INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES

Vol 15, Issue 11, (2025) E-ISSN: 2222-6990

Technologies for Safety and Health Management in Malaysia’s Construction Industry: Adoption and Benefits

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DOI Link: http://dx.doi.org/10.6007/IJARBSS/v15-i11/26901

Published Date: 06 November 2025

Abstract

The construction industry significantly contributes to Malaysia's economic growth and employment; however, it remains one of the most hazardous sectors globally, necessitating effective Occupational Safety and Health (OSH) management. This study aims to identify available technologies for OSH management, examine key barriers to their adoption, and propose solutions to enhance their implementation in the Malaysian construction industry. A quantitative research approach was employed, beginning with a comprehensive literature review to identify relevant technologies. The findings informed the development of a structured questionnaire, which was distributed to construction professionals, including site engineers, site supervisors, safety officers and project managers in Kuala Lumpur. Data collected from the survey was analyzed to determine prevalent technologies and adoption challenges. The results indicate that Radio Frequency Identification (RFID), Exoskeletons/Exosuits and Wearable Sensing Devices are the top three technologies utilized for OSH management; however, their adoption faces significant challenges, including limited technical support, high initial investment costs and restricted functionality. These barriers hinder widespread implementation despite the potential benefits in reducing workplace accidents and enhancing safety culture. The findings provide valuable insights for contractors, policymakers and industry stakeholders to develop strategies for overcoming these barriers. Addressing these challenges through improved technical support, cost-effective solutions and enhanced functionality could facilitate greater adoption of safety technologies, ultimately fostering a safer construction environment in Malaysia.

Keywords: Construction, Technologies, Safety and Health Management

Introduction

The construction industry plays a vital role in economic growth by developing essential infrastructure that supports various sectors. However, it remains one of the most hazardous industries globally, with high rates of workplace injuries and fatalities (Berglund et al., 2023). Over the past few decades, numerous safety strategies, ranging from behavioral approaches to engineering controls, have been implemented to improve safety performance (Rozenfeld et al., 2010). Despite these efforts, accident rates in construction remain concerning, indicating that conventional safety-management practices alone are insufficient.

In response to these challenges, researchers and industry professionals have increasingly explored the role of technology in enhancing safety outcomes. From the early 2000s to the early 2010s, research on technology-driven safety management gained significant attention (Zhou et al., 2013). Emerging technologies can detect workplace hazards that may be difficult for workers to identify and mitigate risks early in the project lifecycle. The construction sector has historically adopted technology to improve productivity and efficiency, but recent advancements are now being integrated into OSH management. Technologies such as AI for hazard prediction, IoT for real-time monitoring, and cloud computing for data management are transforming safety practices by reducing human error and enhancing decision-making (Khudzari et al., 2021; Park et al., 2020).

Several studies have examined the effectiveness of these technologies in construction safety. Yap et al. (2023) identified wearable safety devices, R&A, and BIM as key tools for improving safety planning, increasing awareness, and predicting hazards. Similarly, Nnaji & Karakhan (2020) analyzed the challenges of implementing such innovations in the U.S. construction industry, highlighting barriers that contractors must overcome. Despite the proven benefits of safety technologies, their adoption remains slow in many developing countries, including Malaysia. In Malaysia, the slow adoption of OSH technologies is attributed to several industry-specific challenges. First, the fragmented nature of the construction sector, with many SMEs operating under tight budgets, limits investment in advanced safety solutions (Tayib et al., 2022). Second, a lack of regulatory enforcement and clear guidelines on technology-driven OSH compliance further discourages widespread adoption (Bachche, 2023). Studies have identified persistent reliance on traditional safety-management methods, high implementation costs, and resistance to technological change as key obstacles to adoption (Naji et al., 2024). Although technologies such as ambient intelligence (introduced in 1988) and RFID-based safety tracking (applied in 1999) have existed for decades, their practical use in the Malaysian construction sector remains limited.

This study explores the adoption of emerging technologies in OSH management within Malaysia's construction industry. Although previous research has examined the effectiveness of specific technologies, such as AI, IoT and BIM, in improving safety performance (Yap et al., 2023), studies focusing on their adoption in the Malaysian context remain scarce (Popov et al., 2016). Furthermore, existing literature has primarily emphasized barriers to implementation without offering comprehensive strategies to overcome these obstacles (Nnaji & Karakhan, 2020). This study aims to bridge this gap by identifying available safety technologies, analyzing the key challenges hindering their adoption, and proposing targeted solutions. Through providing a localized perspective, this research functions as a benchmark for safety managers in selecting and implementing appropriate technologies to enhance workplace safety in Malaysia.

Background

Occupational Safety and Health management (OSH management) in Construction

Construction sites exhibit higher fatality rates than other industries, with Malaysia recording the highest number of fatalities in 2018. Effective Occupational Safety and Health (OSH) management remains crucial for reducing these fatalities. A structured safety and health management system, incorporating hazard controls such as elimination, substitution, engineering, administrative controls, and personal protective equipment (PPE), proves essential (Popov et al., 2016). Regulations, including the Occupational Safety and Health Act of 1994, emphasize shared responsibility among all project stakeholders to ensure safety (Awang & Kamil, 2014; Gheisari & Esmaeili, 2019). Traditional safety management techniques that rely on worker perception and experience prove inadequate due to the dynamic and complex nature of construction sites (Xu & Wang, 2020). Consequently, new technologies for OSH management are increasingly valued for their potential to reduce safety risks and establish safer working environments (Yap et al., 2023).

Application of Technology for Safety and Health Management in Construction

In the construction industry, advancements in technology increasingly focus on enhancing safety and health-management practices. Building Information Modeling (BIM) stands out as a widely utilized tool for safety planning, offering potential benefits in accident reduction and improved worker awareness (Nnaji & Karakhan, 2020; Mordue & Finch, 2019; Marefat et al., 2019). BIM not only enhances safety planning but also results in long-term cost savings by reducing rework, minimizing delays and improving project efficiency. Studies indicate that BIM adoption can lead to a 5-15% reduction in project costs through improved coordination and risk mitigation [17]. Wearable sensing devices, such as inertial measuring units (IMUs), provide real-time monitoring of workers' movements to prevent falls and assess psychological data (Nnaji & Karakhan, 2020; Saeed & Yas, 2023). Mobile devices on site facilitate immediate access to safety information and incident reporting, while Radio Frequency Identification (RFID) tags in Personal Protective Equipment (PPE) aid in location tracking and hazard avoidance (Ahn et al., 2019). These technologies contribute to financial benefits by reducing compensation claims, medical costs and lost workdays due to injuries. Research by Xu et al. (2022) highlights that wearable sensors can decrease workplace injury costs by up to 20% through early risk detection.

Laser scanning and LiDAR technology contribute to hazard recognition through digital maps and precise measurements of construction sites, enabling enhanced equipment maneuverability and safety planning. Quick Response (QR) codes provide swift access to safety procedures and contactless reporting, proving especially valuable during health crises like the COVID-19 pandemic. Camera network systems deliver comprehensive surveillance for accident prevention and worker monitoring (Zhang et al., 2019). Digital signage improves safety communication on-site, while photogrammetry assists in flaw detection and virtual-environment creation (Mohammadi et al., 2020). Exoskeletons safeguard workers from musculoskeletal issues, while Artificial Intelligence (AI) automates safety monitoring and hazard-prediction tasks (Cho et al., 2018). Unmanned Aerial Vehicles (UAVs) perform inspections in hazardous areas, and augmented reality (AR) and virtual reality (VR) technologies enhance safety training and risk perception (Şerban et al., 2016); Haupt et al., 2019). By automating inspections in dangerous areas, UAVs reduce labor costs and increase efficiency. AI-driven safety monitoring improves cost-effectiveness by decreasing accident frequency, which can result in an estimated 10-25% reduction in insurance premiums for construction firms (Zhou et al., 2013). Finally, robot and automation systems replace workers in repetitive or high-risk tasks, minimizing worker exposure to hazards. These technologies collectively represent a transformative shift toward prioritizing safety and health in the construction industry. While these technologies offer significant potential for cost savings, the literature lacks thorough long-term ROI analyses. Future research should examine detailed cost-benefit analyses of these safety technologies to quantify their financial impact and guide industry adoption (Pshichenko, 2024).

Benefits and Limitations of Using Technologies for Safety and Health Management

The integration of technology into Occupational Safety and Health (OSH) management within the construction industry yields numerous benefits, including enhanced hazard awareness, improved safety warnings, and effective hazard visualization. Virtual reality (VR) and augmented reality (AR) simulations help workers identify potential risks in a safe environment, while real-time safety systems swiftly alert workers to dangerous conditions on-site (Stone et al., 2021). Furthermore, technologies like Building Information Modelling (BIM) facilitate hazard elimination during the design phase and deliver comprehensive risk assessments through advanced imaging technologies, such as LiDAR and 3D scanning (Teizer et al., 2010).

Moreover, technologies enhance safety training effectiveness by providing interactive, immersive experiences for workers to simulate dangerous scenarios and evaluate their responses. Augmented-reality systems aid in accident investigations by projecting digital reconstructions onto the physical world, thereby improving the understanding of complex events (Nnaji & Karakhan, 2020). Furthermore, mobile apps enable efficient injury and near-miss reporting, while robots and automated systems protect workers from hazardous tasks. However, the adoption of technologies for OSH management faces several challenges. High initial costs, client reluctance, and the need for extensive worker training pose significant barriers (Azhar, 2011). Concerns about data security, data fragmentation, and potential worker resistance further complicate the integration process.

Additionally, the lack of standardized procedures and governmental regulations, coupled with data-interoperability issues and slim profit margins in the industry, hinder widespread adoption. In the Malaysian context, while the Department of Occupational Safety and Health (DOSH) under the Ministry of Human Resources enforces the Occupational Safety and Health Act 1994 (OSHA 1994), the existing regulatory framework fails to provide specific guidelines or incentives for emerging OSH technologies' adoption. This regulatory gap often leads to uncertainty among industry stakeholders, limiting their willingness to invest in new systems. Furthermore, the absence of decision-support tools, liability concerns regarding data accuracy, and the need for proper maintenance of safety technologies create additional challenges (Nnaji & Karakhan, 2020). The table below summarizes the information related to the benefits and limitations of OSH technologies.

Table 1
Comparison of OSH Technologies, Benefits, and Limitations

Technology	Benefits	Limitations	References
Building Information Modeling (BIM)	Enhances hazard identification during the design phase; improves safety planning and risk assessment	High implementation cost; requires technical expertise	Nnaji & Karakhan (2020); Mordue & Finch (2019); Marefat et al. (2019)
Wearable Sensing Devices (IMUs, Smart Helmets, etc.)	Real-time monitoring of workers' physical conditions; reduces risk of falls and overexertion	Privacy concerns; potential discomfort for workers	Nnaji & Karakhan (2020); Ahn et al. (2019)
Mobile Safety Apps	Facilitates instant safety reporting and access to guidelines	Requires smartphone access and user training	Nnaji & Karakhan (2020); Borhani (2019)
Radio Frequency Identification (RFID)	Tracks PPE usage and worker location; improves site safety compliance	Data management challenges; limited range of detection	Nnaji & Karakhan (2020); Borhani (2019)
Laser Scanning & LiDAR	Enhances hazard detection through accurate site mapping	Expensive; requires specialized equipment and expertise	Mohammadi et al. (2020)
Quick Response (QR) Codes	Enables rapid access to safety protocols and digital reporting	Requires internet connectivity and smartphone access	Mohammadi et al. (2020)
Camera Network Systems	Provides continuous surveillance for accident prevention	Privacy concerns; high data storage requirements	Zhang et al. (2019)
Exoskeletons	Reduces strain and musculoskeletal injuries	High cost; limited adaptability to all tasks	Cho et al. (2018)
Artificial Intelligence (AI)	Automates safety monitoring; predicts hazards based on data patterns	Data privacy concerns; requires extensive dataset training	Cho et al. (2018)
Unmanned Aerial Vehicles (UAVs)	Inspects hazardous areas without worker exposure	Regulatory restrictions; requires skilled operators	Zhou et al. (2013) Şerban et al. (2016); Haupt et al. (2019)
Augmented Reality (AR) & Virtual Reality (VR)	Enhances safety training and risk perception	High initial cost; requires specialized hardware	Zhou et al. (2013) Şerban et al. (2016); Haupt et al. (2019)
Robotics & Automation	Reduces human exposure to hazardous tasks	Expensive; integration challenges with existing workflows	Nnaji & Karakhan, (2020)

Barriers to Adopting Technologies for OSH Management

Resistance to technological adoption in the construction sector persists, attributed to various challenges spanning technological, organizational and environmental factors. Significant upfront investment, including costs for acquiring specialized software and hardware, hinders widespread adoption. Moreover, extensive training is often required to effectively utilize complex OSH technologies, contributing to adoption hesitancy among safety executives. Additionally, concerns regarding technical support availability and doubts about technology reliability pose obstacles to implementation.

Client reluctance to demand the use of new technologies, coupled with interoperability issues and limited technology useful life, further inhibits adoption efforts (Nnaji & Karakhan, 2020; Gambatese et al., 2017). The complexity of OSH technologies and their limited attributes and features also contributes to adoption challenges, making them difficult for users to understand and utilize effectively (Hossain & Yeoh, 2018). Furthermore, organizational preferences for existing safety-management processes and a lack of information on the effectiveness of safety technologies impedes adoption. Moreover, limited opportunities to observe and test safety technologies hinder stakeholders' ability to evaluate their applicability and functionality in specific work situations (Khudzari et al., 2021). Overall, addressing these challenges is crucial for promoting widespread adoption of OSH technologies in the construction industry and realizing their potential benefits for improving safety and health outcomes. While OSH technology adoption faces challenges globally, the nature and severity of these barriers differ significantly between developing and developed countries. In developing countries, the high initial cost of OSH technologies remains a primary barrier, owing to limited financial resources and insufficient investment in safety infrastructure (Yap et al., 2022).

In contrast, developed countries possess better financial support mechanisms, government incentives, and robust corporate safety policies that facilitate technology adoption (Putrevu & Mertzanis, 2024). Developed nations maintain well-established safety regulations and enforcement agencies that mandate OSH technology use. However, in developing countries, inconsistent regulatory enforcement, outdated safety laws, and insufficient government incentives impede adoption (Ncube & Kanda, 2018**)**. Developed countries possess advanced digital infrastructure, including reliable internet connectivity and cloud-based data management, which enables seamless implementation of OSH technologies. Conversely, developing countries grapple with inadequate digital infrastructure, interoperability issues, and a shortage of skilled personnel to maintain and integrate these technologies (Badri et al., 2018). The workforce in developed countries receives more exposure to technology-driven training programs and continuous professional development, facilitating easier adaptation to new OSH solutions. In developing countries, insufficient training opportunities, resistance to change, and poor digital literacy among workers create significant challenges (Vukićević et al., 2021). These disparities underscore the necessity for context-specific strategies to enhance OSH technology adoption in developing countries.

Research Methodology

This study employs quantitative research methods, which are widely utilized in construction-management research to systematically collect and analyze numerical data, allowing for the objective measurement of variables (Weyant, 2022). The research design follows a descriptive-survey approach, which is suitable for studies that aim to assess perceptions, attitudes and the extent of technology adoption within specific populations (Arbale & Mutisya, 2024). A structured questionnaire was used to collect data from professionals in the Malaysian construction industry, thereby ensuring a standardized approach to data collection (Taherdoost, 2022). The unit of analysis in this study comprises individual construction professionals, including project managers, site supervisors, safety officers and engineers. The focus on individuals as the unit of analysis aligns with prior research in occupational safety and health (OSH) management, where professionals' insights are crucial to understanding industry challenges and technological-adoption trends. Through purposive sampling, the study ensures that only individuals with relevant expertise contribute to the findings, thereby enhancing data reliability and applicability in the construction sector.

Literature Search Parameters

A literature review is a critical analysis and summary of existing research and literature regarding a specific topic within any subject area. The information from previous studies comes from journals, papers, books, articles, and other reliable sources. This review process was conducted to identify technologies utilized for safety and health management. Furthermore, the review process was implemented as a method to identify limitations, barriers, and benefits associated with safety and health technologies in the construction industry. This literature review served as the foundation that guided the development of the questionnaire for this study.

Survey Development

The research methodology employed in this study sought to identify technologies available for Occupational Safety and Health (OSH) management in the construction sector, examine significant barriers to adopting these technologies, and suggest solutions to overcome such barriers. To collect the necessary data, a structured questionnaire was developed based on the literature review, comprising three main sections:

a) Section A concentrated on collecting respondents' demographic background information, including their job position, age, work experience in the construction industry, and highest academic qualifications. This section established context for understanding respondents' viewpoints and experiences.
b) Section B evaluated the level of agreement among respondents regarding their companies' utilization of technologies for OSH management. Respondents rated their agreement levels using a Likert scale from 1 (strongly disagree) to 5 (strongly agree/have used). This section determined the extent of technology adoption in the construction sector.
c) Section C examined the barriers to adopting technologies for OSH management and requested solutions to overcome these barriers. Respondents ranked the barriers using a Likert scale and offered their opinions or suggestions on overcoming these barriers through an open-ended question. This section identified common challenges facing construction companies and potential strategies to address them.

Validity and Reliability

Before distributing the survey form, content validation, including expert review and a pilot study, was conducted to ensure the questionnaire's validity and reliability. Content validation involved sending the questionnaire to three experts who possessed extensive experience in academia and the construction industry. Based on their feedback, adjustments were made to enhance the questionnaire's clarity and relevance. The pilot study involved administering the questionnaire to a small sample of respondents to assess its usability and reliability. Ten respondents with five years or more working experience in the construction industry were selected to answer the questionnaire. The selected respondents comprised four Safety and

Health Officers, two project managers, two site safety supervisors, one site supervisor, and one site engineer. After obtaining results from the ten respondents chosen in the pilot study, their responses in the survey form were entered into IBM SPSS Statistics software. The collected data were analyzed using Cronbach's alpha test to measure internal consistency. The results showed a Cronbach's alpha value of 0.847, indicating acceptable reliability for the questionnaire (Hassan et al., 2020; Memon et al., 2023).

Population and Sampling

According to Berndt (2020), a sample is a group that serves as a source of information for the larger group. For this research, the researcher opted to use purposive sampling. The intentional selection of participants based on their attributes is known as purposive sampling. Three main aspects of their attributes were considered for selecting the participants of this research: their job role, working experience, and qualifications. The inclusion criteria required participants to have a relevant job role in construction, a minimum of three years of experience, and at least a diploma or bachelor's degree in civil engineering or a related field. Individuals with insufficient experience, unrelated professions, or incomplete responses were excluded to ensure data reliability. Ethical considerations were upheld by obtaining informed consent, ensuring participant anonymity, allowing voluntary withdrawal, and securing approval from relevant authorities before data collection. Since the methodology used questionnaires, it was necessary to determine the sample size before distributing the forms to respondents. The population needed to be identified initially. There are two categories for population size: known population size and unknown population size. The formula used to obtain the number of respondents for an unknown population size is shown in Equation 1.

$$\text{Population of unknown } (\mathrm{n_e}) = \frac{\mathrm{z^2 p(1-p)}}{\mathrm{e^2}}$$

Where
ne = The population of unknown sample
z^2 = The value of the standard normal distribution according to Z table (which is 95% of confidence level under the normal curve)
p = The maximum variability of population
e = The number acceptable margin error

$$\text{Population of unknown } (\mathrm{n_e}) = \frac{(1.96)^2(0.5)(1-0.5)}{0.08^2} = 150$$

The questionnaire was distributed to respondents from construction companies in Kuala Lumpur through online platforms. The target participants included project managers, site supervisors, site engineers, safety and health officers, and other individuals actively engaged in construction projects within the region. The number of respondents obtained in this study was 174 respondents, which was deemed sufficient as the required unknown population calculation was 150 respondents only.

Measures for Data Analysis

The collected information was analysis using SPSS, which proved efficient in handling survey data with its robust statistical capabilities. SPSS was preferred due to its suitability for descriptive and ranking-based analyses rather than latent variable modeling. The research employed the Average Index Analysis method to measure the strength of agreement among respondents regarding specific statements or items and enabling structured interpretation of consensus levels. The Relative Importance Index (RII) assessed and ranked the relative significance of various barriers in technology adoption for OSH management based on respondents' opinions. These indices provided a structured approach to quantifying and comparing respondent perspectives.

Results and Discussion

Respondents' Demographic Background

A total of 174 surveys were collected, and the summary of the respondents' demographic background is depicted in Table 2. The majority of the respondents were safety and health officers, followed by site engineers and site supervisors. Most respondents were aged between 30-35 years old and had 3-5 years of experience. Lastly, most respondents' highest academic qualifications were Bachelor's degrees, followed by Diplomas.

Table 2
Respondents' demographic background

Description	Number of respondents
Job position	
Safety and Health officer	64
Site safety supervisor	34
Site engineer	35
Site supervisor	30
Project manager	11
Age (years old)	
24-29	38
30-35	69
36-40	48
41-50	19
Working experience	
< 3 years	33
3-5 years	69
6-10 years	54
>10 years	18
Highest academic qualification	
Bachelor's Degree	71
Master's Degree	35
Diploma	51
PhD	17

The demographic distribution highlights the diversity of respondents in terms of job roles, experience, and educational background which may influence their perceptions of OSH technologies. Safety and Health Officers (37%) and Site Safety Supervisors (20%) are directly responsible for implementing safety measures, making them more inclined toward technology adoption. In contrast, Site Engineers and Site Supervisors (both 20% and 17%, respectively) may view OSH technologies differently due to their focus on project execution rather than compliance. Additionally, the age and experience distribution indicates that a majority of respondents (40%) have 3-5 years of experience, suggesting a workforce with moderate exposure to safety practices. Those with advanced qualifications, such as Master's degrees and PhDs, might have a more research-driven or strategic perspective on OSH implementation. By incorporating these insights, the study better contextualizes how respondents' backgrounds shape their views on OSH technologies.

Technologies Used for OSH Management in Construction Company

Firstly, respondents were asked about their enthusiasm level regarding technology adoption for safety and health purposes in the construction industry. Most respondents, comprising 60 individuals (34.5%), were extremely enthusiastic about adopting technologies for safety and health use in construction. Additionally, 39 respondents (22.4%) were very enthusiastic, followed by 29 respondents (16.7%) who were moderately enthusiastic about adopting these technologies. Lastly, an equal number of respondents, 23 (13.2%), were slightly or not at all enthusiastic about adopting technologies for safety and health use in the construction industry.

Subsequently, respondents indicated whether their companies had used or intended to use specific technologies. The average index and relative index for each technology were calculated. Table 3 summarizes these responses. Radio Frequency Identification (RFID) scored the highest average index of 4.77 and a Relative Importance Index (RII) of 0.893. RFID, as noted by Borhani (2016), can embed tags in PPE to warn workers of nearby hazards, significantly reducing accidents on construction sites. Furthermore, RFID's high ranking can be attributed to its ease of integration with existing safety protocols, cost-effectiveness, and ability to provide real-time hazard warnings (Shahar et al., 2023). Unlike other technologies, RFID does not require direct line-of-sight or complex setup procedures, making it more practical for widespread adoption in dynamic construction environments (Soomro et al., 2024). Exoskeletons/exosuits and wearable sensing devices followed with average indices of 4.46 each. Exoskeletons, or wearable robots, alleviate physical strain and prevent musculoskeletal issues (Cho et al., 2018), while wearable sensing devices, such as inertial measuring units (IMUs), are crucial for fall prevention (Ahn et al., 2019). Their respective RIIs were 0.892 and 0.891, ranking them second and third. Robots and automation ranked fourth, with an average index of 4.45 and an RII of 0.890. These technologies efficiently handle high-risk tasks, significantly reducing safety hazards for workers. For instance, articulated robots perform precise welding in risky situations, while bricklaying machines operate effectively in extreme conditions to prevent worker dehydration. Laser Scanning and LiDAR, with an average index of 4.44 and an RII of 0.889, ranked fifth. These advanced technologies provide detailed 3-D scans to identify potential blind spots on construction sites [28]. Photogrammetry ranked as the least-favored technology, despite its capability to create accurate virtual environments and digital elevation models for comprehensive hazard assessment (Mohammadi et al., 2020; Calantropio et al., 2018). The lower ranking of photogrammetry likely stems from its heavy dependency on environmental conditions and the specialized expertise required for data interpretation. In the construction industry, where swift decision-making is crucial, technologies requiring extensive post-processing time often appear less practical (Kontrimovicius et al., 2023). Its key limitations include difficulty in poor lighting, weather sensitivity, and complex data processing requiring advanced software and hardware.

In conclusion, RFID, exoskeletons, and wearable sensing devices emerged as the most effective technologies for enhancing safety and health management in construction, while photogrammetry remained less favored because of its inherent environmental and technical constraints.

Table 3
Summary of respondents' scores for each technology used for OSH management

Technologies used for OSH management	AI	RII	Ranking (based on RII)
Building Information Modelling	4.44	0.887	6
Wearable Sensing Devices	4.46	0.891	3
Mobile Devices Onsite	4.33	0.867	14
Radio Frequency Identification	4.47	0.893	1
Laser Scanning and LiDAR	4.44	0.889	5
Quick Response Codes	4.34	0.869	13
Camera Network Systems	4.39	0.878	9
Digital Signage	4.35	0.870	12
Photogrammetry	4.31	0.862	15
Exoskeletons/Exosuits	4.46	0.892	2
Artificial Intelligence	4.40	0.880	8
Unmanned Aerial Vehicles	4.38	0.876	11
Augmented Reality	4.39	0.877	10
Virtual Reality	4.43	0.885	7
Robot and Automation	4.45	0.890	4

The Adoption Barriers for Technologies for Safety and Health Management

The respondents were asked whether they faced any barriers that influenced their decision to adopt technologies for safety and health management. Most respondents, 62 (35.6%), faced extremely significant barriers that influenced their decision to adopt technologies for safety and health management. Next, 40 respondents (23%) were very concerned about this issue, followed by 25 respondents (14.4%) who faced moderate barriers. Twenty-eight respondents (16.1%) stated that they faced slight barriers that influenced their decision. Lastly, only 19 respondents (10.9%) indicated that they faced no barriers.

The respondents then rated the barriers to adopting technologies for safety and health management. Table 4 summarizes the responses to these barriers. From the analysis, several critical barriers hindered the adoption of these technologies. The most significant barrier concerned technical support availability. Accessing consistent and timely technical assistance was challenging, especially in remote or multiple locations. This issue was compounded when dealing with solutions tailored to specific OSH criteria, leading to inconsistent support quality. For example, Li et al. (Li et al., 2018) developed a concept for underground construction, while Lu et al. (2021) created an application based on a country-specific database, neither of which were easily adaptable to other contexts.

Table 4
Summary of respondents' scores for each barrier to adopting technology for OSH management

Barriers to adopting technologies for OSH management	AI	RII	Ranking (based on RII)
Extensive upfront investment required	4.51	0.901	2
Need for extensive training before achieving optimum performance	4.36	0.872	10
Concerns regarding the technical support availability	4.57	0.914	1
Doubts regarding the reliability of these technologies	4.46	0.892	4
Client rarely demands for their use	4.43	0.886	6
Difficulty associated with interoperability	4.41	0.882	9
Limited technology useful life	4.43	0.868	11
Need for extensive technical support to achieve optimum performance	4.41	0.882	9
Limited attributes and features	4.51	0.901	2
The technologies tend to be complex to use	4.45	0.890	5
Organization prefers using existing processes to manage safety	4.43	0.885	7
Lack of information on the effectiveness of safety and health technology	4.47	0.893	3
Limited opportunity(ies) to observe and try safety and health technologies	4.41	0.883	8

Limited attributes and features, along with extensive upfront investment, were the second major barriers. Many technologies lacked crucial features necessary for effective OSH management (Hossain & Yeoh, 2018). High initial costs for OSH-specific technologies deterred adoption, as managers often questioned the value and cost-effectiveness of replacing traditional methods. However, to address financial constraints, government incentives could play a crucial role in reducing the cost burden for companies. In some countries, financial aid, tax benefits, and subsidy programs encouraged the adoption of OSH technologies. For instance, Singapore's WSH initiatives provided funding support for companies implementing safety-enhancing technologies (Cheak, 2022). Similarly, the European Union offered grants and incentives to SMEs to facilitate workplace safety innovations (Nastasia & Rives, 2024). Implementing similar incentive programs in this study's context could significantly enhance companies' willingness to invest in OSH technology.

The lack of information on the effectiveness of safety and health technologies was the third barrier. Traditional construction companies were often reluctant to implement new safety innovations due to high costs and insufficient knowledge, preferring to maintain the status quo. Doubts about the reliability of these technologies ranked fourth. Given the novelty of many OSH technologies, there was often a lack of extensive case studies or proven track records to support their reliability across various work environments. Lastly, the complexity of using these technologies was a significant barrier. Despite potential safety benefits, complex interfaces and technical language deterred effective deployment (Borhani, 2016). Increased complexity led to higher error rates, affecting the dependability and efficacy of OSH management.

Solutions to Overcome Barriers for Adopting Technologies for Safety and Health Management

This section analyzes responses regarding solutions to overcome barriers in adopting technologies for safety and health management. The ideas from respondents were categorized and aligned with previously identified significant barriers to technology adoption in construction project safety and health management. Table 5 summarizes respondents' suggestions corresponding to specific barriers.

Table 5
Barriers to adopting technologies for safety and health management and its solution

Barriers to adopting technologies for safety and health management	**Solution**	**Responsible party**
Concerns regarding technical support availability	- Form dedicated team - Provide ongoing troubleshooting - Establish feedback systems for tech issues	Industry
Limited attributes and features	- Collaborate with tech providers - Customize technology to suit different job roles - Vendor partnerships	Industry
Extensive upfront investment required	- Demostratecost-effectiveness - Share ROI data - Conduct cost-benefit analysis for the implemented technology	Government and industry
Lack of information on the effectiveness of safety and health technology	- Share case studies - Educational programs on safety technology awareness and benefits	Government and industry
Doubts regarding the reliability of these technologies	- Run pilot programs - Issue clear usage guidelines - Address data security/privacy concerns	Industry
Technology tends to be complex to use	- Design user-friendly interfaces - Develop clear guides - Offer continuous training	Industry
Clients rarely demand their use	- Form dedicated tech teams - Offer incentives - Celebrate adoption milestone	Industry
Organization prefers using existing processes to manage safety	- Highlight success stories of technology implementation. - Ensure compatibility with existing systems and workflows - Foster a culture of innovation and openness to change	Industry
Limited opportunity (ies) to observe and try safety and health technologies	- Pilot test technologies before full-scale implementation - Offer pilot programs for testing new technologies	Industry
Need for extensive technical support to achieve optimum performance	- Provide ongoing technical assistance and troubleshooting - Establish self-services portals so users can find solutions to common problems	Industry

	- Provide comprehensive training on technology use	
Difficulty associated with interoperability	- Promote IT-safety collaboration - Improve communication	Industry
Need for extensive training before achieving optimum performance	- Provide comprehensive training on technology use - Provide ongoing education on emerging safety tech - Encourage peer-to-peer knowledge sharing	Government and industry
Limited technology useful life	- Set up maintenance schedules - Plan for system upgrades	Industry

Implementing dedicated technical support mechanisms, such as 24/7 help desks and rapid-response troubleshooting teams, can significantly reduce operational downtime and enhance user satisfaction. However, small and medium-sized enterprises (SMEs) often face financial and logistical constraints, limiting their ability to maintain in-house technical teams. For such firms, scalable alternatives, including shared support services, vendor-managed support contracts, and centralized assistance systems, may offer more feasible, cost-effective approaches. Furthermore, fostering collaboration among SMEs through consortium-based support models could enable resource pooling while enhancing access to technical expertise.

A frequently cited obstacle to adopting new Occupational Safety and Health (OSH) technologies is the perception of high upfront costs. To address this concern, stakeholders require clear evidence of return on investment (ROI). During the past decade, advanced digital tools have become essential for companies managing contemporary construction projects (Smithies et al., 2025). Firms implementing these digital solutions have achieved an average 25% improvement in project efficiency and a 20% decrease in operational costs (McKinsey Global Institute, 2017).

Zhang et al. (2017) demonstrated that sensor-based technologies in construction safety management enhance real-time monitoring and hazard identification, thereby reducing accident rates. Moreover, these technologies address the limitations of conventional safety management methods, which struggle to manage dynamic, complex construction environments effectively. AI-driven safety monitoring systems deployed across construction sites have reduced safety-related incidents, as noted by Psico-smart Editorial Team (2024). These systems utilize real-time data analytics to identify hazards proactively, including unsafe worker positioning and equipment malfunctions. Presenting such regionally relevant case studies helps Malaysian construction stakeholders recognize OSH technology investments' long-term value.

By combining practical implementation strategies with empirically supported success stories, this approach addresses existing adoption barriers while providing a structured framework for OSH technologies' progressive integration in Malaysia's construction sector. Future initiatives should prioritize stakeholder education, pilot programs, and policy incentives to accelerate industry-wide adoption.

Discussion and Conclusion

This study comprehensively explores the current landscape of Occupational Safety and Health (OSH) management technologies within the construction industry in Kuala Lumpur. Through an integrative literature review and questionnaire survey targeting site engineers, site supervisors, site safety supervisors, safety and health officers, and project managers, the research identified fifteen key technologies being utilized or considered for enhancing workplace safety. Technologies such as Radio Frequency Identification (RFID), wearable sensing devices, and Building Information Modeling (BIM) emerged as prominent tools because of their effectiveness in real-time hazard identification, reducing physical strain, and improving safety protocols.

The second objective focused on identifying significant barriers to technology adoption. Through literature review and data analysis, thirteen key barriers were highlighted, with concerns regarding technical support availability, limited attributes and features, and extensive upfront investment costs being most significant. The study revealed that inadequate technical support leads to inconsistent implementation and maintenance issues, particularly in remote construction sites. Furthermore, the limitations in OSH technology functionality and high costs associated with initial deployment deterred many construction firms from adopting these innovations.

To address these barriers, the study proposed several solutions based on respondents' feedback. Continuous technical support, including dedicated account managers for troubleshooting, was suggested to alleviate concerns about technical assistance. Customizing technological solutions with vendors to meet specific organizational needs was recommended to overcome limitations in attributes and features. Moreover, demonstrating long-term cost benefits and efficiency could help justify the initial investment to stakeholders. For policymakers, these findings emphasize the need for regulatory frameworks and financial incentives that encourage OSH technology adoption. Government agencies could implement tax reductions or grants to offset initial costs, making them more accessible to construction firms. Furthermore, enforcing mandatory OSH training programs that integrate digital tools can ensure widespread adoption and effective use of these innovations. Construction firms can benefit from strategic collaborations with technology providers to develop cost-effective, user-friendly safety solutions tailored to their needs. Encouraging a safety-driven organizational culture by integrating these technologies into daily site operations will enhance overall workplace safety.

Although this study was limited by time constraints and focused solely on the Kuala Lumpur area, it offers meaningful insights into OSH technology adoption within the Malaysian construction sector. To build on these findings, future research should expand the geographical scope to include other Malaysian regions and engage with industry associations to capture a wider range of perspectives. It would be valuable to involve construction workers directly in future studies. Their hands-on experience and practical insights can offer a more grounded understanding of real-world challenges and opportunities surrounding OSH technology use, perspectives that might not be fully captured through managerial or policy-level analysis alone. Additionally, there is growing potential in exploring AI's role in OSH management. Technologies such as AI-driven predictive analytics, real-time monitoring, and automated safety compliance tools could significantly improve workplace safety by identifying hazards proactively. Investigating the practicality and effectiveness of these AI-based solutions within the construction environment may yield further insights into enhancing safety performance while minimizing human error. By addressing current barriers and incorporating these future directions, the industry can continue progressing toward safer and more resilient construction practices nationwide.

Acknowledgement
This study was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot Q464).

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