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EVALUATING THE KEY CHALLENGES OF IMPLEMENTING SMART PPE IN NIGERIA'S CONSTRUCTION SECTOR

Sunday Adesina Ajobo[1]
Subashini Suresh[2]
Suresh Renukappa[3]

Abstract

Purpose of the Research: Construction incidents have high repercussions on both the workforce and the construction project, which impact not just the workforce and the project but also their families and local communities. The frequency of accidents within the construction industry makes it imperative to prioritize safety in the industry. Smart Personal Protective Equipment (Smart PPEs) stand as a potential tool to transform safety protocols within the construction. The aim of this research is to evaluate the integration of Smart PPEs in Nigeria's construction sector.

Design/methodology/approach: The research was conducted using a cross-sectional survey method. The survey was conducted using Google Forms filled by 84 stakeholders in Nigeria's construction industry. The survey data were analysed using descriptive statistics function of Microsoft Excel and Statistical Package for Social Sciences (SPSS),

Findings: The results indicate that 84 % of participants were industry stakeholders and adequate education and experience in the construction industry. The study revealed several challenges in the application of Smart PPEs in the construction industry. The cost of Smart PPEs, lack of technical knowledge on usage, limited customisation and supply stands as a significant challenges. Privacy concerns and interoperability issues contribute significantly to the challenges. Resistance to change, difficulty of integrating with existing systems, environmental factors, lack of regulatory standards and cyber security threats further compound the challenges faced in the Smart PPEs adoption.

Originality/value: Study on Smart PPEs application are rare within the Nigeria construction context. The study provides evidence-based data on the challenges of Smart PPEs adoption in Nigeria. Additionally, the study revealed that there are significance challenges in the application of smart PPEs in Nigeria's construction industry, particularly the prohibitive cost. It adds to the ongoing academic debate on the adoption and application of smart PPEs and recommends enhanced collaboration between manufacturers and construction firms as solution to overcome adoption obstacles.

Keywords: Smart PPEs, Application, Challenges, construction industry

[1] Faculty of Science and Engineering, University of Wolverhampton, U.K
[2] Faculty of Science and Engineering, University of Wolverhampton, U.K
[3] Faculty of Science and Engineering, University of Wolverhampton, U.K

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Introduction

The construction sector contribute substantial the global economy development through providing employment (Alaloul et al., 2020; Norouzi et al., 2021). Financial support from governments, construction firms, and investors has fueled the industry's growth with a positive revenue performance trajectory (Debrah, Chan, and Darko, 2022). The past decade has witnessed consistent expansion of the sector globally, attributed to population growth, urbanization, and widespread infrastructure development projects (Patel et al., 2022; Razzaq et al., 2022). China and India have drove spending and enhancing overall industry revenue (Zhong et al., 2021).

Data from Statista (2023) revealed global construction market reached a value of 6.4 trillion US dollars in 2020 and projected to reach 14.4 trillion US dollars by 2030. Kudryavtseva, Nikishina, and Vasileva (2020) has estimated the revenue may surpass 15 trillion dollars by 2025. The anticipated trajectory indicates a steady and consistent increase in the global construction industry over the coming years, which suggest the size might double by 2025 or 2030. Another report by Parada and Rutgers (2022) highlighted that Global Powers of Construction (GPoC) achieved a total revenue of US$ 1,940 trillion in 2022 with a 6.3% increase over 2021. However, the industry faced significant challenges in the past year, marked by commodity price surges, disruptions in the supply chain and inflation triggered by war outbreak Europe. The sector also grappled with the repercussions of the 2019 coronavirus outbreak, which reduced construction volume. Data from the Office for National Statistics of Great Britain in 2021 indicated that despite 15% growth in various segments of the sector, construction statistics in Great Britain remained below the 2019 levels (Figure 1). Table 1 further illustrated that the percentage change in construction work output value between 2020 and 2021 across different types.

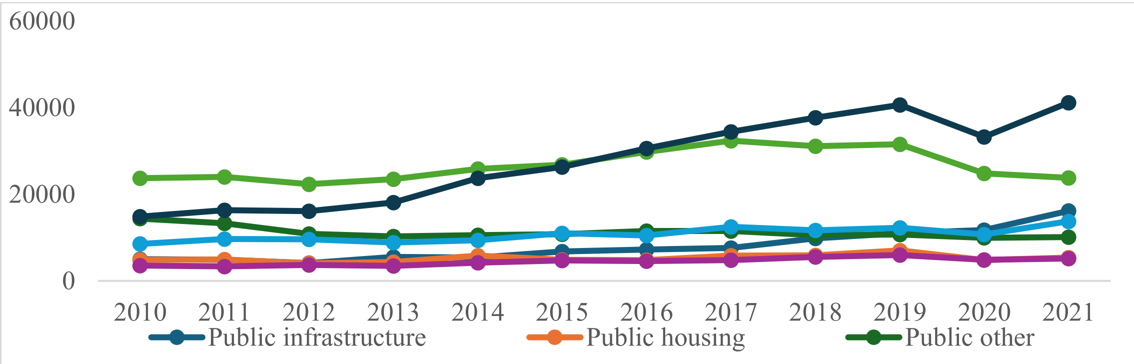

Figure 1: Growth Trend in Construction Work in Great Britain between 2010 and 2021

Despite experiencing revenue growth and technological advancements, construction sites continue to pose significant risks with potential for severe accidents and fatalities (Lakhiar and Lakhiar, 2021). Usami et al. (2021) emphasized the importance of identifying vulnerable areas in construction works and formulating targeted safety measures. Site accidents were attributed to equipment failures, falls from heights, incidents involving moving equipment, caught-between accidents and electrical hazards (Rafindadi et al., 2020). Human error, inadequate training, and communication gaps further contribute to the heightened risk of accidents (Ung, 2019). Ammad et al. (2021) reported a 2% increase in transportation accidents in 2019 with

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about 2122 cases, and 11% rise in crashes, trips and slides incidents with over 642 lives loses to hazardous work conditions.

Table1: Breakdown of Percentage Change in Construction Work Output Value between 2020 and 2021 According to Type

Type of Work	Sector	Percentage (%)	Annual Change (£ million)	2021 Value (£ million)
Total new work		15.3	15,380	115,579
	Total private	13.8	10,162	83,892
	Total public	19.7	5,218	31,687
New housing		22.4	8,508	46,545
	Private	23.7	7,887	41,149
	Public	13.0	620	5,396
Total infrastructure		33.0	7,415	29,911
	Private	28.1	3,015	13,760
	Public	37.4	4,400	16,151
Other	Public	2.0	198	10,140
	Private Industrial	6.1	299	5,197
	Private Industrial	23.7	-1,039	23,786

Source: Office for National Statistics – Construction statistics, Great Britain: 2021

The consequences of construction accidents extend beyond the workers to affecting their families, communities and the industry. For instance, injuries and fatalities result in increased medical costs, worker downtime, legal liabilities and project delays, which negatively affecting productivity and financial performance (Selleck, Cattani, and Hassall, 2023). Given the alarming accident data, prioritizing safety in the construction industry becomes imperative (Swuste et al., 2020). Singh et al. (2022) argue that comprehensive safety measures not only save lives but also enhance overall productivity, while at the same time ensuring sustainable growth. Hence, establishing a safety culture within construction companies is important (Rafindadi et al., 2020). This involves adoption of advanced technologies like smart personal protective equipment (Smart PPEs), which have potential to revolutionize construction practices and enhance safety. This study examine the challenges of smart PPEs application in the Nigerian construction industry.

Literature review

The construction industry faces significant safety challenges due to its reliance on heavy equipment and high-risk activities (Sanni-Anibire et al., 2020). The sector's growth and increasing project complexity have led to heightened stakeholder expectations for efficiency and safety (Vuorinen and Martinsuo, 2019). Protecting construction workers requires safety interventions that focus on the safe use of tools and the environment, as well as improved employee awareness and attitudes. A lack of knowledge about Personal Protective Equipment (PPE) and its effective use contributes to accidents during infrastructure projects (Martin et al., 2021).

The construction sector experiences a disproportionately high number of fatal work injuries compared to other industries (Abdalla et al., 2018). Accidents involving moving machinery, debris, and falling equipment often result in fatalities, particularly head injuries. Transportation accidents and exposure to hazardous substances or environmental conditions also contribute to worker deaths (Birhan and Endawoke, 2023). Personal Protective Equipment (PPE) plays a crucial role in mitigating the risks associated with construction accidents and is designed to shield workers from workplace hazards and detect potential dangers (Martin et al., 2021).

Health and safety efforts in the construction industry aim to safeguard the well-being and physical integrity of individuals in the workplace (Tamers et al., 2020). These efforts involve strategies, protocols, and regulations to prevent accidents, injuries, and illnesses arising from hazards or risks. Safety is categorized into different levels to address various aspects of risk and protection (Stephen et al., 2025). Smart digital technologies offer diverse safety options and can be integrated into PPEs like exoskeletons and drones.

Smart PPE technologies include Information and Communication Technology (ICT), Internet of Things (IoT), Artificial Intelligence (AI), augmented and virtual reality (AR/VR), connectivity devices, big data, cameras, and wearable devices (Martin et al., 2021). ICT technologies, such as mobile devices and teleconferencing software, enable the monitoring of activities. Wearable devices with sensors can be integrated into clothing or equipment to provide data, while big data collection devices use machine learning and AI for advanced data analysis (Tamers et al., 2020). Virtual Reality (VR) and Augmented Reality (AR) simulate real-world experiences, and Unmanned aerial systems (UAS) gather environmental information. RFID technology detects electromagnetic signals and allows for the reading and writing of hazard data (Martin et al., 2021).

Smart Personal Protective Equipment (PPE) encompasses a range of advanced safety solutions, including smart helmets, eyewear, hearing protection, and clothing, integrating sensors, biometrics, and wireless connectivity to enhance worker safety and productivity (Tamers et al., 2020). While a 2018 survey indicated that many multinational companies planned to incorporate Virtual Reality (VR) and Augmented Reality (AR) technologies, primarily in sectors like ICT, automotive, and aviation, it remains uncertain how widely these are used for Occupational Safety and Health (OSH) smart PPE monitoring (Ali, 2019). Interviews suggest a growing use of digital monitoring technologies for OSH purposes, particularly in high-risk industries and large corporations, though data specific to new OSH smart PPE monitoring systems in European workplaces is limited. Existing data shows that while PCs and mobile devices are widely used, the adoption of wearable devices and collaborative robots for OSH is less prevalent, but company size significantly impacts digital technology adoption, with larger establishments having more resources for implementation and training (Li et al., 2022).

Smart PPEs are essential for identifying and mitigating hazards through real-time measurements of workers' exposure to pressure, heat, radiation, noise, dust, biological agents, chemicals and UV radiation (Rasouli, Alipouri and Chamanzad, 2024). Advanced OSH monitoring wearables like smart glasses, hard hats, bands, and shoes connected to smartphones and smartwatches, effectively measure individual and environmental exposures, with cameras, wireless sensor networks (WSNs), and drones also contributing to environmental hazard assessment. Wearable smart PPE,

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equipped with dosimeters and radiometers, enables real-time and cumulative exposure tracking of nano-objects, dust, gas, mercury and UV radiation across various sectors (Cui et al., 2023). Additionally, smart systems with GPS tracking can trace exposure, identify contamination sources, and monitor body temperature to prevent heat-related illnesses, highlighting the broad capabilities of OSH monitoring systems beyond the specific hazards listed in Figure 3.

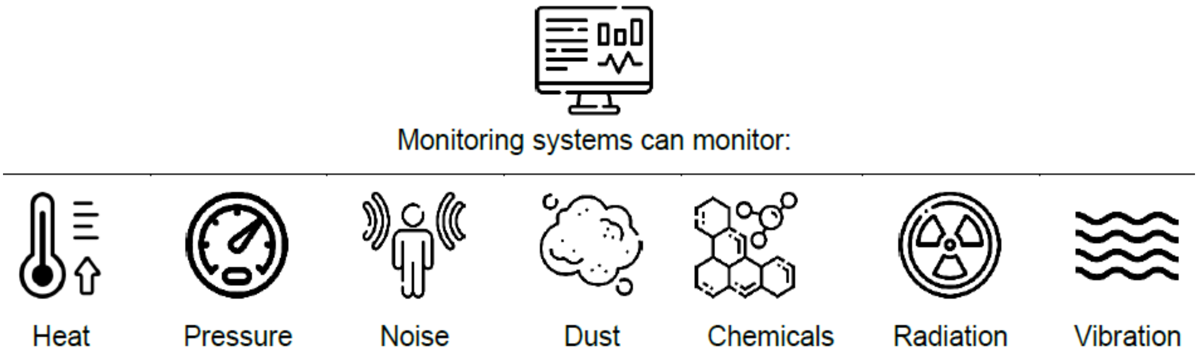

Figure 2: Hazards Identified by Smart PPEs in Workplace and Environments

Several factors drive the adoption and use of smart Personal Protective Equipment (PPE) monitoring systems, primarily categorized as technological advancements, legislation and standardization, and organizational elements. Technological progress, the evolution of end-user industries, and the integration of Internet of Things (IoT) technologies drive the investment in next-generation PPE, as products with advanced situation awareness and real-time communication capabilities enhance worker safety (Agarwal et al., 2019).

Purchasers and users are generally receptive to smart and wearable PPE products if they align with safety and financial objectives, and Occupational Health and Safety (OHS) managers ensure workforce safety while meeting regulatory requirements and budget constraints (Abd Latib et al., 2016). The rapid growth of IoT technology, with billions of devices in use, significantly influences the adoption of smart PPE, particularly with the integration of 5G platforms for larger companies seeking a return on investment (Podgorski et al., 2017). Smart PPEs are increasingly designed as multi-functional, offering protection against a range of hazards, and "systems approach" tend to outperform in the market (Ali, 2019).

Companies that facilitate the adoption of smart PPEs are those that create an ecosystem with minimal disruption and cost while demonstrating improved ROI, as the utilization of smart and wearable products can potentially prevent accidents and safeguard workers (Márquez-Sánchez et al., 2021). RealWear, Guardhat, Blackline Safety, Corvex, Kinetic and Levitate Technologies commonly provide services to high-risk industries such as mining, oil and gas, and manufacturing (Schirgi, 2019). Guardhat offers a complete situational awareness system, including its KYRA platform that integrates with third-party platforms and connectable sensors (Shilling, 2022). Blackline Safety has developed multi-gas detection equipment that connects workers with a live monitoring team and features built-in cellular and satellite connectivity. RealWear provides wearable Android tablets, the HMT-1 and HMT-1Z1, along with a cloud-based Foresight platform, offering a voice-activated, hands-free platform (Schirgi, 2019).

2.1 Risks Associated with Smart PPE Devices

OSH smart PPE monitoring systems change how risk effort is distributed. This potentially create new biomechanical constraints and risk factors for musculoskeletal disorders (MSDs) (Podgorski et al., 2017). Exoskeletons, for example, must reduce pressure in certain body parts without increasing it in others, as the overall impact could harm workers' health. These systems may also hinder movement, causing collisions, discomfort, skin irritation, increased cardiovascular load and stress. Overconfidence in workers' abilities due to a false sense of invulnerability is another concern, as is the potential for disorientation, motion sickness, and eye strain from virtual reality (VR) and augmented reality (AR) (Lyons et al. 2021).

Smart digital technologies can malfunction resulting in risks to workers. Batteries may overheat, catch fire, or explode, and sensor-based vests may allow water penetration, causing short circuits or electric shocks. Unmanned smart aircraft systems (UAS) may have safety risks due to system malfunction or cyberattacks, especially in semi-autonomous or autonomous UAVs (Ramos, Cruz and Simões, 2021). OSH smart PPE monitoring systems may intensify or de-intensify work, adding workload or leading to physical deconditioning by removing workers from manual tasks, affecting muscle/bone density or joint flexibility.

The introduction of OSH smart PPE monitoring systems can create psychosocial hazards, leading to workers' reluctance to use them (Lemos, Gaspar and Lima, 2022). Worker trust issues, especially towards technologies like AI, and concerns about technologies malfunctioning or being uncomfortable and challenging to customize can result in stress and anxiety. Disadvantaged workers may be affected disproportionately with stress levels heightened for those subjected to close performance monitoring. The introduction of new technology in the workplace may also lead to stress among older workers (Morsy and Rothstein, 2019).

2.2 Challenges of Smart PPEs Implementation

The introduction of novel Occupational Safety and Health (OSH) monitoring systems presents several challenges, beginning with data privacy, ownership, and security due to the extensive collection of sensitive personal information (National Academies of Sciences et al., 2018). Protocols for data access, storage, and transfer must include robust security measures to prevent breaches. Concerns also arise regarding the potential for 'digital surveillance' and increased control over workers, which can lead to stress and anxiety, particularly in high-demand environments (Hu et al., 2024).
Another challenge is the potential for workplace discrimination based on collected data, affecting hiring, retention, or firing decisions, which can compromise workers' dignity and self-fulfillment. The adoption of algorithmic management can impact working relationships, communication, and trust, potentially reducing interaction and task variety and fostering job dissatisfaction and feelings of isolation. Opacity in algorithmic decision-making may also create perceptions of injustice and alienation (Hu et al., 2024).

Additional concerns include the lack of calibration of algorithms for a diverse workforce, leading to biases based on gender, race, ethnicity, and other factors, emphasizing the need for unbiased data collection and meticulous algorithmic calibration. Cognitive overload for both management and workers, especially with the incorporation of VR/AR, poses further challenges, particularly for older workers (Aquino, 2024). Addressing these multifaceted issues is essential to effectively implement the OSH monitoring systems while safeguarding workers' privacy, dignity, and overall well-being.

Methodology

The research methodology employed Saunders et al. (2016) "Research Onion" framework. The framework explored the core philosophy of the research and moves through layers of ontology, epistemology, and axiology to ensure that the chosen research tools and techniques align with the underlying philosophy. The study adopted the positivist philosophy for a deductive theoretical stance and interpretivist philosophy for an inductive methodology.

The research adopted cross-sectional survey to collect data from construction firms and their staff because of its cost-effectiveness. Quantitative primary data were gather through a closed-ended questionnaire using Google form to collect data and perspectives from different hierarchical groups in the Nigeria construction industry on smart Personal Protective Equipment (PPEs) applications. Quantitative data from questionnaires were analyze using descriptive functions of Microsoft Excel and SPSS, The study adheres to ethical guidelines by ensuring data privacy and safety through informed consent and compliance with the Data Protection Act of 2018.

Findings and discussion

The study's participants were primarily stakeholders with a smaller representation of non-stakeholders and those with uncertain status (Table 2). This result implied that the data collected largely reflects the perspectives of individuals directly involved or invested in the subject matter.

Table 2: Status of the Study Participants

Participants' Status	Frequency	Percentage (%)
Stakeholders	71	84.52
Non-Stakeholders	9	10.71
Uncertain	4	4.76
Total Response	84	100.00

The adoption of smart PPEs showed that a majority of respondents have adopted smart PPE (Table 3). This indicates a significant level of acceptance and implementation of smart PPE technologies within the surveyed group. Li et al. (2022) cited increasing worker safety and regulatory compliance as significant drivers of smart PPEs adoption within the construction industry. Although there is variation among those who have adopted smart PPE, the extent of adoption rated low to high with majority stating that moderate level of adoption rates. However, a significant majority of respondents (73.81%) expressed concern about the adoption of smart PPE. This highlights potential challenges in smart PPE adoption with cost, complexity, or perceived limitations as major adoption barriers. Musarat, et al. (2024) identified high initial costs as obstacle on the way to widespread acceptance of smart PPE, especially for small or medium-sized businesses (SMBs).

Table 3: Smart PPEs Adoption Characteristics

SN	Smart PPEs Adoption Characteristics	Frequency	Percentage (%)
1	Status of Smart PPE Adoption		
	Adopted	50	59.52
	Not adopted	23	27.38
	Not certain of adoption	11	13.10
	Total Response	84	100.00
2	Extend of Adoption		
	Very high	6	12.00
	High	8	16.00
	Moderate	21	42.00
	Low	10	20.00
	Very low	5	10.00
	Total Response	50	100.00
3	Concern on Adoption		
	Concerned	62	73.81
	Not concerned	16	19.05
	Indifference	6	7.14
	Total Response	84	100.00

Finding from Table 4 identified limited evidence of safety provided by Smart PPEs and awareness as notable concern. The top concerns among participants on smart PPEs application were limited awareness level, security and privacy, which aligns with findings by Podgorski et al. (2017) and Adrah, Denu, and Buadu (2023). On the other hand, limited evidence of safety and hidden employee surveillance were noted in Vatcha (2020) even though they were among the least concerns identified among participants. The group Cronbach's Alpha reliability value of 0.940 suggests the assessment instrument was highly reliable.

Table 4: Concerns on Smart PPEs Adoption in Construction Industry

Concerns on Smart PPEs Application	Mean Standard Deviation	±Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Limited evidence of safety	3.43±1.144	0.649	0.933
Limited awareness level	3.74±1.099	0.654	0.937
Potentially hidden employee surveillance	3.52±1.070	0.647	0.933
Exposure to productivity pressure	3.67±1.068	0.749	0.929
Data ethics	3.71±1.059	0.782	0.927
Data protection	3.68±1.077	0.799	0.930
Security and privacy	3.73±1.101	0.820	0.926
Other concerns	3.33±1.186	0.518	0.938
Group Cronbach's Alpha reliability value			*0.940*

Challenges of Smart PPEs Adoption

The primary challenge in adopting smart PPEs is the cost associated with these advanced safety solutions. This factor was identify by Márquez-Sánchez et al. (2021)

even though smart PPE offers enhanced safety performance and improved decision-making. This means significant upfront investment identify by Cagno et al. (2024) can reduce adoption barrier particularly for small and medium-sized businesses. Also, organizations needs to evaluate the long-term benefits and potential return on investment when considering the adoption of smart PPE. Another significant obstacle is the lack of technical knowledge on how to use smart PPEs. Akhmetov (2023) had posited that as workers become more familiar with cutting-edge smart PPE technologies, they also develop skills that aid application and enhance their safety. Additionally, companies adopting smart PPE technology can provide training and education to support workers in harnessing the full potential of these advanced safety solutions.

Further challenges include privacy concerns, interoperability, reliability, data management, maintenance and repairs, resistance to change, integration with existing systems, limited customization, environmental factors, lack of regulatory standards and cyber security threats. Most of these challenges were noted in different research including studies of Dhirani, Armstrong and Newe, (2021) and Sargiotis (2024). Also noted in Farotimi, Adegoke and Akeroro (2023) is the fact that deployment of technology in PPE offers great potential with several challenges such as privacy concerns, data security and the initial cost of adopting these technologies, hence, organizations must navigate these challenges in harnessing the benefits offered by this technologies.

The high Cronbach's alpha value of 0.900 indicates strong internal consistency among the items measuring the challenges of smart PPE adoption. This suggests that the identified challenges were perceived consistently as relevant and interconnected, reinforcing the need for strategies that address these barriers and facilitate the successful implementation across industries. Şahin (2023) posited that ensuring the selected solutions comply with relevant safety regulations and industry standards is crucial. In addition, companies must research and select smart PPE products that meet their specific safety requirements and regulatory obligations.

Table 5: Challenges of Smart PPEs Adoption

Challenges of Smart PPEs Application	Mean ± STD	SMC	CAID
Cost of smart PPEs	4.30±0.757	0.139	0.907
Lack of technical k0w on how to use	3.92±0.881	0.285	0.903
Limited supply of smart PPEs	4.01±0.912	0.333	0.902
Privacy concerns	3.48±1.124	0.588	0.897
Interoperability	3.57±0.948	0.626	0.895
Reliability	3.52±1.012	0.567	0.893
Data management	3.52±1.114	0.591	0.890
Maintenance and repairs	3.90±0.926	0.581	0.892
Resistance to change	3.69±0.981	0.632	0.894
Integration with existing systems	3.70±1.015	0.607	0.892
Limited customisation	3.63±0.889	0.562	0.893
Environmental factors	3.63±1.084	0.635	0.890

Lack of regulatory standards	3.76±1.013	0.501	0.897
Cyber security threats	3.31±1.242	0.536	0.894
Standardized Items Cronbach's Alpha Value			*0.900*

Findings revealed significant concerns and challenges on smart PPEs application in Nigeria's construction industry.
The result showed an average mean score of 3.601 and 3.711, average variances score of 1.213 and 1.000 and inter-item correlation (0.663) and (0.391) for concerns and challenges respectively (Table 6). These indicate strong positive consistency in both concerns and challenges among respondents.

Table 6: Concerns and Challenges on Smart PPEs Used

		Mean ± Variance	Min.	Max.	Range	Max./ Min.
Concerns	Item Means	3.601±0.024	3.333	3.738	.405	1.121
	Item Variances	1.213±0.010	1.122	1.406	.283	1.253
	Inter-Item Correlations	0.663±0.008	0.488	0.859	0.371	1.761
Challenges	Item Means	3.711±0.064	3.310	4.298	0.988	1.299
	Item Variances	1.000±0.061	0.573	1.542	0.969	2.690
	Inter-Item Correlations	0.391±0.023	0.072	0.702	0.630	9.740

The ANOVA statistics showed significant concerned about the use smart PPEs in the construction industry in Nigeria as indicated by F-value of 4.809 and 8.983 for concerns and challenges as indicated by p-values of 0.000 at 2-tail (95 %) and (99 %) confidence level (Table 7).

Table 7: ANOVA Test of Concern and challenges on Smart PPEs Adoption

Concerns		Sum of Squares	df	Mean Square	F	Sig
Between People		566.119	83	6.821		
Within People	Between Items	13.857	7	1.980	4.809	.000
	Residual	239.143	581	.412		
	Total	253.000	588	.430		
Total		819.119	671	1.221		
Challenges		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig**
Between People		512.415	83	6.174		
Within People	Between Items	70.248	13	5.404	8.983	.000
	Residual	649.037	1079	.602		
	Total	719.286	1092	.659		
Total		1231.701	1175	1.048		

Conclusions and recommendations

Adoption of smart PPE stood at 60 %, which reflect a high safety concern and commitment to worker well-being, regulatory compliance, and enhanced safety measures. Although, smart PPEs provide substantial protection, there are concerns about privacy, productivity pressure, and data security. Cost of smart PPEs, limited supply, technical expertise, maintenance and cybersecurity threats are top challenges of the application of smart PPEs in Nigeria's construction sector. Other challenges associated with adoption of smart PPEs ranges from financial, technical, logistical, privacy, interoperability, reliability, data management, maintenance, resistance to change, integration, customization, and broader environmental, regulatory and cyber security considerations. Reducing cost of smart PPE and ensuring a consistent and reliable supply chain as ways of handling the challenges identified in the adoption. Also, providing resources, technical support and training to workers are ways to address knowledge gaps in the application of smart PPEs in Nigeria's construction industry.

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