competitiveness, productivity, and efficiency of executing tasks while reducing costs. DT has been described as the conversion of analog information into digital forms through the use of modern technologies which offer new capabilities for improved performance (Ezeokoli et al. 2016). DT also involves the collection of innovative tools and software applications that can be used during the various phases of a construction project from conception to completion (Ikuabe et al. 2022). Four critical components of DT were described by Olanipekun and Sutrisna (2021). They include automation systems, connectivity, digital access, and digital data. According to them, Automation involves the use of innovative technologies to produce self-organizing systems such as robots for improving worker safety and addressing labour shortages and blockchain technology for making executable payments to contractors for the job done. Connectivity embraces the connections and synchronization of different activities such as the fusing the physical-to-digital-to-physical in construction activities using technologies like augmented reality (AR), virtual reality (VR) and mixed reality (MR), cloud computing, Internet of Things (IoT), and sensor-based technologies (Olanipekun and Sutrisna 2021). Through automation systems, digital access is derived which deals with the access to internet connections and networks to carry out activities in real-time. Through the use of data analytics on construction sites, it is possible to generate meaningful insights, make on-the-spot decisions, and even future projects (Ngo et al. 2020). In the case of digital technologies, data is generated and evaluated when used on construction sites. For example, the use of unmanned aerial vehicles and wearable sensors can serve as a collection point of digital data on construction sites (Aghimien et al. 2022).

Application of digital technologies (DT) in the construction industry

Several existing works of literature have highlighted how digital technologies (DT) are transforming the landscape of the construction industry. One of the ways through which this is possible is the advent of building information modeling (BIM) which arose from the need for a more articulate exchange of information among construction professionals to address issues such as fragmented project delivery, excessive expenditure, compromised quality, and ineffective facility management of projects that were evident in the traditional method of procurement. According to Babatunde et al. (2020), BIM is used to apply and maintain a constructed digital representation of information across several phases of a construction project. The use of BIM can result in better project delivery, great efficiency, improved communications and collaborations, shorter project lifecycles, reduced errors, full project visualization, streamlined planning, and better cost assessments (Adekunle et al. 2021). In a similar vein, machine learning with Artificial Intelligence (AI) can help in procurement management by tracking spending, eliminating errors, predicting future demands, and monitoring risks. Thus, these technologies can lead to intelligent decision-making which can lead to enhanced productivity and improved safety practices on construction sites (Nagitta et al. 2022). In addition, AI can be used to automate repetitive tasks which can improve productivity while augmented reality (AR) and virtual reality (VR) can ensure fast and accurate simulation for the architectural and structural planning of construction projects (Oke and Arowoiya, 2021a).

Another relevant DT that can improve the activities of constriction projects is cloud computing. According to Bello et al. (2021), cloud computing has been found to provide real-time tracking capabilities which can provide prompt data on the purchasing and usage of materials as well as real-time reports and dashboards to provide updates. Cloud storage allows construction professionals to store and access key documents and data in real-time, leading to improved communication and flexibility between team members (Oke et al. 2021). During the construction phase of infrastructure projects, Aghimien et al. (2022) submitted that unmanned aerial vehicles or drones can be used to inspect and survey the construction site, establish progress reports, track equipment, and conduct security surveillance. Data captured by drones can be downloaded into BIM and used to manage the entire project as noted by Kim et al. (2020). This resonates with the submission of Elghaish et al. (2021) who state that the use of drones can provide accurate and comprehensive data during the construction stage of a project. Drones are also useful in gaining monitoring access to hostile site areas where factors such as height, radiation, wind, and weather can lead to accidents among professionals as stated by Aghimien et al. (2022). Through data analytics, construction professionals can use analytical reports to break down complex project data and predict their behaviours and outcomes in real-time (Tiwari et al. 2018). This predictive information can help construction

professionals to make well-informed decisions based on historical data to keep projects on schedule and within budget.

Meanwhile, another game-changing technology transforming the horizon of the construction industry is the advent of the Internet of Things (IoT). According to Ghosh et al. (2020), IoT involves the utilization of internet-connected sensors that are situated across the construction sites to obtain real-time data on activities, performances, and conditions which can enhance the decision-making process of construction professionals. The integration of IoT into construction activities can enhance predictive maintenance, track productivity, and promote efficiency among professionals. One of the features of the IoT is the creation of wearable technologies such as smart boots, smart hard hats, power gloves, smart goggles, and smart watches which provides added safety for construction workers. Furthermore, with the prevalence of 3D printing technology, the use of manual labour can be reduced with machines creating and assembling structures which can be more cost-effective and convenient. The use of 3D printers can lead to a reduction in construction wastes, reduction in material and labour costs, reduction in site fatalities and injuries, improved recycling processes, and improved productivity (Aghimien et al. 2021). More so, through the use of robotics and automated workflows, the automation of labor-intensive processes is made possible which provides cost-saving options for construction professionals (Ojha et al. 2022). Another aspect of the 4IR era is gamification which can be used by construction organizations to increase the engagement and motivation of their employees, boost social interaction and teamwork, foster creativity and innovation as well as develop corporate image (Polyanska et al. 2022). Therefore, as technology continues to advance, the design and construction of projects will continue to be more effective and efficient. Table 1 presents a summary of selected DT according to several existing works of literature.

Research methodology

As stated throughout this research, the technologies accompanying the Fourth Industrial Revolution have the tendency to transform the construction industry in a tremendous way (Aghimien et al. 2022). Therefore, this study is aimed at examining the level of awareness of professionals and the usage of digital technologies to achieve sustainable construction in a developing economy such as Nigeria. This study sought the responses of registered professionals in the Nigerian construction industry who are actively engaged in construction activities. Therefore, the target population for this study was construction professionals from construction organizations in Lagos State, Nigeria such as architects, builders, engineers, and quantity surveyors. A quantitative research approach was used *via* a well-structured questionnaire to obtain data from the respondents. This approach was deemed appropriate because it allows the quantification and generalization of data using statistical analysis (Aliu and Aigbavboa, 2021).

For this study, a convenience sampling technique was adopted to obtain data from construction professionals. As a non-probability sampling technique, convenience sampling encourages the selection of respondents based on their accessibility, availability, and proximity to the researcher (Oke and Aghimien 2018). Also, due to the ability of the convenience sampling technique in obtaining data from respondents that meet the criteria for eligibility within a short space of time, it was considered suitable for this study. Due to the ease of data collection and time-saving tendencies, a close-ended questionnaire was adopted which was structured into two parts. The first aspect of the questionnaire examined the background information of the respondents while the second aspect focused on the questions around the various digital technologies (DT) obtained from existing literature using a five-point Likert scale. Due to its high-reliability coefficients and a high likelihood of responses that adequately reflect opinions, the Likert scale was adopted in this study over other scales. Hence a five-point Likert scale of 'very high significance', 'high significance', 'average', 'low significance', and 'very low significance' was adopted for this questionnaire.

Before the questionnaires were circulated to the construction professionals, they were pilot tested on a small representative sample to check their suitability and applicability for the study. Data obtained from the pilot study were not included in this study, but the feedback was used to improve the overall structure and flow of the questionnaire in achieving the objectives of the study. The pilot testing of the questionnaires helped to improve the validity of the study. A total of one hundred and twenty-one (121) questionnaires were administered to the construction professionals and ninety-eight (98) were retrieved and suitable for analysis, signifying a response rate of 81%. This response rate percentage was deemed suitable for analysis as it goes way above the 30% threshold for construction-related studies which was recommended by (Ogunsanya et al. 2021). Questionnaires were sent to professionals using electronic means like Google Forms and the process spanned over two months.

Results

Background information of respondents

This section presents a summary of the background data obtained from the targeted respondents considered for this study. Some of the data obtained from the respondents were their academic qualifications, professional qualifications and years of experience of the respondents as shown in Table 2. With regards to their academic qualifications, most of the respondents possess a bachelor's degree with (52%; $f = 51$) while 18.4% ($f = 18$) possess a masters degree. On the other hand, 5.3% ($f = 5$) possess a doctorate degree. In terms of professions, 28.6% ($f = 28$) were quantity surveyors and professionally registered with the Quantity Surveyors Registration Board of Nigeria (QSRBN), 27.5% ($f = 5$) were engineers and professionally registered with the Council for the Regulation of Engineering in Nigeria (COREN), 23.5% ($f = 23$) were architects and were registered with the Architects Registration Council of Nigeria (ARCON) and 20.4% ($f = 20$) and were registered with the Council of Registered Builders of Nigeria (CORBON).

Awareness of digital technologies (DT) tools in construction

Through the use of the Statistical Package for the Social Sciences (SPSS), the consistency of respondents' opinions was determined using parameters such as the mean item scores (MIS) and Kruskal-Wallis H-test. Unlike the Mann–Whitney U test (which is used to compare only two groups), the Kruskal-Wallis is a non-parametric test that is often used to examine the significant difference in opinions of three or more classifications of respondents which in this case was made possible as construction professionals such as architects, builders, engineers, and quantity surveyor all responded to the questionnaire. Thus, Table 3 explains the awareness of digital technologies (DT) tools in the Nigerian construction industry by analyzing the various MIS of the variables based on the opinions of the various

Table 1. List of selected digital technologies.

S/N	Digital technologies	Brief description	Literature sources
1.	3D printing	Also called additive manufacturing. This is the creation of buildings from a digital file using printing concrete, polymer, or other materials in a layer-by-layer approach.	Aghimien et al. (2021); Ali et al. (2022); Oke et al. (2022)
2.	5G networks	An advanced generation of wireless technology that connects everyone and everything with massive network capacity, superior reliability, higher performance, and ultra-low latency.	Huseien et al. (2022); Kim et al. (2022); Sigov et al. (2022)
3.	Artificial intelligence (AI)	The ability of technology and machines to make decisions and solve complex problems using algorithms that are inspired by human intelligence.	Aliu et al. (2021); Rivera et al. (2021)
4.	Augmented reality (AR)	Technologies that bring virtual elements and computer-generated objects into a physical or real environment using display devices.	Aliu et al. (2021); Rivera et al. (2021); Nassereddine et al. (2022)
5.	Automation	Granting machine autonomy in executing construction activities by a combination of automated systems and processes.	Aliu et al. (2021); Srivastava et al. (2022)
6.	Big Data	The technique of collecting, handling, and analyzing vast amounts of data sets to solve critical issues and make informed decisions for future activities.	Chou et al. (2016); Rivera et al. (2021)
7.	Big data analytics	The processing of large amounts of data by using advanced analytic techniques to identify patterns, correlations, and market trends to make extrapolations that can lead to better decisions.	Aliu et al. (2021); Rivera et al. (2021)
8.	Building Information Modeling	Using an intelligent model which is enabled by a cloud platform to produce a digital representation of a building to ensure the effective planning, design, construction, operations, and maintenance process.	Babatunde et al. (2020); Adekunle et al. (2021); Aliu et al. (2021); Rivera et al. (2021)
9.	Cloud computing	Using a network of remote servers hosted in the cloud to store, process, and access real-time data using internet technologies.	Aliu et al. (2021); Oke et al. (2021); Ikuabe et al. (2022)
10.	Cryptocurrency	Using digital currencies created by encryption algorithms to securely make payments over the internet without the need for a decentralized system.	Rivera et al. (2021); Akinradewo et al. (2022)
11.	Cyber-Physical Systems (CPS)	Described as groups of hardware and software components that are integrated to operate a process successfully, safely, and efficiently.	Rivera et al. (2021); Ikuabe et al. (2022)
12.	Cybersecurity	The adoption of practices, processes, and technologies to protect data, software, devices, networks, and programs from criminal use or unauthorized access.	Rivera et al. (2021); Sonkor and García de Soto (2021)
13.	Digital twin	Digital representation or reflections of a real-world physical process or system which is synchronized at a specific frequency and fidelity and used for modeling purposes.	Opoku et al. (2021); Rivera et al. (2021)
14.	Gamification	Process of incorporating game elements such as badges, levels, points, progressions, challenges, leader boards, and even rewards into a non-game environment to boost motivation levels of employees.	Deterding et al. (2011); Zakaria et al. (2016)
15.	Internet of Services	The availability of every component required to use software applications such as the software itself, platforms, tools, and the internet.	Aliu et al. (2021)
16.	Internet of Things	The network of objects and physical devices to obtain real-time data on activities, performances, and conditions that can enhance the decision-making process.	Gamil et al. (2020); Oke and Arowoiya (2021b)
17.	Mixed reality	The combination of augmented reality (AR) and virtual reality (VR) which blends the real-world environment (physical world) and a computer-generated one (digital world).	Aliu et al. (2021); Rivera et al. (2021)
18.	Mobile computing	The transmission of data, voice, and video *via* a computer or any other wireless or mobile device when in motion and while executing activities.	Noghabi et al. (2020); Rivera et al. (2021)
19.	Modular construction	Constructing a building off-site under controlled conditions while using the same codes, materials, and standards as conventionally built facilities, before being transported to the job site and assembled.	Akinradewo et al. (2021); Rivera et al. (2021)
20.	Nanotechnology	The process of improving and enhancing material properties of construction materials such as durability, life span, resistance, and strength.	Aliu et al. (2021); Salari (2022)
21.	Robotics	The programming of machines to interact autonomously with objects to perform tasks in a safer and more streamlined way.	Aghimien et al. (2019); Aliu et al. (2021); Rivera et al. (2021)
22.	Sensor-based technologies	The use of sensors to acquire *real-time data which can be fed into* algorithms and analytics to execute tasks and make real-time decisions.	Rivera et al. (2021)
23.	Smart factory	The application of several combinations of modern technologies to continuously obtain and share data which enhances the efficiency and flexibility of executing tasks.	Aliu et al. (2021); Pech et al. (2021)
24.	Social media	The use of computer-based technologies to disseminate real-time data through the building of virtual networks for content sharing.	Rivera et al. (2021); Wang et al. (2022)
25.	Unmanned aerial vehicles	*An aircraft that is remotely piloted that carries sensors for* monitoring, assessing, and inspecting ongoing activities.	Aliu et al. (2021); Aghimien et al. (2022); Oke et al. (2022)
26.	Virtual reality	The use of a computer-generated environment or simulated experience where users are immersed in virtual surroundings.	Aliu et al. (2021); Rivera et al. (2021)
27.	Wearable technologies	The use of devices that gathers data from the surrounding environment to provide valuable insights into what issues need to be addressed and what actions need to be taken.	Aliu et al. (2021); Rivera et al. (2021)

Table 2. Background information of the respondents.

	Frequency	Percent (%)
Academic qualifications		
National Diploma	13	13.3
Higher National Diploma	11	11.2
Bachelors	51	52
Masters	18	18.4
PhD	5	5.1
Total	**98**	**100.0**
Professional qualifications		
Architects Registration Council of Nigeria (ARCON)	23	23.5
Council of Registered Builders of Nigeria (CORBON)	20	20.4
Quantity Surveyors Registration Board of Nigeria (QSRBN)	28	28.6
Council for the Regulation of Engineering in Nigeria (COREN)	27	27.5
Total	**98**	**100.0**
Years of experience		
Less than 5 years	53	54.1
6 to 10 years	29	29.6
11 to 15 years	10	10.2
16 to 20 years	2	2.0
21years above	4	4.1
Total	**98**	**100.0**
Nature of the organization		
Consulting	51	52.0
Contracting	26	26.5
Government establishment	12	12.2
Client organization	9	9.3
Total	**98**	**100.0**

construction professionals and the significant relationships in their opinions. Following a similar approach by Aliu and Aigbavboa (2021) and Ogunsanya et al. (2022), for each of the identified technology, a threshold of 3.5 was considered. Thus, the level of awareness of DT was considered significant if it attains a MIS score of 3.5 and above. On the other hand, it is considered insignificant when a MIS score is less than 3.5. The reliability statistics revealed a Cronbach's alpha value of 0.921, signifying a very high level of internal consistency for the scale of items. With a MIS score of 4.67, building information modeling (BIM) is ranked first according to architects. This means that architects believe that the level of awareness of BIM in the construction industry is the highest among the aforementioned variables. Meanwhile, artificial intelligence was ranked first by builders with a MIS of 4.61, Big Data was ranked first by quantity surveyors with a MIS of 4.51, while the engineering section ranked unmanned aerial vehicles first with a MIS of 3.91. Overall, social media was ranked first across the various categories of respondents with a MIS of 4.65. The Kruskal–Wallis test indicates no significant difference in the perception of the different categories of construction professionals as regards the identified technologies because the significant *p-values* were above the threshold of 0.05.

Usage of digital technologies (DT) tools in construction

Table 4 explains the rankings of the usage of digital technologies (DT) tools also by analyzing the various MIS of the variables based on the opinions of the various construction professionals and the significant relationships in their opinions. Again, Kruskal-Wallis was used to examine the significant difference in opinions of the respondents regarding the level of usage of DT in the construction industry. Also, the level of usage of DT was considered significant if it attains a MIS score of 3.5 and above. The reliability statistics revealed a Cronbach's alpha value of 0.885, signifying a very high level of internal consistency for the scale of items. From Table 4, artificial intelligence is ranked first in the architect section with a MIS of 3.76. This implies that the architects believe that the level of usage of mobile computing is the highest with respect to other technologies. Big Data was ranked first among the builders, cloud computing was top-ranked among quantity surveyors while engineers ranked Internet of Services (IoS) first. Across the respective professions, social media had the highest level of usage with a MIS of 3.87. Again, the Kruskal–Wallis test indicates no significant difference in the perception of respondents as the significant *p-values* were above the threshold of 0.05.

Discussions

This study evaluated the level of awareness of professionals and the usage of digital technologies (DT) in the execution of activities, operations, and activities in the Nigerian construction industry. Table 3 shows that there is generally a high level of awareness of DT considering that 18 of the 27 DT had MIS of 3.5 and above. This implies that there is a growing awareness of the technologies accompanying the Fourth Industrial Revolution (4IR) which aligns with the submissions of Osunsanmi et al. (2020) and Adekunle et al. (2022). Table 3 also shows that there is little knowledge around certain DT such as mixed reality (MR), wearable technologies, modular construction, Internet of Services (IoS), 5 G networks, automation, digital twin, gamification, Internet of Services (IoS), and nanotechnology. The emergent implication of this finding is that there is a need for construction organizations or even the government in developing economies including Nigeria to create avenues to promote the knowledge and awareness of these DT due to their roles in improving the activities, operations, and activities of the construction industry. However, despite the considerably increasing awareness of these technologies, the implementation of these innovative tools in the construction industry remains passive which is a major cause for concern. In fact, Table 4 shows that of the 27 DT considered in this study, only 7 are above the 3.5 thresholds of the MIS. These are social

Table 3. Level of awareness of Digital technologies in the construction industry.

Profession of respondents	Architect		Builder		Quantity Surveyor		Engineer		Overall		Kruskal-Wallis	
Digital technologies	MIS	Rank	MIS	Rank	MIS	Rank	MIS	Rank	MIS	Rank	Chi-sq.	Sig.
Social media	4.26	7	4.52	5	4.29	7	3.63	17	4.65	1	0.66	0.09
Internet of Things	3.82	15	4.07	15	4.01	15	3.82	5	4.64	2	3.34	0.56
Mobile computing	3.63	22	4.34	8	4.02	14	3.62	18	4.55	3	0.20	0.89
Building Information Modeling	4.67	1	4.33	9	4.44	3	3.73	10	4.53	4	1.70	0.71
Virtual reality	3.64	21	3.46	21	4.32	6	3.72	11	4.51	5	0.74	0.18
Robotics	3.98	11	4.55	2	3.67	22	3.44	23	4.44	6	2.87	0.90
Unmanned aerial vehicles	4.51	4	3.96	18	4.03	13	3.91	1	4.42	7	7.91	0.52
Cloud computing	3.66	19	4.21	10	3.75	21	3.64	16	4.33	8	1.78	0.69
Big Data	4.34	6	3.11	24	4.51	1	3.75	8	4.31	9	1.03	0.99
Cyber-Physical Systems	3.77	17	4.46	6	3.76	20	3.74	9	4.22	10	3.59	0.71
Augmented reality	3.83	14	4.06	17	4.19	9	3.05	27	4.19	11	6.15	0.18
Smart factory	3.50	26	2.78	27	4.10	11	3.89	2	4.06	12	3.97	0.61
Artificial intelligence	4.66	2	4.61	1	3.56	26	3.57	22	4.01	13	7.38	0.81
Cryptocurrency	3.81	16	3.66	20	4.45	2	3.58	21	3.98	14	1.18	0.80
Sensor-based technologies	3.52	25	4.44	7	3.45	27	3.85	4	3.95	15	1.14	0.92
3D printing	4.15	8	3.07	25	4.21	8	3.69	14	3.89	16	4.20	0.69
Cybersecurity	3.56	24	4.52	4	3.66	23	3.68	15	3.71	17	7.98	0.98
Big data analytics	4.01	10	4.06	15	4.00	16	3.88	3	3.67	18	2.22	0.91
Mixed reality	3.22	27	4.09	13	3.97	18	3.61	19	3.49	19	1.65	0.13
Wearable technologies	4.09	9	3.36	22	3.96	19	3.60	20	3.48	20	0.76	0.61
Modular construction	3.61	23	4.18	11	4.41	4	3.76	7	3.33	21	1.74	0.15
Internet of Services	4.56	3	4.17	12	4.15	10	3.70	13	3.29	22	4.56	0.78
5G networks	3.65	20	3.92	19	3.98	17	3.41	24	3.17	23	2.47	0.89
Automation	3.91	12	4.54	3	4.41	5	3.77	6	3.03	24	3.91	0.51
Digital twin	4.44	5	2.88	27	3.61	24	3.33	25	3.02	25	4.78	0.98
Gamification	3.71	18	2.98	26	3.31	27	3.11	27	3.01	26	2.03	0.95
Nanotechnology	3.11	27	3.23	23	3.60	25	3.32	26	2.88	27	4.35	0.71

**Significant at $p < 0.05$; MIS = Mean item scores.

Table 4. Level of usage of Digital technologies in the construction industry.

Profession of respondents	Architect		Builder		Quantity Surveyor		Engineer		Overall		Kruskal-Wallis	
Digital technologies	MIS	Rank	MIS	Rank	MIS	Rank	MIS	Rank	MIS	Rank	Chi-sq.	Sig.
Social media	3.29	14	3.59	2	3.52	7	3.49	8	3.87	1	1.94	0.96
Internet of Things	3.30	13	2.98	21	3.22	18	3.31	13	3.85	2	4.60	0.99
Mobile computing	3.13	23	3.29	16	3.50	8	3.57	3	3.83	3	7.18	0.91
Cloud computing	3.63	4	3.58	3	3.66	1	3.41	12	3.76	4	2.92	0.25
Big data analytics	3.62	5	2.93	22	3.20	20	3.20	19	3.68	5	1.65	0.56
Unmanned aerial vehicles	2.98	24	3.45	9	3.27	17	3.52	5	3.58	6	0.76	0.34
Automation	3.44	11	3.21	20	3.65	2	2.81	24	3.53	7	1.64	0.91
Big Data	3.23	16	3.61	1	3.21	19	3.28	15	3.47	8	4.86	0.81
Building Information Modeling	2.82	26	3.47	8	3.33	15	3.58	2	3.43	9	1.64	0.68
Sensor-based technologies	3.65	2	3.22	19	2.90	25	2.77	25	3.24	10	4.10	0.98
3D printing	2.92	25	3.33	14	3.64	3	3.30	14	3.18	11	7.88	0.61
Cybersecurity	3.48	9	2.88	23	3.48	9	3.23	19	3.13	12	2.72	0.81
Modular construction	3.22	17	3.31	15	2.87	26	2.76	26	3.11	13	1.95	0.56
Internet of Services	3.46	10	3.57	4	3.39	14	3.59	1	3.08	14	4.12	0.71
Nanotechnology	3.20	18	2.81	25	2.77	27	3.26	17	3.07	15	6.22	0.51
Artificial intelligence	3.76	1	3.48	7	3.44	10	2.59	27	3.06	16	7.65	0.32
Virtual reality	2.72	27	2.86	24	2.77	27	3.51	6	3.00	17	2.76	0.51
Cyber-Physical Systems	2.72	27	3.44	10	3.43	11	3.11	20	2.97	18	4.74	0.71
Augmented reality	3.61	6	3.37	13	3.18	21	3.50	7	2.91	19	4.86	0.84
Robotics	3.64	3	3.55	5	3.60	4	3.54	4	2.90	20	1.47	0.92
Smart factory	3.16	20	3.38	12	3.12	22	3.27	16	2.89	21	4.91	0.87
5G networks	3.24	15	3.38	12	3.42	12	2.91	22	2.67	22	6.03	0.56
Mixed reality	3.50	8	3.25	18	2.92	23	3.46	9	2.56	23	7.99	0.83
Cryptocurrency	3.55	7	3.42	11	3.56	5	3.10	21	2.34	24	4.37	0.84
Wearable technologies	3.18	19	2.75	26	3.40	13	3.44	11	2.16	25	2.48	0.91
Digital twin	3.15	21	3.27	17	3.30	16	2.87	23	2.15	26	1.95	0.74
Gamification	3.14	22	2.66	27	2.91	24	3.25	18	2.07	27	5.76	0.81

**Significant at $p < 0.05$; MIS = Mean item scores.

media, the Internet of Things (IoT), mobile computing, cloud computing, big data analytics, unmanned aerial vehicles, and automation. This implies that being aware does not translate to adoption. According to Oesterreich and Teuteberg (2016), Aliu et al. (2021), and Khin and Kee (2022), some of the reasons why the construction sector has generally struggled to adopt DT are the lack of organizational digitization strategies, lack of senior management support, unsuitable framework to adopt digital technologies, network limitations, complexities of technological applications, legal and contractual uncertainties, lack of standards and reference architectures and the high implementation cost of technologies.

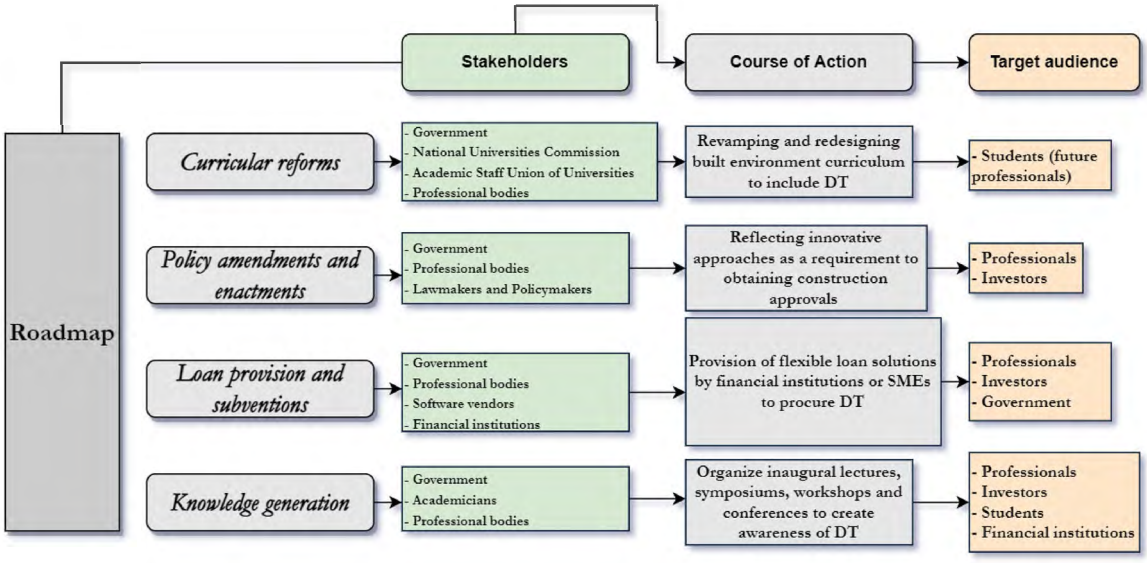


Figure 1. Roadmap for effective implementation of digital technologies in the Nigerian construction industry.

Roadmap to foster the implementation of digital technologies

To promote both the level of awareness and adoption of digital technologies, this study proposes a roadmap that would foster the effective implementation of smart and innovative technologies in the Nigerian construction industry as shown in Figure 1. A key step is to embark on a curricula reform, an approach which requires the attention of key stakeholders such as the National University Commission (NUC), Academic Staff Union of Universities (ASUU), professional bodies, and the government. As one of the parastatals under the jurisdiction of the Federal Ministry of Education in Nigeria, the NUC is tasked with regulating and coordinating academic programs in Nigerian universities. Thus, the NUC in conjunction with ASUU could oversee the infusing of the Science, Technology, Engineering, and Math (STEM) components with 4IR thinking by designing built environment courses to promote the knowledge of smart technologies as well as their applications in the construction industry context. This can successfully be achieved by consulting with the relevant professional bodies within the built environment such as the Nigerian Institute of Architects (NIA), Council for the Regulation of Engineering in Nigeria (COREN), and Nigerian Institute of Quantity Surveyors (NIQS) among several others. The responsibility of amending and enacting policies that foster the implementation of DT falls on the government, policymakers, lawmakers, and even professional bodies. By underscoring the importance of innovative technologies in addressing pressing issues on construction sites like health and safety concerns, contractors and sub-contractors will be obligated to incorporate smart technologies and digitally savvy experts as they bid for construction projects. This can go a long way in not only improving the level of awareness but also the application and integration of smart technologies into a construction project. In the aspect of loan provisions and subventions, the role of the government in creating incentives for the construction sector to acquire DT cannot be overstated. The government along with software vendors and financial institutions must be at the forefront of championing the digital transformation mantra by subsidizing the cost of technologies so that they can be easily procured in construction and other sectors. This can go a long way in offsetting the implementation costs of DT for construction organizations. This can also provide top-level managers with sufficient financial resources to train their employees and conduct pilot testing prior to a full-scale implementation of DT.

Conclusion and recommendations

Apart from helping construction organizations to remain agile and competitive, the adoption of digital technologies (DT) has the propensity to enhance the decision-making process as well as improve the efficiency and productivity of construction activities and projects. Thus, this study examined the awareness and usage of DT among construction professionals in the Nigerian construction industry. This study used mean item scores (MIS) to assess the level of awareness and usage of DT while the Kruskal-Wallis test was used to examine the significant difference in opinions of the respondents considered for this study. This study found that the construction professionals had very good knowledge of certain technologies such as social media, the Internet of Things (IoT), mobile computing, building information modeling (BIM), and virtual reality which were ranked as the top five. However, the level of awareness of these DT has not translated into adoption and implementation. Findings from the study revealed that the top five most used DT were social media, Internet of Things (IoT), mobile computing, cloud computing, and Big data analytics. Overall, the Kruskal–Wallis test indicated that there are no significant differences in the perception of the different categories of construction professionals.

One of the most significant contributions of this study is the detailing of a roadmap to achieve digital transformation in the construction industries of developing countries through the lens of the Nigerian construction industry. Thus, future researches and studies can benefit from the findings of this study. Several practical implications were also generated in this study. Firstly, to encourage the adoption and implementation of DT in the construction industry, the roles of higher education institutions (academicians), construction industry stakeholders and the government cannot be overstated as they play a key role in amplifying the notion and idea behind innovation. For academia, this study has remarkably added to the body of knowledge and

literature with a substantial contribution to digitalization and DT literature. This study, therefore, recommends that universities in Nigeria must make conscientious efforts to inculcate 4IR components into built environment courses to further amplify and promote the knowledge of smart technologies as well as their applications in the construction industry context. Secondly, it is pertinent for the government to show concern for the adoption of smart technologies and innovative tools by creating an enabling environment through the establishment and enactment of policies that foster the digital transformation of the construction industry. For construction organisations, this study highlights the need for governments in conjunction with industry top-level managers to establish seminars, workshops, and technical presentations to further educate professionals on the benefits of adopting DT in executing construction projects in Nigeria. As a limitation, this study was limited to construction professionals in Lagos State, therefore, future studies could be conducted in other States across Nigeria to validate the findings of this study. Future researches could also be conducted to comparatively study the level of awareness and usage of DT among both developed and developing countries to study convergences and divergences in the opinions of construction professionals.

Disclosure statement

No potential conflict of interest was reported by the authors.

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