Benefits and challenges of wearable safety devices in the construction sector

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Abstract

Purpose – Construction organizations must maintain a productive workforce without sacrificing their health and safety. The global construction sector loses billions of dollars yearly to poor health and safety practices. This study aims to investigate benefits derivable from using wearable technologies to improve construction health and safety. The study also reports the challenges associated with adopting wearable technologies.

Design/methodology/approach – The study adopted a quantitative design, administering close-ended questions to professionals in the Nigerian construction industry. The research data were analysed using descriptive and inferential statistics.

Findings – The study found that the critical areas construction organizations can benefit from using WSDs include slips and trips, sensing environmental concerns, collision avoidance, falling from a high level and electrocution. However, key barriers preventing the organizations from adopting wearable technologies are related to cost, technology and human factors.

Practical implications – The time and cost lost to H&S incidents in the Nigerian construction sector can be reduced by implementing the report of this study.

Originality/value – Studies on WSDs have continued to increase in developed countries, but Nigeria is yet to experience a leap in the research area. This study provides insights into the Nigerian reality to provide directions for practice and theory.

Keywords Construction management, Ergonomics, Health and safety, Safety, Technology, Wearable safety devices

Paper type Research paper

Introduction

The construction sector is one of the most dangerous industries (Kamoli and Mahmud, 2022). Construction operations are risky, with a high accident and fatality record (Chan *et al.*, 2016; Nnaji and Awolusi, 2021). The number of accidents and fatalities in the industry is disproportionate to its workforce (International Labor Organization (ILO), 2018). It is among the highest compared to other industries (Umeokafor *et al.*, 2022). The construction industry's injuries constituted 7% of non-fatal injuries and 14% of workplace deaths in the United

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States in 2018 (US Bureau of Labor Statistics, 2019). Incidents in the Canadian construction industry constituted around 10% of lost-time claims and 20% of workplace fatalities over three years (Association of Workers Compensation Boards of Canada, 2020). Fifty-four thousand injuries were recorded each year in Great Britain, the second-highest number of injuries among all industries (Health and Safety Executive, 2019), which cost the British economy 1.2 billion pounds in 2017–18 (Health and Safety Executive, 2019). In three years (2014–2016), occupational accidents in the Nigerian construction industry accounted for 39.24% of occupational accidents in every sector of the economy (Kamoli and Mahmud, 2022).

Over the years, H&S incidents in Nigeria have influenced the productivity of the construction sector, making the sector to contribute only 4% to the gross domestic product (GDP) (Kamoli and Mahmud, 2022). Sixty thousand fatal accidents reportedly occur on construction sites worldwide yearly, equating to one fatal accident every 10 min (Chen and Luo, 2016). Due to these H&S incidents, 3.94% of global GDP is lost yearly (ILO, 2018). The current construction H&S statistics create a negative outlook for the industry and undermine contractors' H&S performance. The need for improvement has continued to trigger debates in academia and industry (Awolusi *et al.*, 2018), which produces the publication of H&S research articles and H&S-based conferences. The industry has extensively used various training methods to provide practitioners with H&S information to mitigate the high rates of fatal and non-fatal workplace injuries (Namian *et al.*, 2020). Traditional training systems and other H&S programs offered to construction practitioners still need to provide competitive H&S performance on construction projects (Loosemore and Malouf, 2019). Some of the H&S programs need to consider modern construction methods (Chan *et al.*, 2016).

The construction sector is lately considering technological innovations as an alternative means of addressing its H&S challenges (Awolusi *et al.*, 2018). The construction management and engineering literature are rife with the need to train and educate construction workers on using digital technologies to solve H&S challenges. One of these technologies is wearable safety devices (WSDs) (Ahn *et al.*, 2019). WSDs are small wearables or accessories that workers can attach to their bodies to monitor their health and safety (Nnaji *et al.*, 2021). The devices can be in the form of smartwatches and wristbands that integrate various sensors to monitor workers' H&S (Guo *et al.*, 2017). Wearable safety technologies have proven to be effective in preventing musculoskeletal disorders, preventing falls, assessing physical workload and fatigue, assessing hazard identification skills and monitoring workers' mental status (Ahn *et al.*, 2019). Despite the associated benefits, the technology is still new, particularly to construction organizations in developing countries. Therefore, challenges of adoption by construction organizations are inevitable.

Scholars in the field of construction have published research articles that address WSDs. Publications from the United States are the highest number of articles in the research domain (Choi *et al.*, 2017; Hwang and Lee, 2017; Lee *et al.*, 2017; Nath *et al.*, 2017; Awolusi *et al.*, 2018; Ahn *et al.*, 2019; Bangaru *et al.*, 2020; Nnaji *et al.*, 2021; Okpala *et al.*, 2021; Jeon and Cai, 2022). Publications have emanated from other developed countries, including Australia (Arabshahi *et al.*, 2021b), China (Guo *et al.*, 2017) and Slovenia (Kamisalic *et al.*, 2018). In the construction industry, WSD research is still at an early stage, and there currently needs to be more studies in developing countries. Wearable safety technologies can be maximized to improve H&S in construction.

Despite the increasing interventions to improve construction H&S, Nigeria is still searching for more viable options (Okoye, 2018). Occupational hazards, risk assessment and control, risk management and techniques have been largely investigated in Nigerian construction (Odeyinka *et al.*, 2004; Ijigah *et al.*, 2013; Odimabo and Oduoza, 2013; Oranusi *et al.*, 2014; Edmund, 2015). A few other studies address hazards through design (Umeokafor, 2017) and community roles in promoting construction H&S (Umeokafor, 2018). Some studies have focused on the general practice of safety management and accident prevention (Oreoluwa and Olasunkanmi, 2018). Although the recommendations from the existing studies are steps in the right direction, there is a need for more research on technology-based tools to overcome the H&S challenges in the Nigerian construction sector. Given that wearable safety technologies could improve accuracy in assessing and identifying risk factors (Conte *et al.*, 2011), this study aims to investigate benefits derivable by Nigerian construction organizations from using WSDs and challenges that hamper the adoption of the technology.

Wearable safety devices research

Although WSDs are useful H&S tools, their application in construction is still in its infancy compared to other industries (Nnaji *et al.*, 2021). Nnaji and Awolusi (2021) examine the critical success factors influencing the implementation of WSDs for H&S monitoring in construction. The research reports critical success factors as contingent on the type of organization, organization size, and organization experience using WSDs. Key strategies to improve the implementation of WSDs include educating and training workers, promoting personalized WSDs, and conducting detailed and continuous assessments of WSDs. Abuwarda *et al.* (2022) examine ubiquitous WSDs suitable for the health and construction sectors. The study reports H&S metrics that could be measured using WSDs in both sectors. Specific devices, such as a chest sensor that records heart rate and its variability, are reported (Arabshahi *et al.*, 2021a; Abuwarda *et al.*, 2022). Bangaru *et al.* (2020) alluded to the use of sensors but argued that not all sensors could be used for construction applications. Bangaru *et al.* (2020) evaluate the data quality and reliability of forearm electromyography (EMG) and inertial measurement unit (IMU) wristband sensors for construction activity classification. The study's classification results conclude that the forearm-based EMG and IMU data can be used to generate reliable models for detecting construction activities. Awolusi *et al.* (2018) examine wearable applications in non-construction industries and highlight the potential of their integration into construction.

Table 1 shows the wearable detection technologies in the healthcare sector that have demonstrated high potential and suitability for H&S in the construction sector.

Construction hazard	Metric	Detection technology
Mental Fatigue *Mental Stress* Heat Stress	Brain/Nervous System Activity	Wearable electroencephalogram (EEG); Head and eye cameras; Electrodermal Activity (EDA)
Falls, Slip and trips Musculoskeletal disorders Work Intensity/ Physical Fatigue	Body posture, body speed, body rotation and orientation	Accelerometer (bracelet/wrist band); Gyroscope sensor; Electromyography (EMG) Inertial Momentum unit (IMU) Sensor
Fatigue Physical Intensity	Heart rate, Heart rate variability, Respiratory rate, Blood pressure Physical work intensity	ECG, infrared, and bio-radar; Electromyography (EMG)
General Health	Sleep quality and quantity	ActiGraph Sensor; Nasa task load index (TLX)
Heat or cold	Body temperature	Thermistor
Fire and explosion	Smoke and fire detection	Infrared; Light sensor; Temperature sensor
Caught-in/Struck-by object	Proximity detection, location tracking	Radio frequency identification (RFID); Ultra-wideband (UWB); infrared; radar; Bluetooth; Global positioning system (GPS)

Source(s): Abuwarda *et al.* (2022)

Table 1. Construction hazards monitoring metrics

Jeon and Cai (2022) demonstrate the act of coupling wearable electroencephalograms (EEGs), virtual reality (VR), and machine learning for workplace hazard detection. The study correlates EEG signal patterns with construction hazard types and develops an EEG classifier based on immersive VR experiments. Nath *et al.* (2017) studied the ergonomic analysis of the posture of construction workers using wearable mobile sensors. The study develops a low-cost, ubiquitous approach that uses built-in smartphone sensors to unobtrusively monitor workers' posture and autonomously identify potential work-related ergonomic risks. The authors proposed an approach beneficial to construction workers exposed to work-related musculoskeletal disorders due to poor posture. Although the study primarily focuses on postural analysis for trunk and shoulder flexion in a manual screw-driving task, the developed methodology and analysis techniques can be generalized to other field activities with minimal modifications.

Arabshahi *et al.* (2021a) classified WSDs into physiological and integrated personal protective equipment (PPE) sensors. The study identifies common safety technologies and reports on the extent of their implementation. Choi *et al.* (2017) examine determinants of worker acceptance of wearable technology in the professional work context. Nnaji *et al.* (2021) identified and evaluated the types of WSDs most preferred by field workers. Choi *et al.* (2017) found perceived usefulness, social influence, and perceived privacy risk associated with worker intent to adopt smart vests and wristbands. In order to mitigate resistance to WSDs adoption, Nnaji *et al.* (2021) encourage managers that have used WSDs to share their experiences with their workers.

Benefits of using WSDs

This section reports the common benefits of WSDs. Physiological WSDs monitor emotional well-being, fatigue, physical workload, and posture recognition (Ahn *et al.*, 2019). Wearable electroencephalograms (EEGs) are used to observe stress levels, mental exhaustion, and emotional states (Wang *et al.*, 2017) by tracking and recording brain wave patterns. EEGs provide a basis for investigating and treating psychological problems in construction workers and help avoid unsafe behaviour (Arabshahi *et al.*, 2021a). Besides, electrocardiograms (ECGs) are effective in chest sensors to monitor the heart rate of construction workers (Lee *et al.*, 2017). Electrocardiogram, EEGs, and infrared temperature sensors have been integrated to monitor real-time physical fatigue in workers (Aryal *et al.*, 2017). The spinal biomechanics of construction workers can be monitored by EMG by measuring the electrical activities of the muscles (Arabshahi *et al.*, 2021a). EMG enhances the safety of construction workers exposed to repetitive lifting and tying of rebar (Antwi-Afari *et al.*, 2017; Umer *et al.*, 2017). Wristband-type heart rate monitors detect significant fluctuations in exercise demands (Kamisalic *et al.*, 2018; Hwang and Lee, 2017), estimate energy expenditure (Lee *et al.*, 2017), and track heart rate (Hashiguchi *et al.*, 2020). Nnaji *et al.* (2021) found smartphone-based WSDs, smart hard hats, and smart safety vests to be the most popular WSDs and preferred by field workers. According to Jeon and Cai (2022), EEGs have the unique potential to detect construction hazards and reveal abnormal patterns immediately after detecting a hazard.

Wearable safety technologies attached to PPE enable safety risk detection and health monitoring (Arabshahi *et al.*, 2021a). Inertial Measurement Units (IMUs) are the most common motion sensors in PPE to detect awkward postures (Chen *et al.*, 2017), gait abnormalities (Yang *et al.*, 2017), and fall risk assessments (Nnaji *et al.*, 2021). Pressure sensors and three-axis accelerometers are valid for evaluating PPE wear (Dong *et al.*, 2018). Dust sensors can monitor fine dust levels and protect workers from excessive respirable dust (Smaoui *et al.*, 2018). Adjiski *et al.* (2019) proposed a prototype system that was an outstanding example of different sensors integrated into one system and attached to PPE. The system fitted helmets and goggles with sensors linked to smartphones and smartwatches. Sensors used in the system included gas sensors, dust sensors, sound sensors, smoke sensors, temperature sensors, accelerometers, gyroscopes, magnetometers, heart rate sensors, and cameras. Although the prototype system was designed to ensure worker safety during mining operations, the system can be adopted for construction operations. Adopting WSDs can save a significant part of capital lost to accidents and fatalities in the construction sector (Arabshahi *et al.*, 2021a). Benefits associated with using WSDs are presented in Table 2.

Barriers to WSDs adoption

Despite the health and safety benefits of WSDs, the technology presents significant challenges (Abuwarda *et al.*, 2022). Studies have reported workers' resistance to the use of WSDs (Awolusi *et al.*, 2018; Ahn *et al.*, 2019), which affects the wider adoption of the technology in construction (Nnaji *et al.*, 2019; Won *et al.*, 2013). Some workers deliberately ignore notifications from WSDs or find ways to circumvent using the technology (Nnaji and Awolusi, 2021). Such an attitude is usually caused by ignorance (Nnaji and Awolusi, 2021). Nnaji *et al.* (2021) attributed workers' reluctance to use WSDs to the ability of the devices to capture workers' personal and private information. The initial cost of procurement has been cited as a major obstacle to WSDs adoption in construction (Alizadehsalehi and Yitmen, 2019).

Training, maintenance, and operational costs (Goodrum *et al.*, 2011) are other cost-related barriers. Besides cost-related barriers, personnel challenges also play a role, for instance, the need for more interest and well-trained staff (Alreshidi *et al.*, 2017; Didehvar *et al.*, 2018). Complications arising from a lack of integrity are some barriers to implementing WSDs (Golizadeh *et al.*, 2019; Schall *et al.*, 2018). Changes in management and complications at construction sites affect acceptance of the technology (Didehvar *et al.*, 2018; Golizadeh *et al.*, 2019). Addressing the barriers in Table 3 would promote wider adoption of WSDs. For WSDs to be accepted by end-users in the construction industry, their value-added impact must be continuously identified, evaluated, and established (Awolusi *et al.*, 2018). Limited implementation of the technologies has also been linked to the lack of reliable data and critical information needed to integrate WSDs into work processes (Nnaji *et al.*, 2019, 2021).

Abuwarda *et al.* (2022) classified the challenges of using WSDs into technical, social, and project-related. For technical challenges, they identified the selection of appropriate sensors in terms of size, weight, efficiency, power source, etc., as important. This will enhance the

Benefits	Authors
Monitor emotional well-being and fatigue	Ahn *et al.* (2019), Aryal *et al.* (2017)
Observe stress levels, mental exhaustion, and emotional states	Wang *et al.* (2017)
Investigating and treating psychological problems	Arabshahi *et al.* (2021a)
Monitor workers' heart rates	Lee *et al.* (2017), Kamisalic *et al.* (2018), Hwang and Lee (2017), Hashiguchi *et al.* (2020)
Monitoring spinal biomechanics of workers	Arabshahi *et al.* (2021a)
Estimate energy expenditure	Lee *et al.* (2017)
Monitoring physical workload and posture recognition	Ahn *et al.* (2019), Chen *et al.* (2017)
Detect construction hazards and reveal abnormal patterns	Jeon and Cai (2022), Arabshahi *et al.* (2021a)
Gait abnormalities	Yang *et al.* (2017)
Fall risk assessments	Nnaji *et al.* (2021)
Monitor and prevention of dust	Smaoui *et al.* (2018)

Source(s): Table created by Author

Table 2.
Benefits of WSDs

Barriers	Authors
Concern for usability	Lee *et al.* (2017)
Lack of integration with existing construction practices and operations	Nnaji and Awolusi (2021)
Health and safety concern	Abuwarda *et al.* (2022)
Initial cost	Nnaji *et al.* (2021), Nnaji and Awolusi (2021)
Maintenance cost	Dithebe *et al.* (2019)
Operating cost	Goodrum *et al.* (2011)
Cost of training and employing professionals	Arabshahi *et al.* (2021a)
Uncertain cost-benefit relation	Dithebe *et al.* (2019)
Technology-related operational difficulties	Nnaji and Awolusi (2021)
Challenge of power supply	Heller, 2015
Data management challenge	Ahmed *et al.* (2018)
Lack of proper information technology (IT) infrastructure	Didehvar *et al.* (2018)
Technology immaturity	Golizadeh *et al.* (2019)
Employees compliance	Alizadehsalehi and Yitmen (2019)
Legal or ethical concerns	Haikio *et al.* (2020)
Resistance to change	Didehvar *et al.* (2018)
Organization culture	Adriaanse *et al.* (2010)
Lack of government support	Rogers *et al.* (2015)
Temporary nature of construction	Adriaanse *et al.* (2010)
Privacy	Choi *et al.* (2017)
Site-related issues	Golizadeh *et al.* (2019)
Manufacturing requirement	Schall *et al.* (2018)
Lack of well-trained staff	Akinbile and Oni (2016)
Long data processing time	Arabshahi *et al.* (2021a), Nnaji *et al.* (2021)
High data storage capacity	Abuwarda *et al.* (2022)
Interference with essential activities	Lee *et al.* (2017)
Individual privacy and ownership of data	Nnaji *et al.* (2021)
Former unsuccessful experience	Arabshahi *et al.* (2021b)

Source(s): Table created by Author

Table 3.
Barriers to the adoption of WSDs

measurement of the required metrics, the choice of wireless communication network, connectivity protocol, and cloud storage of data and analysis tools. Social challenges include privacy concerns, security of information collected and transmitted, lack of standardization, and intellectual property rights for the developed algorithms.

According to Nnaji *et al.* (2021), when data protection concerns are taken into account, the novelty of collecting data can create nervousness among workers, who may feel that they do not have full control over the end-use of the data. Project/organisation-based challenges include financial challenges, limited interoperability with existing systems, and the need for information technology (IT) infrastructure (Masum *et al.*, 2013). There are liability concerns (e.g. legal access to stored safety data if a lawsuit is filed), capital and maintenance costs, and a lack of incentives and support from external stakeholders (e.g. clients, governments, safety regulatory agencies, and insurance companies) (Abuwarda *et al.*, 2022). Nnaji *et al.* (2021) opine that there is no standard or government regulation for adopting wearable technologies in the construction industry. Okpala *et al.* (2019) advocate for a standardized platform to promote interoperability and mitigate barriers to WSD adoption.

Methodology

Positivism and interpretivism are the main philosophies that underpin research. Positivists believe that a phenomenon can only be understood and explained through objective, observable and verifiable facts (Du Plooy-Cilliers *et al.*, 2014). Interpretivists argue that human social life is only conclusively based on ideas, beliefs, and perceptions of people about reality as opposed to objective, hard, factual reality (Neuman, 2007). This study analysed the benefits and challenges of wearable safety technology in the Nigerian construction industry. The study was conducted in Lagos and Abuja cities in Nigeria. Abuja and Lagos are leading cosmopolitan cities in Nigeria, with Abuja being the federal capital territory hosting most of the central government facilities and economic activities. Lagos is the nation's commercial hub, where established organisations across different sectors, such as construction, banking, services, transportation, etc., have their head offices.

Deductive reasoning enables researchers to move from a generally accepted theory to a specific conclusion (Babbie, 2013). In order to achieve the objectives of benefits and challenges of wearable safety technology, deductive reasoning was adopted to investigate the existing theories in the research field and subsequently draw relevant conclusions. Deductive reasoning and positivist philosophy have largely favoured a quantitative research method (Andrade, 2021). Consequently, quantitative research was adopted for this study.

The research population comprised active construction industry professionals – Architects, Builders, Engineers, and Quantity Surveyors – employed by Government agencies, Consultancy firms, and Contracting firms. Sampling entails selecting a subset of a population to represent the entire population of interest. It helps to extract acceptable respondents to represent the larger population from whom data is collected (Welman *et al.*, 2005). Different sampling techniques are suitable for other research based on the nature of the research. Purposive sampling enables the researcher to identify people with the knowledge or experience to participate in a study (Blumberg *et al.*, 2008). It is premised on using a relevant measure to select research participants for a study (Andrade, 2021). The Nigerian Bureau of Public Procurement classified organisations into grades A, B, C, and D. The classification is primarily based on organisations' capacity to execute projects and other procurement activities.

Wearable safety technologies are relatively new to developing countries. Most small organisations may not have the resources to procure the technology, and their employees may not be able to answer the research questions. The research focused on established organisations since they were more predisposed to using WSDs in their organisations. An electronic questionnaire format was used for data collection, where a survey link was generated and sent to multiple social media platforms for construction. The survey was open from May 15, 2022, through September 4, 2022. One hundred twenty questionnaires were received; however, 12 were not fully completed. Therefore, 108, representing 90%, were used for the analysis.

The questions for the questionnaire survey for the benefits of using wearable safety technologies were captured on a 5-point Likert scale where 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree, whilst the questions for the barriers to the adoption of wearable safety technologies were captured on a 4-point Likert scale where 1 = , not a barrier; 2 = slightly a barrier; 3 = somewhat a barrier; 4 = a serious barrier. Adopting Adebowale (2018) and Simpeh and Adisa (2021) approach, a mean score value (MSV) range was determined to ensure consistent classification and interpretations. Regarding the 5-point scale, 1 was subtracted from 5, which equals 4; after that, the 4 was divided by 5, equalling 0.8, which becomes the MSV range. Thus, the MSV range for "strongly disagree" becomes $>1.00 \leq 1.80$; "disagree" becomes $>1.80 \leq 2.60$; "neither agree nor disagree" becomes $>2.60 \leq 3.40$; "agree" becomes $>3.40 \leq 4.20$; and "strongly agree" becomes $>4.20 \leq 5.00$. For the 4-point scale, 1 was subtracted from 4, which equals 3; after that, the 3 was divided by 4, equalling 0.75, which becomes the MSV range. Therefore, the MSV range for "not a barrier" becomes $>1.00 \leq 1.75$; "slightly a barrier" becomes >1.75 ≤ 2.50; “somewhat a barrier” becomes >2.50 ≤ 3.25; and a serious barrier’ becomes >3.25 ≤ 4.00.

Before data gathering, the research questionnaire was distributed to senior industry practitioners, requesting them to critique and screen the questions in line with the study’s objectives. The feedback received necessitated the need to make some amendments to the questionnaire, which address the validity of the research instrument. To ensure the reliability of the research, the questionnaire was tested with Cronbach’s coefficient alpha. Cho and Kim (2015) clarified that whilst a value of 0.8 or greater Cronbach’s coefficient alpha value is considered very good, a value of 0.6–0.7 indicates an acceptable level of reliability. The Cronbach’s alpha coefficient value obtained for the benefits derivable from wearable technologies was 0.887, while 0.936 was obtained for the barriers. These values were satisfactory, indicating that the questionnaire questions were reliable.

Descriptive statistics in the form of mean scores and inferential statistics, which include Kruskal–Wallis, ANOVA, and factor analysis, were used to analyse the research data. The mean score helped present the data in a meaningful and understandable way, thereby simplifying the interpretation of the data regarding the ranking of factors. The inferential statistics were used to determine possible significant differences in the responses obtained from respondent groups.

Data presentation

Respondents’ information

Table 4 summarizes the demographic information of the respondents. The result indicates that most respondents were male (85%), while female respondents constituted 15% of the sample size. Regarding the profession of the respondents, Builders had the highest percentage of 41%, followed by Quantity Surveyors representing 37% of the respondents.

Category	Classification	Frequency	%
Gender	Male	92	85
	Female	16	15
Total		108	100
Profession			
	Architect	12	11
	Builder	44	41
	Engineer	12	11
	Quantity Surveyor	40	37
Total		108	100
Employer type			
	Government Agency	48	44
	Consultancy	20	19
	Contracting	40	37
Total		108	100
Highest Level of Education			
	BSc/B.Tech	44	41
	HND	10	9
	MSc/M.Tech	36	33
	PhD	18	17
Total		*108*	*100*

Source(s): Table created by Author

Table 4. Demography of respondents

Both the Architects and Engineers had 12% representation. 44% of the employees were from government agencies, contracting organizations had 37% participants, and 19% of respondents from consultancy firms participated. Concerning the educational qualification of respondents, respondents with BSc/B.Tech constituted 41%, followed by MSc/M.Tech that represents 33%. Respondents with Ph.D. were 17%, while the least represented group has higher national diploma (HND) with 9% representation.

Benefits of using WSDs

A reliability test was conducted relative to the benefits of adopting WSDs in the Nigerian construction industry. The result indicates a Cronbach's value of 0.887. The factors were satisfactory because Cronbach's value exceeds the 0.50 threshold (Oke *et al.*, 2020).

Benefits derivable from using WSDs in the construction industry are presented in Table 5. Slips, trip, or fall is ranked first with a MSV of 4.31, followed by struck-by-object in the second position with a MSV of 4.24. Caught-in or between hazards is ranked third with a MSV of 4.20, and sensing environmental concerns is ranked fourth with a MSV of 4.15. The fifth-ranked benefit with a MSV of 4.07 was collision avoidance.

Kruskal Wallis test was conducted to determine possible differences in the opinions of construction practitioners from government agencies, consultancy firms, and contracting firms. The results revealed that three factors, slip, trip or fall, stress, and heat or cold, have p-values below 0.05. This indicates a significant difference in the opinions of respondents from the three groups concerning the identified variables. The remaining eight factors have p-values above 0.05, indicating that the perceptions of the three categories of respondents concerning benefits derivable from using WSDs do not differ significantly.

Table 6 presents the ANOVA test conducted to examine likely differences in general respondents' opinions. The p-values of five variables, which include struck-by objects and falling

Employer	Government agencies		Consultancy firms		Contracting firms		Total		Kruskal–Wallis	AsympSig
Variables	MSV	RK	MSV	RK	MSV	RK	MSV	RK		
Struck-by object	4.17	2	4.40	2	4.25	4	4.24	2	2.904	0.234
Caught-in or between hazard	4.04	4	4.30	3	4.35	2	4.20	3	5.872	0.053
Falling from a high level	3.92	6	4.30	3	4.10	7	4.06	6	3.182	0.204
Slips, trip or fall	4.08	3	4.60	1	4.45	1	4.31	1	9.406	0.009*
Stress	4.33	1	3.70	10	4.00	8	4.00	8	6.199	0.045*
Heat or cold (working environment)	3.88	9	3.70	11	4.35	2	4.02	7	6.198	0.045*
Explosions/fire	3.71	10	4.10	8	3.90	10	3.85	10	3.436	0.179
Electrocution	3.92	6	4.20	6	4.00	8	4.00	8	5.058	0.080
Cave in	3.50	11	3.80	9	3.75	11	3.65	11	1.975	0.373
Sensing environmental concerns (carbon monoxide, gas leaks etc.)	4.00	5	4.30	3	4.25	4	4.15	4	2.846	0.241
Collision avoidance	3.92	6	4.20	6	4.20	6	4.07	5	4.027	0.134

Note(s): The significant level at $p \leq 0.05$
Source(s): Table created by Author

Table 5. Benefits derivable from using wearable safety devices

Table 6.
ANOVA of benefits derivable from wearable safety devices

WSDs adoption level	Sum of squares	Df	Mean square	*F*	Sig
Struck-by object	8.169	3	2.723	5.096	0.002*
Caught-in or between hazard	1.858	3	0.619	1.624	0.188
Falling from a high level	6.855	3	2.285	2.737	0.047*
Slips and trips	1.525	3	0.508	0.758	0.520
Stress	12.855	3	4.285	4.009	0.010*
Heat or cold (working environment)	7.787	3	2.596	2.642	0.053
Explosions/Fire	12.569	3	4.190	3.376	0.021*
Electrocution	2.475	3	0.825	0.958	0.415
Cave in	7.593	3	2.531	2.829	0.042*
Sensing environmental concerns (carbon monoxide, gas leaks, etc.)	2.276	3	0.759	1.171	0.324
Collision avoidance	4.626	3	1.542	2.035	0.113

Note(s): The significant level at $p \leq 0.05$
Source(s): Table created by Author

from a high level, are less than 0.05, indicating a significant difference in respondents' perceptions. Caught-in or between hazard and slip, trip or fall, and other four factors have *p*-values greater than 0.05, implying no significant difference in respondents' perception of the factors.

Challenges of using WSDs

The twenty-nine factors identified as challenges associated with the adoption of WSDs are subjected to a reliability test. The test reveals a Cronbach's value of 0.936. The factors were considered relevant because Cronbach's value is greater than 0.50 (Oke *et al.*, 2020).

Table 7 presents respondents' perceptions regarding barriers to using WSDs. Initial cost (MSV = 3.57) and maintenance cost (MSV = 3.44) achieved the first and second positions, respectively, in ranking. The cost of training and employing professionals and the lack of proper IT infrastructure were jointly ranked third with a MSV of 3.33. Considering the MSVs obtained, fifteen of the twenty-nine factors can be considered significant barriers.

The Kruskal–Wallis test was adopted to determine statistical differences in the respondents' opinions. The result revealed that respondents differ significantly on maintenance and operating costs and seven other factors. The remaining twenty factors have *p*-values greater than 0.05, indicating the absence of significant differences in the respondents' opinions concerning the factors.

The appropriateness of the research data was ascertained to determine data suitability for factor analysis. Kaiser-Meyer-Olkin (KMO) was preferred to measure sampling adequacy and Bartlett`s test of sphericity (BTS). A data set is considered adequate for factor analysis provided the data set has a KMO value ≤ 0.50 and BTS of $p \leq 0.05$. From Table 8, it can be observed that the obtained KMO value is 0.756. The value is adequate for factor analysis because it meets the 0.50 threshold, while the BTS was significant with $p = 0.000$.

It is essential to examine the number of variables and sample size before conducting factor analysis (Whitley *et al.*, 2013). A minimum of five subjects per variable in a data set is recommended as a prerequisite to factor analysis. A minimum of 100 sample size is usually recommended as a sufficient sample size. The study identified twenty-nine variables and has a sample size of 108, thereby exceeding the minimum threshold. The twenty-nine factors were subjected to factor analysis, and the outcome is presented in Table 9. All the variables had a commonality score greater than 0.20, which aligns with the recommendation for factor analysis.

Employer type Variables	Government agencies MSV	 RK	Consultancy firms MSV	 RK	Contracting firms MSV	 RK	Total MSV	 RK	Kruskal–Wallis	AsympSig
Concern for usability	2.50	27	2.50	24	2.65	26	2.56	24	0.680	0.712
Lack of integration with existing construction practices and operations	2.88	14	3.20	8	3.05	17	3.00	15	3.822	0.148
Health and safety concern	2.71	19	2.30	27	2.15	29	2.43	28	4.792	0.091
Initial cost	3.58	1	3.30	7	3.70	1	3.57	1	0.872	0.647
Maintenance cost	3.25	2	3.40	4	3.70	1	3.44	2	11.109	0.004*
Operating cost	3.04	9	2.90	12	3.50	5	3.19	7	7.638	0.022*
Cost of training and employing professionals	3.13	4	3.40	4	3.55	4	3.33	3	4.567	0.102
Uncertain cost-benefit relation	2.88	14	2.90	12	3.25	14	3.02	14	4.030	0.133
Technology-related operational difficulties	3.08	7	2.70	17	3.15	16	3.04	13	1.744	0.418
Challenge of power supply	2.88	14	3.40	4	2.56	5	2.99	16	11.590	0.003*
Data management challenge	2.63	21	3.00	11	3.40	9	2.98	17	16.406	0.000*
Lack of proper IT infrastructure	2.96	12	3.50	2	3.70	1	3.33	3	15.836	0.000*
Technology immaturity	3.12	5	3.50	2	3.45	8	3.31	5	6.732	0.035*
Lack of well-trained staff	3.17	3	3.60	1	3.30	12	3.30	6	3.967	0.138
Employees compliance	2.92	12	3.10	9	3.40	9	3.13	10	4.945	0.084
Legal or ethical concerns	2.33	29	2.60	20	2.70	21	2.52	27	2.824	0.244
Resistance to change	3.04	9	2.90	12	3.30	12	3.11	11	5.506	0.064
Organization culture	3.04	9	2.60	20	3.40	9	3.09	12	10.390	0.006*
Lack of government support	3.08	7	2.60	20	3.50	7	3.15	9	12.870	0.002*
Temporary nature of construction	2.82	17	2.60	20	2.85	20	2.81	18	0.920	0.631
Privacy	2.67	21	2.80	15	2.45	27	2.61	24	1.693	0.429
Site-related issues	2.67	21	2.30	27	3.00	18	2.72	20	7.223	0.027*
Manufacturing requirement	2.79	18	2.50	24	2.70	21	2.70	21	0.879	0.644
Security	3.12	5	3.10	9	3.25	14	3.17	8	0.456	0.456
Long data processing time	2.71	19	2.70	17	3.00	18	2.81	18	2.413	0.299
High data storage capacity	2.58	25	2.70	17	2.70	21	2.65	23	0.178	0.915
Interference with essential activities	2.63	23	2.10	29	2.30	28	2.41	29	4.501	0.105
Individual privacy and ownership of data	2.42	28	2.50	24	2.70	21	2.54	25	1.846	0.397
Former unsuccessful experience	2.58	25	2.80	15	2.70	21	2.67	22	0.909	0.635

Note(s): Significant level of $p \leq 0.05$ was adopted
Source(s): Table created by Author

Table 7.
Barriers to the use of wearable devices

The screen plot in Figure 1 shows that the total number of factors that could be retained was seven because it shows the breakpoint of the data displaced just before the curve begins to flatten. Therefore, seven components were extracted, accounting for 64.073% of the total variance of the barriers. A cutoff point of 0.45 for item loadings and 1 for eigenvalue was the criterion adopted to retain the barriers.

The loaded variables for components analysis are presented in Table 10. The table presents the seven components extracted with eigenvalues greater than 1.0 with a factor loading of 0.30 as the baseline for removal. As indicated in the table, the total variance explained for each component drawn are component 1 (15.608%), component 2 (27.439%), component 3 (36.765%), component 4 (45.196%), component 5 (52.333%), component 6 (58.756%), and component 7 (64.073%). The seven clustered components of the barriers to using of WSDs are presented. In order to categorize the barriers into relevant groups, a

Table 8. KMO and Bartlett's test

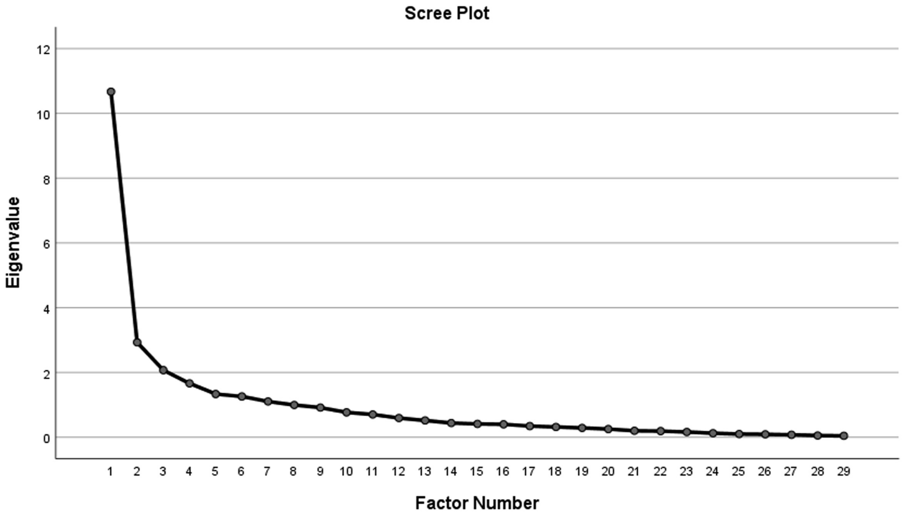
KMO and Bartlett's test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.756
Bartlett's test of Sphericity	Approx. Chi-Square	2,379.504
	Df	406
	Sig	0.000

Source(s): Table created by Author

Table 9. Commonalities for the barriers to the use of wearable devices

Barrier	Initial	Extraction
Concern for usability	0.641	0.543
Lack of integration with existing construction practices and operations	0.753	0.631
Health and safety concern	0.721	0.502
Initial cost	0.553	0.243
Maintenance cost	0.693	0.656
Operating cost	0.802	0.864
Cost of training and employing professionals	0.723	0.562
Uncertain cost-benefit relation	0.770	0.595
Technology-related operational difficulties	0.727	0.571
Challenge of power supply	0.820	0.671
Data management challenge	0.879	0.654
Lack of proper IT infrastructure	0.751	0.454
Technology immaturity	0.802	0.757
Lack of well-trained staff	0.857	0.645
Employees compliance	0.703	0.555
Legal or ethical concerns	0.769	0.618
Resistance to change	0.796	0.766
Organization culture	0.797	0.713
Lack of government support	0.750	0.665
Temporary nature of construction	0.832	0.724
Privacy	0.792	0.677
Site-related issues	0.702	0.576
Manufacturing requirement	0.747	0.684
Lack of well-trained staff	0.744	0.687
Long data processing time	0.807	0.651
High data storage capacity	0.752	0.630
Interference with essential activities	0.863	0.825
Individual privacy and ownership of data	0.861	0.712
Former unsuccessful experience	0.786	0.753

Source(s): Table created by Author



Source(s): Figure created by Author

Figure 1.
Eigenvalue scree plot

principal component analysis was conducted. Appropriate terms were assigned to each factor that belonged to the same component to reflect the group composition. Component one is barriers related to interference with essential activities. The component explains 15.608% of the variance.

Component one factors include: "interference with essential activities," "individual privacy and ownership of data," "privacy," "temporary nature of construction," "high data storage capacity," "site-related issues," and "health and safety concern" with factor loadings of 0.816, 0.785, 0.774, 0.766, 0.574, 0.541 and 0.527 respectively. Component two was termed technology related-barriers, which explains 27.439% of the variance. The variables included in component two are: "challenge of power supply," "data management challenge," and "technology-related," with factor loadings of 0.777, 0.687, and 0.647, respectively.

Component three was labelled cost related-barriers. The component has a 36.765% variance. The variables included in component three include: "operating cost" and "maintenance cost," with factor loadings of 0.861 and 0.723, respectively. Component four was called legal/ethical related barriers. The component has a 45.196% variance. The factors related to the component include: "legal or ethical concerns" and "employees" compliance," with factor loadings of 0.653 and 0.598, respectively.

Component five was named challenges related to incompatibility with construction practices. The component explains 52.333 of variance. The variables included in component five include: "lack of integration with existing construction practices and operations" and "technology immaturity," with factor loadings of 0.685 and 0.550, respectively. Component six is related to the human-nature challenge with 58.756 of variance. Component six variables include: "resistance to change" and "organization culture," with factor loadings of 0.715 and 0.664, respectively. Component seven was labelled a knowledge-related challenge. The component has a 64.073 variance. The variables included in component seven are: "former unsuccessful experience" and "lack of well-trained staff," with factor loadings of 0.647 and 0.585, respectively. Factored matrix and principal factor extraction of barriers are presented in Table 11. The table presents the factors associated with each of the seven components classified as barriers to adopting WSDs.

Table 10.
Total variance explained for the adoption of wearable safety devices

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	10.669	36.791	36.791	10.330	35.619	35.619	4.526	15.608	15.608
2	2.929	10.100	46.890	2.578	8.888	44.508	3.431	11.831	27.439
3	2.071	7.141	54.031	1.755	6.050	50.558	2.705	9.326	36.765
4	1.662	5.730	59.761	1.282	4.420	54.978	2.445	8.431	45.196
5	1.334	4.599	64.360	1.018	3.510	58.488	2.070	7.138	52.333
6	1.258	4.338	68.699	0.847	2.921	61.409	1.863	6.423	58.756
7	1.104	3.805	72.504	0.772	2.664	64.073	1.542	5.316	64.073
8	0.996	3.435	75.939						
9	0.915	3.156	79.095						
10	0.768	2.648	81.743						
11	0.702	2.419	84.162						
12	0.592	2.043	86.205						
13	0.518	1.788	87.992						
14	0.437	1.508	89.500						
15	0.411	1.418	90.919						
16	0.399	1.375	92.294						
17	0.344	1.188	93.481						
18	0.317	1.093	94.574						
19	0.289	0.995	95.569						
20	0.252	0.868	96.437						

Note(s): Extraction Method: Principal Components Analysis
Source(s): Table created by Author

Table 12 presents reliability test results for the seven factors. Most factors (1, 2, 3, 4, 6, and 7) have Cronbach's Alpha greater than 0.65, as recommended by (Cho and Kim 2015). Factor 5 has a Cronbach's Alpha of 0.588, which is still acceptable because the value exceeds the 0.50 threshold (Oke *et al.*, 2020).

Component factors	Cronbach's alpha coefficient
Factor 1 - Interference with essential activities related-barriers	0.888
Factor 2 - Technology related barriers	0.815
Factor 3 - Cost related-barrier	0.778
Factor 4 – Legal/ethical related-barriers	0.737
Factor 5 - Incompatibility with construction practices related-barriers	0.588
Factor 6 - Human factor-related barriers	0.841
Factor 7 - Knowledge-related barriers	0.758

Source(s): Table created by Author

Table 11. Reliability test for components

Code		Components						
		1	2	3	4	5	6	7
EB27	Interference with essential activities	0.816	–	–	–	–	–	–
EB28	Individual privacy and ownership of data	0.785	–	–	–	–	–	–
EB21	Privacy	0.774	–	–	–	–	–	–
EB20	Temporary nature of construction	0.766	–	–	–	–	–	–
EB26	High data storage capacity	0.574	–	–	–	–	–	–
EB22	Site-related issues	0.541	–	–	–	–	–	–
EB3	Health and safety concern	0.527	–	–	–	–	–	–
EB25	Long data processing time	–	–	–	–	–	–	–
EB10	Challenge of power supply	–	0.777	–	–	–	–	–
EB11	Data management challenge	–	0.687	–	–	–	–	–
EB9	Technology-related operational difficulties	–	0.647	–	–	–	–	–
EB7	Cost of training and employing professionals	–	–	–	–	–	–	–
EB12	Lack of proper IT infrastructure	–	–	–	–	–	–	–
EB6	Operating cost	–	–	0.861	–	–	–	–
EB5	Maintenance cost	–	–	0.723	–	–	–	–
EB23	Manufacturing requirement	–	–	–	–	–	–	–
EB4	Initial cost	–	–	–	–	–	–	–
EB16	Legal or ethical concerns	–	–	–	0.653	–	–	–
EB15	Employees compliance	–	–	–	0.598	–	–	–
EB19	Lack of government support	–	–	–	–	–	–	–
EB2	Lack of integration with existing construction practices and operations	–	–	–	–	0.685	–	–
EB13	Technology immaturity	–	–	–	–	0.550	–	–
EB1	Concern for usability	–	–	–	–	–	–	–
EB8	Uncertain cost-benefit relation	–	–	–	–	–	–	–
EB14	Lack of well-trained staff	–	–	–	–	–	–	–
EB17	Resistance to change	–	–	–	–	–	0.715	–
EB18	Organization culture	–	–	–	–	–	0.664	–
EB29	Former unsuccessful experience	–	–	–	–	–	–	0.647
EB24	Lack of well-trained staff	–	–	–	–	–	–	0.585

Source(s): Table created by Author

Table 12. Factored matrix and principal factor extraction barriers to the adoption of wearable devices

Discussion of the findings

This study investigated benefits derivable from using WSDs and barriers to adopting wearable safety technologies. Construction practitioners' perceptions of the benefits of using WSDs do not differ significantly, indicating their consensus on most benefits. Stress and heat or cold achieving MSVs range $>3.40 \leq 4.20$ implies respondents' agreement with the factors. However, significantly divergent opinions were expressed concerning recognizing the factors as benefits derivable from using WSDs. Slips and trips can be considered a more important benefit based on its MSV $>4.20 \leq 5$.

Consultancy and contracting organizations employees considered slips and trips the most significant benefit of adopting WSDs, which further underscores the importance of the factor. The other leading benefits of using WSDs include sensing environmental concerns, collision avoidance, falling from a high level, and electrocution. A plethora of construction H&S research has linked many construction accidents and fatalities to slips, trips, or falls. Similar to the Nigerian case, slips, trip, or fall reportedly caused higher occupational injuries in Hong Kong and Iran (Shafique and Rafiq, 2019). Construction safety research has reported the potential of wearable safety technologies to mitigate the rate of accidents and fatalities caused by slips, trips, or falls (Abuwarda *et al.*, 2022). Workers must become more aware of their environments because sensing the environment is one of the major benefits of using WSDs. Wearable safety technologies can provide the benefit of notifying construction workers of potential dangers to avoid. Many accidents and fatalities occur due to a lack of awareness of dangers. Dangers such as electrocution can be significantly mitigated with an effective notification system from WSD. Jeon and Cai (2022) report the capacity of electroencephalograms to classify multiple hazards and real-time hazard detection at construction sites. Collision avoidance was expressed as a key benefit of using WSDs. Collison accidents resonate in construction H&S research. Collision accidents are majorly associated with workers and equipment (Jo *et al.*, 2019). Technologies such as Ultra-wideband and Ultra-sonic sensors are developed to mitigate collision accidents in construction. Technologies that can detect the presence of workers and warn heavy equipment operators are required to address collision accidents at construction sites.

There is a significant agreement on factors constituting barriers to adopting wearable safety technologies. Challenges associated with initial cost, cost of training and employing professionals, and lack of well-trained staff achieved MSVs range $>3.25 \leq 4.00$. Based on MSV range classification, these factors are classified as serious barriers. Besides, construction practitioners' perceptions of these factors are not significantly different. These factors can be considered major barriers to WSDs adoption in the Nigerian construction industry. Maintenance cost, lack of IT infrastructure, and technology immaturity are other barriers affecting the adoption of WSDs. Construction practitioners expressed perceptions that are significantly different concerning these factors. However, the MSV range ($>3.25 \leq 4.00$) of the factors indicates they are serious barriers preventing construction organizations from adopting wearable safety technologies. Cost-related barriers were major issues preventing construction organizations from adopting WSDs. Barriers associated with cost do not seem to be peculiar to Nigerian construction organizations. Studies from the United States have also reported cost-related challenges preventing the adoption of WSDs (Nnaji and Awolusi, 2021). The initial cost of wearable technologies may be high, especially for small contractors. However, a successful implementation will provide long-term benefits for construction organizations (Nnaji and Awolusi, 2021; Alizadehsalehi and Yitmen, 2019). Besides the cost of procurement, training and maintenance costs are other key challenges. Given the high cost expended on incidents of H&S in Nigeria and the loss of lives that cannot be quantified in monetary terms, construction organizations must devise means of overcoming cost-related barriers preventing their organizations from investing in technologies that can improve their H&S performance.

The problem of government support and lack of IT are other key issues identified by construction practitioners. Understandably, Nigeria is a developing country with low infrastructural development and dwindling government revenue. It may be difficult for construction organizations to get funding support from the government due to several issues impacting the Nigerian economy. Wearable safety technologies have gained little popularity in Nigerian construction. Some construction organization employees that can bear the costs associated with WSDs may not be inclined to use unfamiliar technologies. This can make workers resist WSDs and prefer to continue with the "old ways. Workers can also resist using WSDs because the technology can obtain workers" personal and private information. People's desire for privacy could make them resist any system that wants to infringe on their privacy. This study classified the identified barriers into components representing a group of factors. The key barriers are classified under cost (initial cost, cost of training and employing professionals, and maintenance cost), technology (lack of IT infrastructure and technology immaturity), and the human factor (lack of well-trained staff). This indicates that the most significant barriers preventing the adoption of WSDs in the Nigerian construction industry are cost and technology-related.

Conclusions, limitations and future research

As the need to improve workers' health and safety management in the construction sector increases, there is a clamour for construction organizations to increasingly adopt and implement innovative technologies to improve workers' health and safety. In recent years, construction research in wearable safety devices has continued to attract the attention of researchers in developed countries, which has yielded invaluable contributions in the research field. Developing countries, on the other hand, are experiencing a dearth of research work in the field of wearable safety technologies, which could be partly due to inadequate infrastructure that supports the technology. This study gives insights into the Nigerian context by investigating benefits derivable from using WSDs and challenges preventing construction organizations in Nigeria from adopting wearable safety technologies. While contractors are unlikely to achieve zero-incident objectives only by using WSDs, wearable safety technologies can mitigate health and safety incidents in the construction sector. Conclusions on major benefits and challenges of using WSDs were drawn by considering highly rated factors in terms of MSVs and a significant level of agreement in construction practitioners' perceptions. Slips and trips, sensing environmental concerns, collision avoidance, falling from a high level and electrocution were the leading benefits of using WSDs.

Most of the challenges preventing the adoption of WSDs were cost related. Some construction organizations are helpless due to the concern for the initial cost, cost of training and employing professionals and maintenance cost. Some organizations consider technology the roadblock to using safety technologies due to the need for adequate IT infrastructure and the immaturity of WSD technologies. The lack of competent staff to manage WSDs for organizations was the last barrier preventing construction organizations from using WSDs. Construction professionals in public sectors, consultancy and contracting firms are the participants of this study. Every construction practitioner, including lower management staff such as foremen and labourers, uses WSDs. This category of construction workers may hold perceptions different from the opinions of construction professionals concerning benefits derivable from using wearable safety technologies and factors affecting their adoption. Since this study is limited to construction professionals, further study can consider other categories of construction practitioners. Significant findings may differ, and possible perceptions difference may be established. The study also needed to be expanded in scope. Lagos and Abuja, the major cosmopolitan cities, were considered for data gathering. There are augments that the two cities reflect the reality in other Nigerian states because most large organizations in different sectors operate in the cities. Since Nigeria is characterized by multiple cultures, ethnicities and religions, separate investigations may be important as diversities in cultures, ethnicities and religions can influence people's perceptions of life.

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