Investigating the role of digitalisation in building collapse: stakeholders' perspective from unexplored approach

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Received 6 April 2023
Revised 17 May 2023
18 June 2023
15 July 2023
Accepted 28 July 2023

Abstract

Purpose – Studies showed that construction digitalisation could prevent or mitigate accidents rate on sites. Digitalisation applications may prevent or mitigate building project collapse (BPC) but with some encumbrances, especially in developing countries. There is a paucity of research on digital technologies application to prevent or mitigate BPC in Nigeria. Thus, the research aims to explore the perceived barriers that may hinder digital technologies from preventing or mitigating building collapse and recommend measures to improve technology applications during development.

Design/methodology/approach – The study is exploratory because of the unexplored approach. The researchers collected data from knowledgeable participants in digitalisation and building collapse in Nigeria. The research employed a phenomenology approach and analysed collected data via a thematic approach. The study achieved saturation at the 29th interviewee.

Findings – Findings show that lax construction digitalisation implementation, absence of regulatory framework, lax policy, unsafe fieldworkers' behaviours, absence of basic infrastructure, government attitude, hesitation to implement and high technology budget, especially in developing countries, are threats to curbing building collapse menace via digitalisation. The study identified technologies relevant to preventing or

The authors would like to convey special thanks to the participants for providing scholarly contributions to enhance the findings of this paper. Also, the authors appreciate the comments, suggestions and recommendations provided by the anonymous reviewers, which helped hone and strengthen the quality of this manuscript during the blind peer-review process.

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Engineering, Construction and Architectural Management
Vol. 31 No. 13, 2024
pp. 23-40
Emerald Publishing Limited
0969-9988
DOI 10.1108/ECAM-04-2023-0337

mitigating building collapse. Also, it proffered measures to prevent or mitigate building collapse via improved digital technology applications during development.

Originality/value – This research contributes to the construction digitalisation literature, especially in developing countries, and investigates the perceived barriers that may hinder digital technologies usage in preventing or mitigating building collapse in Nigeria.

Keywords Building collapse, Digitalisation, Measures, Nigeria, Policies, Stakeholders

Paper type Research paper

1. Introduction

The construction industry is among the dangerous top industries with a history of casualties across the globe (Skinbniewski, 2014; Boateng, 2020; Ebekozien *et al.*, 2023a). Despite several efforts and measures to prevent or mitigate fatal construction site accidents, the International Labour Organisation (ILO) report shows that construction workers in developed countries have a three to four times higher probability of experiencing a fatal accident than workers in other sectors. For developing countries, it is three to six times greater risk (Choi *et al.*, 2020). The emerging countries may be the worst hit because of lax health and safety regulations implementation and compliance. Boateng (2020) and Ebekozien *et al.* (2023a) opined that building project collapse (BPC) is the top regarding fatal occurrence on construction sites, especially in developing countries. They acknowledged that the developed economies are not excluded but at minimum. To corroborate the submission, Lu *et al.* (2021) found that in June 2021, a portion of a four-decade building collapsed in Miami, USA, because of weak resistance to progressive collapse and low safety margin. For developing countries, Boateng (2020, 2021) found that misuse of standard-compliant building resources, substandard construction materials usage, unqualified staffers' engagement and influence of higher house demand in urban areas contribute to building collapse in developing cities. This study focuses on building collapse, majorly from human errors during design and construction. This is because studies (Moullier, 2015; Boateng, 2020; 2020; Okeke *et al.*, 2020; Braithwaite, 2021) revealed that human errors are majorly the cause of building collapse in developing countries.

In Nigeria, the persistent cases of building collapse have become a source of concern to many, especially in cities such as Lagos. In September 2022, at least six incidents were recorded in less than nine months, as reported by Lagos State Emergency Management Agency (BBC Pidgin News, 2022). In November 2021, two buildings collapsed in less than 24 h within the same Lagos City (Ebekozien *et al.*, 2023a). The Agency Reporter (2021) reported that 15 persons were rescued alive, and 46 persons could not survive in the 21-storey building. The developer was among the deceased. Adewole (2021) reported that the second incident (2-storey building) recorded no human casualty. Yan and Kim (2018) opined that real-time management of the collapsed building accident during the construction process via technology-driven might prevent or mitigate collapse buildings. Their submission has stirred the built environment research front-burner to investigate how construction digitalisation technologies usage can prevent or mitigate building collapse. This is germane because the world is emphasising sustainability and waste mitigation. Digitalisation is a process of change required (advanced technologies) to stay current in the industry. The construction industry cannot be exempted.

However, some scholars (Ibrahim *et al.*, 2019; Falana and Ipindola, 2020; Okeke *et al.*, 2020; Mrabure and Awhefeada, 2021; Ebekozien *et al.*, 2023a) investigated building collapse and suggested measures, but the issue of building collapse continues, especially in developing countries, including Nigeria. Boateng (2020) discovered that the internal mechanism of building collapse is challenging. This is because of the underdevelopment conditions in African countries (Kidido *et al.*, 2021). Besides the world gradually embracing digitalisation because of its benefits (Sawhney *et al.*, 2020; Gambo and Musonda, 2021), digitalisation may be a possible solution to human-related issues in the construction industry. They acknowledged that digital technology might influence construction potential in the future. Morrar and Arman (2017), Allen and Iano (2019), and Ebekozien

and Samsurijan (2022) opined that the Fourth Industrial Revolution (4IR) mechanisms could disturb the sector because of past attitudes towards innovative technologies. Ebekozien and Samsurijan (2022) affirmed that the 4IR is branded by a fusion of digital technology applications clouding the lines between the physical and digital spheres. Li *et al.* (2017) identified robotics, cloud computing, Internet of things, blockchain technology, smart factory, artificial intelligence, simulation and modelling, and modularisation as the drivers of the 4IR. The major concern is the level of acceptance for usage (Oesterreich and Teuteberg, 2016; Ebekozien and Samsurijan, 2022). Therefore, applying a digital mechanism for real-time management of the collapsed building during construction may prevent or mitigate building collapse. Proffering measures to mitigate collapsed buildings via digitalisation are pertinent to sustainable development goals in less than a decade. Filling this gap is a component of the theoretical implications.

Among the global measures employed to prevent or mitigate building collapse accidents includes sensors IT systems to check and guide safety decision-making on construction sites regarding real-time management (Yan and Kim, 2018); Ahmed and Kabir (2021) suggested that stakeholders should comply with regulations and building codes; and Boateng (2020) recommended interventions to embrace building regulations compliance and enforcement initiatives. Whether the industry has utilised these solutions, especially IT-related ones, to prevent or mitigate building collapse is still being determined. If not, the study is worth exploring to investigate digitalisation role in preventing or mitigating frequent building collapse in Lagos, Nigeria. Also, to examine if perceived encumbrances are facing its application as acknowledged by Yan and Kim (2018) but not in Nigeria's context. Studies about perceived barriers that may hinder digital technologies application to prevent/mitigate BPC from the perspective of Nigerian stakeholders are limited in the reviewed literature. The study intends to fill the theoretical gap. Thus, the study investigates the perceived barriers hindering digital technologies usage in preventing or mitigating building collapse. In achieving this goal, the study also identifies relevant digital technologies and suggests measures to prevent or mitigate building collapse via improved digital technology applications during development. The study's objectives are:

(1) To identify digital technologies that are relevant in preventing or mitigating building collapse.

(2) To investigate the perceived barriers that may hinder digital technologies usage in preventing or mitigating building collapse.

(3) To suggest measures to prevent or mitigate building collapse via improved digital technology applications during development.

2. Literature review

An overview of building collapse is presented in Section 2.1 and followed by construction digitalisation.

2.1 Building collapse

Building collapse remains a significant concern, especially in developing countries with lax regulations. It is a global phenomenon. Yan and Kim (2018) affirmed that occurrence is frequent during construction. Boateng (2020) and Ebekozien *et al.* (2023a) asserted that several factors could influence building collapse. This includes concrete cracks, reinforcement corrosion, differential settlement of the foundation and long-term waterproofing problem (Lu *et al.*, 2021). Milanesi and Pilotti (2021) affirmed that flash flood events could lead to building collapse. This is because of the flood flow's direct impact on the building's structural parts. Also, accidental loading could induce progressive building collapse (Lu *et al.*, 2021). After the initially localised let-down, they recommended a design with sufficient load rearrangement capacity. Studies (Alinaitwe and Ekolu, 2014; Moullier, 2015; Boateng, 2020; 2020; Okeke *et al.*, 2020; Braithwaite, 2021; Ebekozien *et al.*, 2023a) stated that building collapse is rampant in developing countries and

majorly caused by human errors. Moullier (2015) avowed that the pattern of building collapse is more rampant in Kenya's urban locations, as reported by World Bank. In Ghana, human error was the major cause of the summarised building collapse incidents from 2000 to 2019 (Boateng, 2020). Braithwaite's (2021) compilation of causes of selected collapsed buildings was attributed to human error in Nigeria. This includes Synagogue Church in 2014, with 116 dead, Lekki Gardens in 2016, with 34 dead, and Reigners Bible Church, with 50 dead. Also, in November 2021, 46 persons were killed in a collapsed 21-storey building at Ikoyi, Lagos (Agency Reporter, 2021).

Oni (2010) presented the Lagos State Physical Planning and Development Authority report from 1978 to 2007. It revealed that poor materials and structural defects, leading to 105 cases of collapsed buildings, were caused by human error. Ibrahim *et al.* (2019) corroborated Oni's findings. They found that incompetent contractors, quack professionals, poor workmanship and substandard are responsible for the causes of building collapse. The rampant collapsed buildings in Lagos are not exempted. Thus, enforcing the Building Codes and implementing advanced digital mechanisms may check the excesses. The law may go a long way, but lax enforcement is a huge challenge (Mrabure and Awhefeada, 2021). Table 1 presents the

Authors/Years	Major cause of building collapse	Major suggestion
Ebekozien *et al.* (2023a)	Greed and systematic failures such as failure to learn from the past, systematic corruption, misapplication of standards, regulatory failures, faulty design, lax enforcement, and incompetent staffers	Create enabling laws and environment to strengthen National Building Codes and enforcement, effective regulatory framework to safeguard the safety of workers, and review existing Bye-laws to global best practices
Falana and Ipindola (2020)	Use of substandard materials, faulty design, corruption and developer greed, illegal building conversion by the developer, and non-adherence to approved building plans and specifications	Professional bodies, especially the Standard Organisation of Nigeria and the Council of Registered Engineers of Nigeria, must be awakened to ensure an independent monitoring operation to mitigate future building collapse. Also, soil investigation and material tests should be mandatory for high-rise buildings
Okeke *et al.* (2020)	Poor staffing and insufficient building professionals' engagement. Also, shoddy planning approval activities, from approval to monitoring of the operational building codes and bye-laws	Government should take proactive steps to engage qualified built professionals. Also, ensure that the planning approval offices do the needful per the existing physical development legislation and punish offenders as prescribed in the bye-laws
Ibrahim *et al.* (2019)	Poor workmanship, bad design, substandard materials, non-involvement of registered professionals, and use of incompetent contractors	Relevant practitioners should be engaged in project execution, supervision, and monitoring from inception to completion. Also, the government agencies charged with regulatory materials should do the needful, and erring contractors should be prosecuted
Ede *et al.* (2017)	Poor concrete practices and technology	Improvement of the existing concrete technology. Tests on cement quality should be conducted regularly by the concerned regulatory agencies
Una *et al.* (2015)	Structural problems due to the presence of smectite in the soils	Soil characterisation should be conducted before the commencement of the building. Government should assist developers in cases where smectic contents are high
Oyediran and Famakinwa (2015)	Geotechnical and geological reasons	Soil characterisation should be conducted before the commencement of the building, especially for high-rise buildings

Table 1. Summarised causes and remedies of building collapse in Nigeria

Source(s): Modified from Ebekozien *et al.* (2023a, p. 6)

summarised causes and remedies of building collapse in Nigeria but not from the perspective of construction digitalisation to prevent or mitigate the negative impact on lives and properties. This is key because of the trend in construction digitalisation and digital technology's incentivisation in the sector. This theoretical gap and others form part of the implications.

2.2 Construction digitalisation relevance in the industry

The construction industry is moving along the evolving digital technology across all industry sub-sectors and promoting the 4IR technologies (Ibrahim *et al.*, 2022; Ebekozien *et al.*, 2023c). The speed may be slow, but progress is being made to date. Oesterreich and Teuteberg (2016) underscored that the progress had engrossed many stakeholders to embrace the 4IR technologies concept in the industry. Digital technology applications can offer the prospect of addressing problems linked with construction project administration (Safa *et al.*, 2019). This includes cybersecurity, document ownership, improving building quality, enhancing communication within the parties and decentralisation. Oesterreich and Teuteberg (2016) identified on-time and on-budget delivery of projects, improved sustainability, client relationships, cost and time savings, enhanced structural stability in the sector, better goods and services delivery, and improved collaboration and communication as benefits of construction digitalisation. These benefits, if harnessed, could improve project performance and, by extension, prevent or mitigate building collapse. Akinradewo *et al.* (2021) affirmed that construction digitalisation could be used to transform the construction industry. Exploring the application of this technology to prevent or mitigate building collapse in the industry cannot be overstated.

Onungwa *et al.* (2017) avowed that building information modelling (BIM) could be used to enhance construction project supervision, programming and resolution of conflicts during construction. They opined that promoting BIM in construction management would mitigate the high rate of building collapse in Nigeria. BIM could predict building behaviour under various loading and environmental conditions. The BIM technology would widen construction practitioners' knowledge regarding building behaviour in different conditions and environmental simulation (Qurix and Doshu, 2020). Also, BIM could be used to support design and construction processes in the construction sector. The outcome will improve design quality by eliminating conflicts and mitigating construction rework (Chen and Luo, 2014). Internet of Things (IoT), such as flex sensor can be used to detect and report any bend or failure in the building to the rescue team via an emergency alert alarm (Niranjan and Rakesh, 2020). Also, digital twin (DT), a component of construction digitalisation, offers predictive information about an as-built structure. Boje *et al.* (2020) described a DT as a digital replica of a non-living or living physical entity. This includes physical assets (physical twin), people, places, processes, systems and devices that can be utilised. It is a physics-based probabilistic simulation model continuously updated using sensor information (Levine and Spencer, 2022).

Yan and Kim (2018) discovered that a comprehensive management framework based on real-time control can be used to control accident progression. This corroborated Skinbniewski (2014), who claimed that advances in IT provide an answer for improving building structural stability performance. But the barriers that may hinder digital technologies usage in preventing or mitigating building collapse cannot be overlooked. This is one aspect of the study. Yan and Kim (2018) acknowledged that a few research works (Carbonari *et al.*, 2011; Cheng *et al.*, 2013) had been conducted regarding construction sites and IT but none regarding building collapse. Despite 4IR technologies benefits, building firms are yet to embrace them compared with their counterparts in the automotive or mechanical sector (Oesterreich and Teuteberg, 2016). They discovered inadequate knowledge, hesitation to adopt, high implementation cost, lack of enhanced skills (Ebekozien *et al.*, 2023b), and organisational and process changes as the barriers facing 4IR implementation in the

industry. Others include problems with protection and data security, lack of standards in software, resistance to new technologies and higher digital equipment requirement. The 2015 EU R&D Scorecard reported that the construction and materials industry is top of the lowest R&D industries. The net sale is about 1% (Hernandez *et al.*, 2015). Promoting construction digitalisation cannot be over-emphasised because of the numerous benefits besides building collapse prevention or mitigation.

3. Research method

The researchers employed a phenomenology type of qualitative research design. Creswell and Creswell (2018) described phenomenology as a design emphasising the participant's knowledge and skill during data collection. The participants were developers/building contractors, construction consultant practitioners, selected academicians in the built environment and practices, government agencies and IT experts with experience or involvement in a collapsed building project. Participants P8 and P11 were engaged in the pre-contract stage of a building project that collapsed in less than 12 months in Lagos. Participant P22 has been involved in the closure of many construction sites because of irregularities of the contractors. For others, refer to Table 2. The study involved observing six construction sites

ID	Participant	Years of experience	Rank/Firm
P1	Developers/Building Contractors	25 years	Director, building contractor/developer (medium firm)
P2		31 years	Executive director, developing firm
P3		22 years	Operational manager, large construction firm
P4		25 years	Director, sub-contractor
P5		23 years	Managing director, sub-contractor
P6		28 years	Manager, building firm
P7	Structural Engineers	38 years	Director, Structural engineering consultant
P8		22 years	Partner, Structural engineering consultant
P9		27 years	Managing partner, Structural engineering consultant
P10	Architects	40 years	Principal director, architectural firm
P11		28 years	Director, architectural firm
P12		21 years	Partner, architectural airm
P13	Builders	29 years	Director, builders associates
P14		23 years	Chief executive officer, building firm
P15		20 years	Technical officer, building firm
P16	Quantity Surveyors	30 years	Senior partner, QS consultancy firm
P17		25 years	Senior quantity surveyor/QS firm
P18	Geologists	32 years	Senior partner, geology consultancy firm
P19		25 years	Chief geologist, consultancy firm
P20	Govt. Agencies (Regulatory)	15 years	Senior staff
P21		20 years	Senior staff
P22		18 years	Senior staff
P23		24 years	Management staff
P24	Govt. Agencies (Emergency)	27 years	Management staff
P25		21 years	Senior staff
P26	QS/Academician	22 years	Senior quantity surveyor/QS firm
P27	Architect/Academician	19 years	Senior director/architectural consultancy
P28	Engineer/Academician	20 years	Senior engineer/consultancy firm
P29	IT expert	22 years	Partner, IT consultant
P30		24 years	MD, IT firm
P31		20 years	Manager, IT firm

Source: Authors work (2023)

Table 2. Description of the interviewees' background

(P1–P6). The study adopted face-to-face interviews for the data collection from participants in Lagos, Nigeria. Lagos State was selected because of the frequent building collapse in the state (Ebekozien *et al.*, 2023a). Also, Windapo and Rotimi (2012) claimed that from 1978 to 2008, Lagos State recorded 112 cases of building collapse. This aligns with Okunola (2021), who employed an in-depth face-to-face interview to investigate building collapse in Lagos but not from the perspective of digital technology's role in preventing or mitigating the hazards. Also, a face-to-face interview offers a one-to-one interaction between the researcher and participant, giving a sense of intimacy and in-depth investigation (Saldana, 2015).

The researchers utilised thematic analysis through themes to analyse the collected data. Thirty-one semi-structured interviews were conducted with the help of trained research subordinates. The researchers engaged the participants and six construction sites (P1–P6) between January 2023 and March 2023. The study achieved saturation at the 29th interviewee. Table 2 reveals the rank and the interviewees' years of experience. The study hid interviewees' identities for confidentiality reasons. Each interview section lasted an average of 40 min. The collected data were recorded verbatim and aligned with Saldana (2015) and Jaafar *et al.* (2021). Clearance was sought for areas not clear. Table 2 reveals that the interviewees are well-informed concerning construction digitalisation and building failures. The research used a snowball sampling method aligned with Ibrahim *et al.* (2022) and Ebekozien and Aigbavboa (2021). They asserted that snowball allows the researcher to access more participants. To mitigate biases and inconsistencies, Table 3 was developed to enhance the quality assessment techniques of the qualitative data. Plano-Clark and Creswell (2015) stated that the credibility of qualitative research depends on the investigator's effort as the instrument. The investigators coded the retrieved data (Corbin and Strauss, 2015). Seventy-one codes were generated and clustered into eight sub-themes. Three themes emerged from the eight sub-themes. Appendix shows the cover letter and interview semi-structured questions.

4. Findings and discussion

4.1 Theme 1: relevant digital technologies in preventing or mitigating building collapse

The introduction of a digital approach to monitoring structural stability situations on construction sites is in response to the construction digitalisation era. Besides some external contributing factors, the complex design and materials usage call for an IT approach to mitigate the shortcoming (human errors, inadequate situational awareness, on-site personnel supervision, and manual inspection) associated with the conventional approaches (P8, P18,

Method	Assessment strategies	The phase of research
Reliability	Consistent interviewer (The researcher)	Data collection
Validity	The utilisation of a recognised approach	Data collection
	Semi-structured open interview	Data collection
Generalisability	Recognition of limitation due to sample size potential interviewer bias	Data analysis
Transferability	Compare implications against existing literature	Post data analysis
	Possibility of practical replications	Personal design
Credibility	Pattern matching using themes approach	Data analysis
	Explanation building in sequential order	Data analysis
	Address rival explanations	Data analysis
Dependability	Developing interview guidelines	Research design

Source(s): Yin (2014, p. 34)

Table 3.
The study's quality assessment techniques

P24, P27, P29–P31). This theme identified relevant digital technologies for preventing or mitigating building collapse from the stakeholders' perspective. As against the conventional approach, construction digitalisation will enhance real-time monitoring of the construction safety state. This is helpful for accident management on construction sites during development (majority). Findings reveal that advanced digital technology could be used during development on construction sites to prevent or mitigate building collapse if well implemented. Participant P3 says, "[. . .] *multi-national construction companies use many IT tools to prevent or mitigate fatal scenes during development* [. . .]." "[. . .]. *real-time safety data is key in reporting unsafe behaviour and construction activities that would enhance building collapse* [. . .]" said (Participant P29). When action is taken based on this early warning, on-site safety management will be accomplished. Results align with Guo *et al.* (2014) and Yan and Kim (2018). They affirmed that unsafe construction activities refer to inappropriate operations engaged by fieldworkers on sites and may threaten site structural stability.

Table 4 shows some of the identified tools/technologies and their uses during the development process to enhance construction site structural stability. This includes video surveillance systems, radio frequency identification (RFID), virtual reality (VR), ultra-wide band (UWB), a global positioning system (GPS), Internet of Things and Services (IoT and IoS) (majority), computer vision-based technology, physiological status monitoring (PSM) technology and "Daqri Smart Helmet" (P30). Findings agree with Skinbniewski (2014), Seo *et al.* (2015), Onungwa *et al.* (2017), Yan and Kim (2018), and Boje *et al.* (2020). Skinbniewski (2014) affirmed that IT is critical in building development safety improvement. Also, Skinbniewski (2014) identified computer vision-based technology, ultra-wide band, RFID and GPS tracking technologies for construction sites to prevent or mitigate building collapse. Onungwa *et al.* (2017) avowed that digital technology could be used to enhance construction project supervision, programming and resolution of conflicts during construction. The outcome would mitigate the high rate of building collapse in Nigeria. Boje *et al.* (2020) opined that digital technology would provide predictive information about an as-built structure.

Table 4.
Emerged relevant digital technologies and their uses in preventing or mitigating building collapse

Technology	Description and uses
Radio frequency identification (RFID) Ultra-wide band (UWB) Global Positioning System (GPS)	This is a sensor-based technology. Collect data through sensors attached to the building project entities, such as workplace sensors and accelerometer to provide real-time positioning and environmental data to enhance safety decision-making. RFID is mostly used as a safety warning system on sites (P12, P27 and P29)
Computer vision-based technology	Collect data through videos or photos and analysed 2D and 3D images to provide rich data about a construction site scene and real-time activity tracking to enhance safety decision-making (P22, P30 and P31)
Video surveillance systems	This is a technological tool for monitoring construction environments and can be used to prevent, detect, and mitigate anti-safety-related issues on construction sites. It is an on-site safety technology for human motion and activity analysis (P26 – P31)
Virtual Reality (VR)	Mainly used for construction safety training to create a risk-free virtual learning and training environment (P24, P27 and P30)
Internet of Things and Services (IoTs and IoS)	It combines embedded sensors such as RFID, cloud applications, communication devices, and other intelligence technology to create a virtual network to support a smart factory environment (P24, P27, P29 and P30)
"Daqri Smart Helmet"	It is a wearable computing device to enhance construction site safety. It can display 3D visual overlays in the wearer's field of vision (P25 – P29)
Physiological status monitoring (PSM) technology	It is a remote sensing technology that can differentiate safe from unsafe material handling tasks on construction sites (P18 – P19)

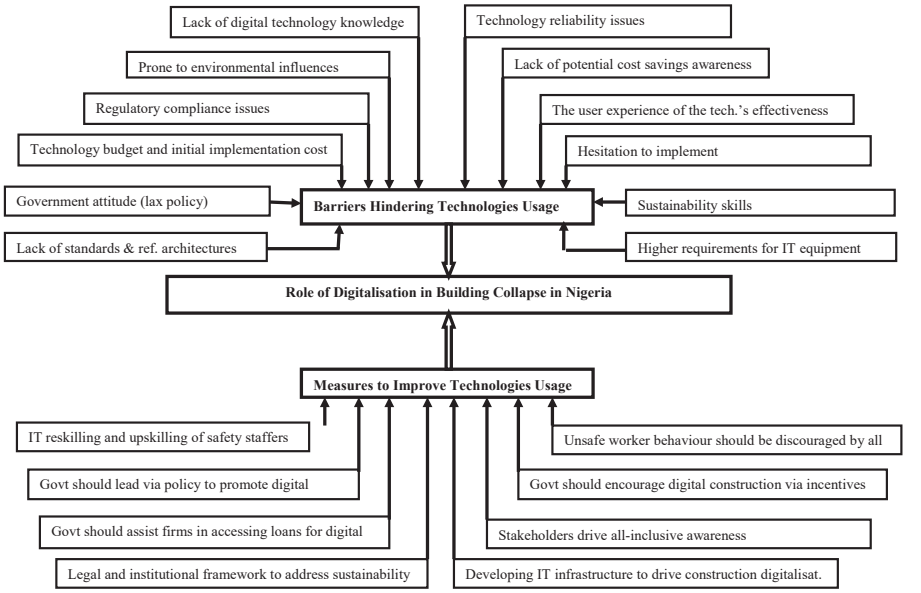
Source: Authors work (2023)

RFID is good at identifying objects and people (P11, P16, P22, P23 and P29 – P31). Participant P16 says, "[. . .]. *I have seen where RFID was used to monitor construction resources, such as materials, mechanical, and workers positioning, focusing on hazard control. It is commonly used sensor-based technology* [. . .]" Seo *et al.* (2015) clustered IT into two groups; computer vision technology and sensor-based technology. The sensor-based technology is an emerging new approach for advancing construction safety management and could be used to abate the scourge of accidents on sites (majority). The technology can enhance construction workplace structural stability performance and widen construction practitioners' knowledge (Chen and Luo, 2014). Findings agree with Qurix and Doshu (2020). They avowed that digital technology could be used to predict building behaviour under various loading and environmental conditions and enhance practitioners' knowledge regarding building behaviour in different conditions and environmental simulations. Yan and Kim (2018) identified video surveillance systems as on-site structural stability management digital tools that mostly work with sound, dust detection and light alarm systems. It is a monitoring system for building sites and opined that IT support could be used as an effective aid for managing construction accidents during development (P3, P12, P20, P25, P29 and P30).

4.2 Theme 2: perceived barriers hindering digital technologies usage in preventing or mitigating building collapse

Several studies have been conducted concerning construction digitalisation and its barriers in developed countries. But none regarding barriers hindering digital technologies usage in preventing or mitigating building collapse. Findings reveal that the majority of Nigerian construction companies are faced with diverse hindrances. Therefore, the sub-section allows the interviewees to identify the perceived barriers hindering digital technologies usage in preventing or mitigating building collapse in Nigeria. Twelve barriers hindering digital technologies usage in preventing or mitigating building collapse emerged. This includes a lack of digital technology knowledge, prone to environmental influences, regulatory compliance issues, technology budget and initial implementation cost, government attitude (lax policy), technology reliability issues and lack of potential cost savings awareness. Others are user experience of the technology's effectiveness, hesitation to implement, sustainability skills, higher requirements for IT equipment, and lack of standards and reference architectures, as presented in Figure 1. From the 12 barriers, higher requirements for IT equipment, lack of potential cost savings awareness, hesitation to implement and initial implementation cost were common barriers hindering digital technologies usage in preventing or mitigating building collapse, as presented in Table 5.

Participant P3 says, "[. . .] *with the naira/US$ exchange rate in the parallel market, how many indigenous construction companies can afford the software for sensor-based technology such as radio frequency identification? The percentage will be minimal. The running cost is not there yet. It's because we are multinational, and most of the software were imported from our base; if not, usage would have been difficult. Moreover, we only use in critical site operations that may be prone to high accident risk [. . .]"* Findings reveal that many medium and small construction firms are not implementing RFID or other digital technologies because of the associated cost. Participant P1, P29 and P31 affirm that they cannot afford most of the software though they know the benefits. Results aligned with Oesterreich and Teuteberg (2016), and discovered that new digital technologies' high implementation costs and investment costs are among the top barriers facing digital technology usage in the building industry. The results align with Yan and Kim (2018) regarding the lack of digital technology knowledge. They affirmed that most IT offers data required during the hazards control process, but users are insufficiently trained regarding IT operations, especially matching with different process phases. Participant P12 says, "[. . .] *how many construction practitioners, especially contractors, are well grounded in IT operations to manage sensor-*



Source(s): Authors work (2023)

Figure 1.
Thematic network of the role of digitalisation in building collapse in Nigeria

Technology	Barriers that cut across (higher requirements for IT equipment, lack of potential cost savings awareness, hesitation to implement, and initial implementation cost)
Radio frequency identification (RFID)	Technology reliability issues and sustainability skills (P31)
Ultra-wide band (UWB)	Technology reliability, prone to environmental influence, and regulatory compliance issues (P12, P23, P26 and P30)
Global Positioning System (GPS)	Technology reliability issues and prone to environmental influences (P30)
Computer vision-based technology	Technology reliability issues and user experience (P4, P9, P14 and P29)
Video surveillance systems	Technology reliability issues, prone to environmental influences, and lack of standards (P2, P14 and P25)
Virtual Reality (VR)	Government attitude (lax policy) and regulatory compliance issues (P1, P8, P25 and P26)
Internet of Things and Services (IoTs and IoS)	
"Daqri Smart Helmet"	Lack of sustainability skills, regulatory compliance issues, and lack of standards (P30 and P31)
Physiological status monitoring (PSM) technology	

Source: Authors work (2023)

Table 5.
Emerged barriers hindering digital technologies usage in preventing or mitigating building collapse

based technology and other digital technologies relevant to improve site safety and a workplace environment? Very few, if at all [. . .]"

Regarding lax regulatory compliance and lack of standards and reference architectures, findings show that Nigeria's building industry is not prepared for a high safety mechanism. Participant P30 says, "[. . .].. *in Nigeria, we don't have a regulatory and legal framework for managing employees' personal data records and handling the recorded data. This is pertinent for a working system allowing RFID technology for safety administration. Unfortunately, this is*

missing in Nigeria [. . .]" Results align with Spencer *et al.* (2004) and Oesterreich and Teuteberg (2016). Spencer *et al.* (2004) identified data acquisition issues, synchronisation, limited memory, data transmission issue and security as encumbrances facing digital technologies that need to be addressed before this can be achieved. Oesterreich and Teuteberg (2016) discovered that before using RFID technology, privacy and data processing restrictions must be checked by legal practitioners from the promptest phases of the process. The inaccessibility of higher requirements for IT equipment and associated infrastructure, such as unstable electricity supply and Internet networks, have compounded the barriers, especially in this part of the world. Findings agree with Manda and Dhaou (2019) and Ebekozien and Samsurijan (2022). They discovered that lacking basic infrastructure, such as electricity, could enhance technological barriers in Nigeria.

4.3 Theme 3: measures to prevent or mitigate building collapse via improved digital technology applications during development

Understanding the root cause of construction site accidents would go a long way to preventing or mitigating them via a digital approach. Therefore, the sub-section offers the interviewees a platform to proffer measures to prevent or mitigate building collapse via improved digital technology applications during development in Nigeria. Eight main measures to improve digital technology applications during development emerged. This includes discouraging unsafe workers' behaviour, IT reskilling and upskilling of safety and operational staffers, government should lead via policies and programmes promoting construction digitalisation, particularly tailored towards preventing or mitigating building collapse, and government should assist construction companies to access loans to mitigate high initial implementation cost. Others are legal and institutional frameworks to address sustainability and continuity regarding policy, developing IT infrastructure to drive construction digitalisation with a focus on preventing or mitigating building collapse, all-inclusive awareness driven by key stakeholders with a focus on the benefits, to embrace digital technology on construction sites, and government should encourage construction digitalisation via incentives to stakeholders, especially the building contractors, as presented in Figure 1. Participant P23 says, "[. . .] *construction sites accident can be avoided or mitigated if the arrangement chain is distressed to prevent or mitigate the disaster* [. . .]" Findings agree with Musella *et al.* (2021). They found that digital technologies via artificial intelligence can be used to detect, assess, and digitalise damage in buildings. Thus, digital technology can be used to manage damaged buildings. This can be achieved by automatically digitalising hazard-induced damage in affected building projects.

To proffer answers to the issue of hesitation to implement and low awareness level of digital technology applications used to prevent or mitigate building collapse in the industry, Participant P27 says, "[. . .] *the Nigerian Government should use the federal and state platforms to develop an enabling and healthy environment via institutional policies to improve awareness and by extension, improve digital technology application usage in the industry* [. . .]" Findings suggest that the campaign for construction digitalisation to prevent or mitigate building collapse should be encouraged by the stakeholders, especially government, via pro-construction digitalisation. NGOs in the housing and IT sectors should be encouraged to bring awareness to the grass-root indigenous contractors regarding the benefits of construction digitalisation besides preventing or mitigating building collapse (P7, P9, P11, P18, P23, P27 and P30). Also, a mechanism to address the issue of funding and basic infrastructure should not be left in the hands of the contractors only. In this instance, the government's role is to provide "soft loans" to construction firms to reduce the pressures from the initial high implementation cost (majority). Also, basic infrastructure provision by government would reduce the pressure on the building developers/contractors (P2, P5, P12, P15, P23, P26 and P28). This is another incentive to encourage construction companies to adopt the technology (Oesterreich and Teuteberg, 2016). Results align with Weerakkoody *et al.* (2011). They suggested that

government policies should be driven toward providing basic IT infrastructure for developing countries. Findings agree that digital technologies have the potentials to mitigate or prevent building collapse with the right policy and guidance to promote embracing construction digitalisation. Construction digitalisation can enhance simulation capabilities, structural stability and optimisation (Hamma-Adama and Kouider, 2018).

Regarding upskilling and reskilling, Participant P28 says, "[. . .] *construction IT practitioners need regular training to enhance their decision making of construction accidents, especially at different stages of the construction process. Preventing or managing accidents requires IT support and commitment from the experts* [. . .]" Results align with Yan and Kim (2018) and Ebekozien *et al.* (2023). They avowed that new evolving IT could provide the real-time four stages of information to support decision-making regarding contribution variables such as workplace, equipment, materials and on-site workers. Training and retraining enhance the relevance of the staffers (P2, P4, P6, P10 and P18). Participant P10 says, "[. . .] *in many sites, safety officers are not well trained and compounded with their 'half-baked' knowledge of IT* [. . .]" Findings emphasise that the government should be involved in the training programmes via logistics and other supporting grants to construction firms apart from policy formulation. Findings align with Smart Nation and Digital Government Office (2018). They affirmed that the Singaporean Government supported the thriving of digitalisation via scholarships and fellowships. The policy objectives of the Singaporean Government might be different but could be modify. Also, SkillsFuture Singapore, another government initiative to support the private sector, developed the platform for lifelong learning TechSkills Accelerator, among others.

5. The study's implications

Past studies on Nigeria's building collapse were from a different perspective than using construction digitalisation to curb the menace in Nigeria. Thus, this study has filled the theoretical gap of using construction digitalisation to proffer an answer to the menace of building collapse during development in Nigeria. Findings show that many construction firms, especially indigenous ones, face diverse construction digitalisation barriers. Adopting this new mechanism, "on-the-spot" observation of six construction sites supplemented with knowledgeable participants' perceptions via face-to-face interviews would contribute to filling the methodological gap. This has added to the existing literature from the developing country's perspective. Also, Figure 1 presents the main findings developed thematic network as part of the study's implications. Besides contributing to the scholarly literature paucity concerning building collapse, the study identified various digital technologies that are relevant in preventing or mitigating building collapse. Likewise, recommendations were proffered to prevent or mitigate building collapse via improved digital technology applications during development. This research would advance knowledge concerning the contribution of construction digitalisation to curb the building collapse menace in Nigeria.

Regarding the study's practical implication to key practitioners in the industry, the research confirms that construction digitalisation, if well implemented from pre-to post-development phases, can prevent or mitigate building collapse. Findings from the study will be useful in reshaping the architecture, engineering and construction (AEC) industry. Also, it can assist construction practitioners to recognise potential digital technologies that can mitigate or prevent building collapse in practice. To achieve this task, barriers need to be addressed. The study's findings and recommendations would stir up policymakers and construction companies' management staffers to promote policies and programmes that can improve construction digitalisation and use digital technology to curb building collapse during development in Nigeria. The relevant government ministries/departments/agencies and construction companies' management staffers should take the privilege of the recommended measures and consider them to curb the building collapse menace in the

future. From the social-economic perspective, the positive influence of mitigating or preventing building collapse, such as construction cost savings, life savings, mitigating environmental hazards, etc., cannot be over-emphasised.

6. Conclusion and recommendations

Rampant building collapse in the built environment, especially in developing countries such as Nigeria, involving massive economic loss and tons of death, calls for more advanced mechanisms to curb this inhumanity. Therefore, this study investigated the perceived barriers that may hinder digital technologies to prevent or mitigate BPC and proffer measures to improve technology applications during development in Nigerian building project sites. Data were collected from observation of six construction sites and complemented with face-to-face interviews with selected participants. The study identified digital technologies relevant to preventing or mitigating building collapse and perceived barriers that could hinder the implementation on construction sites. Also, the study found lax construction digitalisation implementation, absence of regulatory framework, lax policy, unsafe fieldworkers' behaviours, absence of basic infrastructure, government attitude, hesitation to implement and high technology budget as threats to curbing building collapse menace via digitalisation. Thus, measures to prevent building collapse via improved digital technology applications during development were recommended. The researchers clearly state that the results and recommendations are based on the participants' perceptions, with some academic assumptions as reviewed from the relevant literature. This research has some limitations and proposed areas for future studies based on the identified limitations. First, the study engaged six ongoing construction sites and selected experts via face-to-face interviews. Second, the study's population and sample size are specific to Lagos State, Nigeria. Lastly, the study focused on possible digital technologies which could be adopted in the design and construction stages to mitigate or prevent building collapse. Their influence did not affect the robustness of the findings. Future studies could validate the findings and measures suggested via a quantitative approach with wider coverage to enhance generalisation. Also, recommended solutions may be adapted by other countries with similar construction digitalisation and building collapse issues and considered.

Thus, the research suggested the following to prevent or mitigate the building collapse menace via promoting construction digitalisation to curb building collapse on construction project sites.

(1) The study recommends that the government should play a leading responsibility so that more construction companies will embrace digitalisation in their daily site operation and, by extension, curb building collapse on sites. Developing an integrated institutional framework is pertinent to promote construction digitalisation usage among construction practitioners.

(2) Holistic awareness about benefits is key in driving policy and programme that seems vacillated by some stakeholders. Thus, key stakeholders, especially the government and building contractors' unions, should support this approach with a tactical and holistic awareness programme emphasising long-time benefits.

(3) Reskilling and upskilling staffers/operators to drive in new technology is germane. This is because construction digitalisation is a highly digitalised mechanism. This should be all-inclusive and supported by the government via construction digitalisation incentives to motivate more companies to embrace the policy as the global best practice in the 21st century. Also, funding to implement construction digitalisation should be accessible to genuine applicants via government support at a minimal interest.

(4) The study further recommends that basic infrastructure such as electricity should be improved upon via pro-active government policy tailored towards infrastructural provision. Some of these basic facilities might encourage companies to venture into construction digitalisation.

(5) Stakeholders should curb unsafe fieldworkers' behaviours because of the potential threat that could lead to underlying issues on construction sites. This can be achieved via collaborative mechanisms and PSM technology to monitor the physiological status of construction staffers.

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Appendix:
Semi-structured interview questions

Dear Participant,

Request for Interview.

Studies showed that construction digitalisation could prevent or mitigate accidents rate on sites. Digitalisation applications may prevent or mitigate BPC but with some encumbrances, especially in developing countries. There is a paucity of research on digital technologies application to prevent or

mitigate BPC in Nigeria. Therefore, this study is titled: **Investigating the Role of Digitalisation in Building Collapse: Stakeholders' Perspective from Unexplored Approach.** The following objectives will achieve the study's aim.

(1) To identify digital technologies that are relevant in preventing or mitigating building collapse.

(2) To investigate the perceived barriers that may hinder digital technologies usage in preventing or mitigating building collapse.

(3) To suggest measures to prevent or mitigate building collapse via improved digital technology applications during development.

The interview questions are going to be within the stated objectives. Responses offered by you will be collated and analysed together with engaged interviewees. It will make up the value and contribution to achieving the success of this study. Information provided will be treated with confidentiality.

Thanks for the anticipated participation.
Regards.
Yours faithfully,
(Researchers).

Basic questions for the participants

(1) Please, for record purposes, what is the name of your organisation?

(2) What is your position in the organisation and discipline?

(3) Please, how long have you been working?

(4) Are you knowledgeable about construction digitalisation and BPC in Lagos State, Nigeria?

(5) What is your lived experience regarding building projects collapse in Nigeria's construction industry?

(6) Can you identify relevant digital technologies in preventing or mitigating building collapse?

(7) What perceived barriers hinder digital technologies usage in preventing or mitigating building collapse?

(8) Can you suggest measures to prevent or mitigate building collapse via improved digital technology applications during development process?

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