INNOVATIVE TECHNOLOGIES FOR CONSTRUCTION HEALTH AND SAFETY ON CONSTRUCTION SITES IN LAGOS STATE; AWARENESS AND ADOPTION

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ABSTRACT
Purpose *– Construction sites are accident-prone, and construction workers are vulnerable to accident or mishaps; hence, the need for interventions through the emerging technologies in construction health and safety (CHS) in Lagos, to enhance technological implementation to improve worker safety and operational efficiency on construction sites.*

Methodology *- The quantitative research approach was employed, focusing on gathering numerical data via structured questionnaires to analyze the level of awareness and adoption of innovative technology in CHS. Questionnaires were distributed to 200 construction professionals, including Builders, Civil engineers, Architects, H&S officers, and Quantity surveyors. The convenience sampling technique was utilized to ensure that the required sample was harnessed. The data was analyzed using descriptive and inferential statistics, the Relative Importance Index (RII) and Krustal-Wallis was used to assess the perceived importance of awareness and adoption levels of various innovative technologies.*

Findings *- Key findings reveal that Building Information Modeling (BIM) is the most widely recognized innovative technology in CHS, and that Drones and Artificial Intelligence (AI) have a moderate level of awareness among industry professionals; Whereas, awareness of 3D Printing, Internet of Things (IoT), Robotics, Wearable Technologies, Virtual Reality (VR), Mobile Applications, and Augmented Reality (AR) remains low, probably due to barriers such as high implementation costs, limited collaboration and communication among stakeholders, and limited access to training.*

Research Limitation *– The research was limited to Lagos, and did not secure enough evidence to generalize the findings.*

Theoretical Implications *– This study contributes to the body of knowledge on technology adoption in CHS, providing empirical evidence on the gaps between awareness and adoption. It underscores the need for tailored interventions and policies to promote technology integration. The research also hints on strategies for improving H&S outcomes, reducing accidents and promoting workers' well-being.*

Originality *– The study concluded that a moderate negative relationship exists within the variables. This suggests that a high level of awareness of a technology does not necessarily correlate with its adoption.*

KEYWORDS: *Adoption, Awareness, Construction, Health and Safety, Innovative Technologies.*

INTRODUCTION

Construction health and safety (CHS) is a critical aspect of ensuring the well-being of construction workers (Zeng, 2015). In Lagos, a state experiencing rapid economic growth and urbanization, the importance of effective CHS practices cannot be overstated (Nnaji, 2020). The construction industry plays a vital role in the state's economic development; yet, it is one of the most hazards prone sectors in terms of workers H&S (Akinradewo et al., 2021). Construction workers face numerous hazards such as falls from heights, equipment-related injuries, and exposure to dangerous substances, making H&S a critical concern. Traditional H&S measures such as the use of the personal productive equipment (PPE) often fail to address the increasing complex and dynamic nature of construction environments, which demand real-time hazard detection, proactive risk management, and efficient response strategies.

Innovative technologies, such as BIM, drones, wearable sensors, and AI, have emerged as key tools for improving H&S on construction sites. For instance: BIM provides enhanced visualization of construction processes, thereby enabling better H&S planning and coordination (Zhang et al., 2012). Drones have revolutionized site monitoring and inspections, provided real-time data and enabled quick identification of potential hazards (Huang et al., 2021). Wearable technologies, such as smart helmets and vests, can track workers' locations and vital signs, sending alerts when in confined spaces (Li et al., 2017). And AI has introduced advanced predictive analytics that allow for the identification of risks before they materialize, significantly improving hazard prevention and H&S outcomes (Fang et al., 2018).

Many construction firms, particularly small and medium scale (SMEs) firms, are hesitant to invest in new technologies due to perceived financial burdens and the need for specialized training (Gambatese, 2017). However, big international firms operating locally are more likely to implement such technologies due to their exposure to global best practices (Park et al., 2017). Therefore, the stakeholders' awareness of innovative technology's capabilities is a key factor in influencing their adoption in CHS.

Research indicates that construction professionals have limited exposure to advanced technologies like AI, drones or wearable sensors (Manu, 2015). On one hand, the lack of awareness prevents decision-makers from realizing the potential long-term savings in cost and time that result from improved H&S standards; on the other hand, improving awareness through education and training can significantly increase the adoption of these technologies, leading to safer work environments and reduced accident rates (Teizer, 2015).The regulatory environment for construction H&S is less stringent, and enforcement of H&S standards is often inconsistent. This creates an opportunity for research to explore the potential for government-led initiatives that encourage the adoption of innovative technologies through incentives or regulatory reforms (Smith, 2019). Moreover, cultural and socio-economic factors significantly influence the perception and adoption of new technologies. In many cases, the hierarchical and traditional structure of the construction industry in Nigeria leads to resistance to change, particularly when it comes to adopting foreign technologies that may not be seen as immediately relevant to local practices (Kim et al., 2016). Understanding these cultural factors and how they impact the willingness of stakeholders to adopt new technologies is essential for designing effective strategies to promote their use.

Due to the increasing complexities in construction projects, innovative technologies such as BIM, drones, AI, and wearable technologies have emerged as solutions to improve CHS (Olukoya & Adedeji, 2019). Hence, this study the utilization of innovative technologies in CHS in view of exploring and assessing the use of cutting-edge technologies to enhance H&S practices in construction industry. The research examines the awareness and usage of innovative technologies in CHS in Lagos with the specific objective to establish the awareness of the use of innovative technologies and to determine the available innovative technologies in use. Therefore, the study hypothesizes that there is correlation between the level of awareness and the extent to which innovative technologies are adopted for CHS practices in Lagos.

Literature review

Innovative technologies are developed with the problem-solving mindset, aimed to address specific challenges or issues. They are designed to increase efficiency, reduce expenses, improve performance or solve complex problems. (Smallwood, 2020).

Globally, the construction industry has begun to use innovative technologies for improving CHS outcomes. BIM is one of such widely implemented technologies. According to Zhang et al. (2015), BIM improves safety planning by integrating hazard identification into design and construction stages. Additionally, Teizer (2015) emphasizes the use of RFID tags and GPS-based real-time location systems for tracking personnel and equipment, which has shown promise in reducing accidents on-site. Also, drones have become a key tool for conducting aerial surveys, site inspections and real-time monitoring of construction activities, offering improved site visibility and hazard detection (Dadhich et al., 2016). According to Irizarry et al. (2013), drones can identify H&S risks and improve project timelines, thereby further enhance enhancing safety and productivity. Besides, wearable technologies, such as smart helmets and vests embedded with sensors, are increasingly being used for monitoring workers' health and detecting unsafe conditions in real-time. Yang et al. (2017) demonstrates that wearable devices help prevent accidents related to falls, proximity to heavy equipment, and fatigue.

These technologies represent a significant step towards mitigating risks associated with human errors, which accounts for a large percentage of construction-related injuries. In addition to such as emerging technologies, AI and IoT which are being leveraged to predict risks and provide preventive measures. AI systems can analyze large datasets to identify patterns and predict potential accidents, while IoT devices can connect site equipment and workers, generating real-time safety alerts (Zhou et al., 2021). AI-driven technologies are also being explored for their role in hazard detection, such as identifying workers without personal protective equipment (PPE) through computer vision (Fang et al., 2018).

The awareness of innovative technologies in the construction industry varies significantly across regions. Ezeokoli et al. (2020) opines, that, in Nigeria, the awareness of such technologies remains relatively low compared to what obtains in developed countries. The study also noted that despite the potential benefits, a large proportion of construction professionals in Nigeria are not fully aware of the capabilities of technologies such as BIM, drones, and AI in enhancing CHS.

The adoption of innovative technologies in CHS in developing countries is a complex and evolving process, influenced by challenges such as limited resources, infrastructure gaps, and varying levels of technological readiness (Fayek, 2018). Despite these difficulties, developing countries have opportunities to move beyond traditional approaches by embracing advanced technological solutions. However, one major challenge is the lack of access to formal training and education on the operation of the technologies. According to Usman et al. (2019), the Nigerian construction industry faces skills gap, where many professionals lack the technical expertise to implement advanced H&S technologies. This is worsened by the fact that technological integration in construction education lacks global trends, leaving professionals without the necessary knowledge to adopt these systems effectively.

Government policies in Nigeria have also not kept pace with technological advancements, and the absence of national standards or incentives for adopting H&S technologies in construction has limited awareness and usage (Agbo, 2019). In contrast, countries like the United Kingdom and the United States have established regulatory frameworks that encourage the integration of H&S technologies into construction practices (Gambatese et al., 2017). While the construction industry in developed nations is fast embracing innovative technologies, their counterpart in developing countries is slow in the adoption of same. Studies such as Oloke et al. (2018) observe that the adoption of BIM, for example, is still in its infancy in Nigeria as many firms are hesitant to adopt new technologies due to perceived high costs, lack of skilled personnel, and uncertainty about the return on investment.

Drones and wearable technologies have limited usage in Nigeria; they are only in use in large capital-intensive projects. For instance, Olalekan et al. (2020) report that drones are being used for site surveys in some construction projects in Lagos, but their adoption is largely for high-profile projects handled by multinational companies.

The adoption of AI and IoT in CHS is even less widespread. Oyewobi et al. (2019) argues that there is a significant disconnect between the availability of AI-based safety systems and their actual implementation on construction sites. This can be attributed to infrastructural challenges as well as a lack of awareness of the benefits of predictive risk management systems.

Several barriers to the adoption of innovative technologies on construction sites have been identified. One; financial constraints are a significant impediment. Many firms, particularly small and medium enterprises (SMEs), do not have the resources to invest in H&S technologies (Abubakar et al., 2014). Additionally, the high cost of maintenance and the perceived complexity of these technologies further discourage firms from integrating them into their operations. Other barriers such as lack of technical expertise. Olatunji (2017) posits, that the Nigerian construction workforce is predominantly unskilled or semi-skilled, leading to challenges in operating and maintaining advanced technologies. This skills gap is compounded by the absence of structured training programmes that focus on the practical application of these technologies in CHS.

Table 1: Technologies and Use

Technology	Purpose	Study
Bluetooth Low Energy (BLE) technology attached to construction workers' hardhat and equipment.	Monitoring the hazardous proximity of equipment and personnel in real time.	Huang et al. (2021).
Bluetooth device attached to workers hardhat	Real-time monitoring to determine the factors that influence the use of non-helmets on construction sites.	Li et al. (2017).
Wearable Inertial Measurement Units attached to workers ankle.	Assessing the probability of accidents on construction sites by observing the manner in which employees walk.	Yang et al. (2017).
Passive RFID tag attached to workers hard hats at an outdoor construction site.	Proximity detection and alert system designed to prevent collisions between machinery and workers.	Teizer (2015).
UWB technology for real-time location system.	Tracking crane movements at the construction site to predict potential collisions and prevent accidents, providing support to crane operators	Zhang et al., (2012).
GPS real-time location and computer vision are combined into one integrated system.	Determining the location and position of excavators on construction sites.	Soltani et al. (2018).
BIM with Bluetooth Low Energy (BLE) location technology	BLE technology tracks workers' real-time positions, while BIM identifies hazardous areas, either automatically or through manual input	Park et al. (2017).
Computer vision. Cameras are used on heavy construction equipment.	Real-time detection of collision risks between personnel and heavy machinery on construction sites.	Son et al. (2019).
BIM and RFID-based monitoring system is used to track personnel.	The system automatically detects hazards by comparing the optimal or shortest path, derived from BIM components, to the actual routes workers are following.	Kim et al., (2016).
GPS-aided inertial navigation system (INS) sensor is employed for tracking.	Real-time tracking of the position, direction, and speed of objects on construction sites minimizes false alarms in unsafe proximity detection.	Wang & Razavi., (2016).

Audio-based system with microphones put on the construction site.	The system is designed to monitor activities and track construction equipment	Cheng et al. (2017).
Active RFID.	Outdoor proximity alert system for construction sites is to prevent collisions between heavy machinery and workers	Chae & Yoshida (2010).
Ultra-high frequency passive RFID.	Near real-time tracking of materials and workers indoors on construction sites.	Montaser & Moselhi (2014).
GPS for worker and equipment localization, IMUs for head orientation, UWB technology to send alert to workers.	Proximity warning system at construction sites integrates workers' awareness to reduce the occurrence of false alarms in safe conditions.	Chan et al. (2020).
Virtual construction simulation system (VCS) where a 3D model of a construction site.	When a worker approaches a hazardous area, they receive a warning, and the incident is recorded for future training and safety improvement.	Li et al. (2015).
UWB technology for real-time location tracking.	Used for tracking heavy machinery at outdoor construction sites.	Siddiqui et al. (2019).

RESEARCH METHODS

This study employed a quantitative research design. It used a structured questionnaires to gather quantitative data on awareness and adoption of innovative technologies. The choice of the research method was informed by the nature of the problem to be investigated (Sekeran, 2003). The research was conducted in Lagos state, Nigeria, the commercial hub with a rapidly expanding construction sector. Lagos was selected for its modern construction practices and high concentration of professionals, to obtain diverse perspectives on CHS technology adoption.

The questionnaire was divided into two sections; A and B. Section A is the demography of the respondents, and section B consists of questions on the research objectives. Out of 200 respondents, many respondents (51.5%) were between the ages of 21 and30. This shows that the participants were young, and may have attitudes, experiences, and exposure to current trends that are different from those of older participants; 21.5%, were between the ages of 31 and 40, while those from 41 to 50 years make up 17.5%. Convenience sampling technique was adopted to target 200 construction professionals including civil engineers, architects, quantity surveyors, builders, and estate managers to ensure a knowledgeable representation across construction professions. Builders made up the largest group at 41%, indicating their significant presence and influence in the sector. Civil Engineers constituted 15%, Architects, Estate Managers and Quantity Surveyors each representing about 10%- 13%, showing a balanced distribution among these critical professions. H&S Officers made up 6.5%, Urban Planners and Land Surveyors were less represented, with 1.5%-1%. This distribution provides a comprehensive view of the professional landscape, emphasizing the diversity of expertise involved in the construction field.

The questionnaire employed closed-ended questions, using a 5-point Likert scale 1-5 (not aware – extremely aware; and strongly disagree – strongly agree), to measure familiarity with, and adoption of, technologies like wearables, drones and BIM. Descriptive statistics and the Relative Importance Index (RII) were used to analyze and rank the data, with Excel 365 and IBM-SPSS 23 software aiding in the analysis (Bryman, 2016; Field, 2013; Manu, 2015; Zbigniew, 1990).

RESULTS AND DISCUSSION

RII measured the importance of each technology based on respondents' perceptions, calculated by dividing the mean score by the highest mean score among all technologies, higher values indicate greater perceived importance. According to Zbigniew (1990), the Relative Important Index formula can be used to calculate the relative significance index (RII) once the scores of the target respondents have been totaled.

Relative Important Index (RII) =
Where;
A = highest weighting (i.e. 5 used in this study)
N = Sample size
Pi = respondent rating of variables,
Ui = Number of respondents placing identical weighting/rating on variables

Objective 1: Establish the level of awareness on the use of innovative technologies in CHS

To what extent are professionals aware of the various innovative technologies associated with the construction industry? Not Aware (NA) – 1, Slightly Aware (SD) – 2, Moderately Aware (MD) – 3, Very Aware (VA) – 4, Extremely Aware (EA) – 5.

Table 2: Ranking Technologies based on their level of awareness

Technologies	NA	SA	MA	VA	EA	RII	Rank
Building Information Modeling	24	40	57	28	51	0.64	1
Drones	35	35	42	45	43	0.63	2
Artificial Intelligence	42	33	37	46	42	0.61	3
3D printing technology	42	39	39	37	43	0.60	4
Internet of Things	41	38	46	40	35	0.59	5
Robotics	48	33	49	32	39	0.58	6
Wearable technologies	33	47	55	37	28	0.58	7
Virtual Reality technology	51	32	41	40	36	0.58	8
Mobile applications for real-time safety	44	34	53	41	28	0.57	9
Augmented Reality	57	39	55	27	22	0.52	10

Table 2 provides analysis of the respondents' different levels of awareness of innovative technologies, and reveals varied degrees of familiarity and understanding in the industry. BIM, (RII = 0.64), ranked first due to its recognized role in improving project management and H&S. Drones (RII = 0.63) ranked second, and have gained notable traction due to their application in site surveys and safety inspections. AI (RII = 0.61) ranked third, and is moderately understood, especially for its potential for data analysis and hazard prediction; however, its adoption remains uneven due to a gap in technical knowledge and the complexity of integrating AI systems into traditional workflows. 3D Printing Technology (RII = 0.60); placed fourth, though many professionals recognize its potential for prefabrication and rapid construction. IoT (RII = 0.59), ranked fifth, and is acknowledged for its role in real-time monitoring and automation in construction H&S management. Technologies like Robotics, Wearable Technologies, and VR (RII = 0.58) ranked sixth. These innovations are recognized for their H&S benefits, particularly in hazardous environments, and for worker protection. Mobile Applications for Real-Time Safety (RII = 0.57) and AR (RII = 0.52) ranked ninth and tenth respectively. While these technologies have potential for safety protocol dissemination and immersive training, the awareness of them is comparatively low.

Objective 2: Determine the available innovative technologies in use

To what extent are the innovative technologies associated with the construction industry in use? Strongly Disagree (NA) – 1, Disagree (D) – 2, Neutral (N) – 3, Agree (A) – 4, Strongly Agree (FA) – 5.

Table 3: Ranking Technologies based on their level of Adoption

Technologies	SD	D	N	A	SA	RII	Rank
BIM	38	71	57	20	14	0.52	1
Prefabrication & Modular Construction	49	57	63	24	7	0.48	2
Drones	78	32	38	39	13	0.48	3
Mobile Technologies & Apps	89	32	33	32	14	0.45	4
Wearable technologies	70	66	29	21	14	0.44	5
Internet of Things	80	47	38	30	5	0.43	6
AI	96	38	38	24	4	0.40	7
AR & VR	103	34	41	17	5	0.39	8
Blockchain technology	114	35	35	10	6	0.36	9
Robotics	113	41	33	8	5	0.35	10

Table 3 illustrates the extent to which advanced technologies have been embraced in the construction industry in Lagos. The level of adoption varies significantly depending on the type of technology and the professional background of respondents. BIM, (RII = 0.52) ranked first. Technologies such as Drones and Prefabrication & Modular Construction, (RII = 0.48) ranked second. Blockchain technology (RII = 0.36) and Robotics (RII = .35) are least ranked, reflecting limited awareness or perceived relevance among construction professionals.

Wearable Technologies, which include smart helmets and vests for monitoring worker H&S practice shows a more uniform perception across all professional groups. This suggests that wearable technologies are widely recognized for their practical and immediate benefits in improving on-site safety and reducing accidents. The construction industry in Nigeria demonstrates a growing recognition of the importance of innovative technologies.

Test of hypothesis

To determine if there is a correlation between the level of awareness and the extent to which innovative technologies are adopted for CHS practices in Lagos.

Ho There is a correlation between the level of awareness and the extent to which innovative technologies are adopted for CHS practices in Lagos. In testing the hypothesis, the pareto principle often referred to as the 80/20 rule was adopted in selecting the five most highly ranked variable (Harvey and Sotardi, 2018). The top five technologies based on awareness were paired against the top five technologies based on adoption.

Most Aware Technologies; BIM 64%, Drones 63%, Artificial Intelligence 61%, 3D Printing technology 60%, IoT 59%. **Most Adopted Technologies;** BIM 52%, Prefabrication & Modular Construction 48%, Drones 48%, Mobile Technologies & Apps 45%, Wearable Technologies 44%

On the two lists, BIM and Drones appear in the top ranks for both awareness and adoption. This indicates a significant correlation between high awareness and adoption for these technologies, aligning with the Pareto Principle, as these two technologies may represent the 20% of technologies driving most of the adoption outcomes. On the other hand, technologies like Artificial Intelligence and 3D Printing, which have high awareness levels, do not feature among the most adopted technologies. This suggests that while these technologies are well-known, their practical application in CHS is low, which may be due to initial cost, technical complexity, or the need for specialized skills.

Figure 1 below visualizes this relationship, showing how different technologies compare in terms of their awareness and adoption scores. The correlation analysis between the awareness and adoption of innovative technologies in CHS shows a correlation coefficient of approximately **-0.50**. This suggests a moderate negative relationship, meaning that higher awareness of a technology does not necessarily correlate with its adoption.

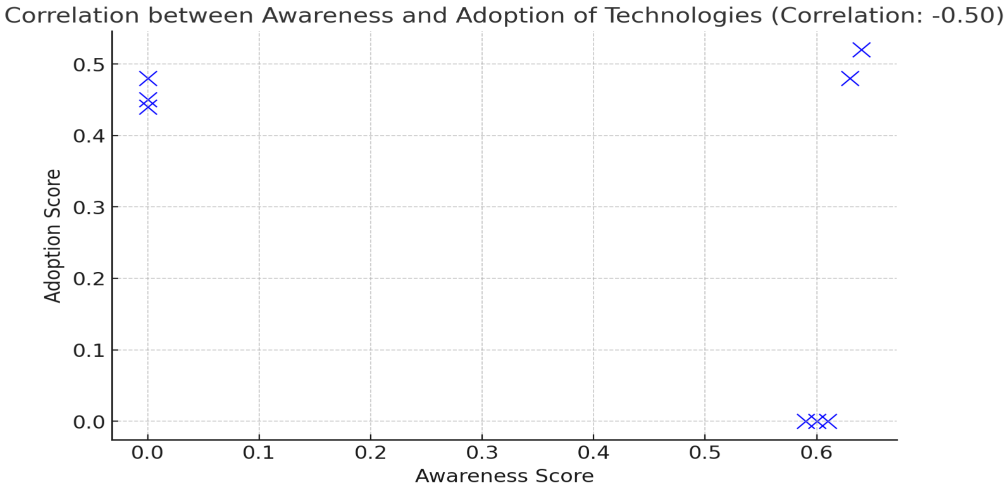

Figure 1: Correlation graph for relationship between awareness and adoption values.

The study shows that BIM and Drones are prevalent technologies when it comes to awareness among construction professionals. The results align with the findings of Akinwale and Olusanya (2016), stating that the awareness of innovative technologies like BIM, and drones in CHS remains low in Nigeria but when compared to other technologies, they are more popular. It also supports the findings of Olanrewaju et al. (2017) indicating that professionals in the construction sector who are aware of these technologies, particularly drones and BIM, are highly motivated to integrate them into their projects. The findings of the research further show that BIM and Drones are dominant technologies when it comes to adoption. The results align with the findings of Adedeji et al. (2018) describing the growing acceptance of BIM in the construction industry. BIM is utilized for project planning, risk assessment, and hazard identification, enhancing H&S management on construction sites. Drones allow project managers to monitor large sites in real-time, identify hazardous areas, and reduce the risk of accidents. However, the rate of adoption is still relatively low, as only about 20-30% of major construction firms have incorporated the use of BIM and Drones into the projects (Afolabi et al., 2019). The authors attribute this low adoption rate to high implementation costs and the lack of technical skills among professionals. In the survey, over 70% of respondents were between ages 21and 40; hence, the viewpoints captured were primarily those of young professionals who may have attitudes, experiences, and exposure to current trends that are different from those of older professionals. This aligns with the view of Nwachukwu et al. (2021) that, there is growing interest among young professionals in adopting these technologies, but that industry-wide awareness is still in its infancy.

The low adoption of IoT, virtual reality (VR) technology and Artificial intelligence (AI) aligns with the findings of Onyegiri et al. (2021) and Adeoye et al. (2022) that the potential and early-stage adoption of IoT are of interest in big construction projects. The adoption rate is currently less than 10%, but growing awareness and the falling cost of sensors are expected to drive higher adoption in the future. VR allows workers to undergo simulated safety drills in a risk-free environment so as to improve their response to potential hazards on-site. The adoption of IoT and VR is very limited, with only a few elite firms in Nigeria utilizing it. Olanipekun et al. (2023) examined the adoption of automated safety monitoring systems, and the study found that the rate of adoption of such systems is about 12% in large firms, but negligible among SMEs.

However, the awareness and adoption of such technologies in Lagos remain under-explored and under-utilized.

CONCLUSION

The study explored how various construction professions in Lagos' construction industry perceive and adopt new technologies that can be directly linked to the Fourth Industrial Revolution (4IR), which represents the integration of advanced digital, physical, and biological systems. 4IR is transforming industries worldwide by leveraging technologies such as AI, IoT, robotics, and big data analytics. These innovations are reshaping traditional practices, optimizing workflows, and driving efficiency, particularly in sectors like construction that have historically lagged in adopting digital technologies. The adoption of technologies like BIM and drones is gaining traction. This reflects the industry's initial steps toward embracing 4IR principles. However, the study reveals uneven awareness and use of other emerging technologies such as blockchain and robotics, which are still in their infancy. This gap mirrors global trends, where the construction sector has been slower than others to adopt these transformative technologies. 4IR technologies are critical to improving CHS, efficiency, and productivity. BIM facilitates real-time collaboration among architects, engineers and contractors, streamlining the planning and execution of projects. Drones allow for more efficient site inspections, while AI and IoT-powered sensors provide predictive insights into how to prevent accidents and improve safety protocols. Taking advantage of these advancements, the construction industry can better manage risks and reduce workplace injuries, and align with global safety standards.

This study emphasizes that collaboration between industry professionals, government bodies, academic institutions, and technology providers is essential to fostering continuous learning and innovation, another core principle of the 4IR. This underscores the importance of Research and Development (R&D), and continuous evaluation in a bid to ensure that the construction industry remains at the forefront of technological innovation, driving the development and adoption of homegrown technologies. Beyond practical work, further research is necessary to ensure the long-term success of these initiatives. Indigenous research will ensure that technologies are both cost-effective and scalable, meeting the specific demands of local construction projects. Continuous research will also allow for the refinement and improvement of these innovations, ensuring that they remain relevant as the industry evolves.

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