Dilani, K., Mapa, M.M.I.S., Konara, G. and Samarakoon, W.K.U.R.M.K.P.K., 2024. Assessing the importance of implementing wearable technologies for construction employees in the Sri Lankan context. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ranadewa, K.A.T.O. and Chandanie, H. (eds). *Proceedings of the 12th World Construction Symposium*, 9-10 August 2024, Sri Lanka. pp. 215-226. DOI: https://doi.org/10.31705/WCS.2024.17. Available from: https://ciobwcs.com/papers/

ASSESSING THE IMPORTANCE OF IMPLEMENTING WEARABLE TECHNOLOGIES FOR CONSTRUCTION EMPLOYEES IN THE SRI LANKAN CONTEXT

K. Dilani[1], M.M.I.S. Mapa[2], Gayani Konara[3], and W.K.U.R.M.K.P.K. Samarakoon[4]

ABSTRACT

Occupational Safety and Health (OSH) is important in the construction industry, as it can help ensure the physical, mental and social well-being of workers when performing work-related tasks. Wearable Safety Devices (WSDs) can proactively detect hazards and perform real-time surveillance, enabling the elimination and control of risks and improved safety outcomes. As useful as it is, there are a few things that affect adoption, such as high initial costs, lack of understanding and privacy concerns. This study identifies wearables technology applications that apply to construction. Based on the outcomes, Sri Lankan construction workers exhibited a preference for wearable technologies. Participants in the construction industry provide data via a questionnaire survey, which is then analysed and prioritised using the Relative Importance Index (RII) for wearable technology applications. The key finding from the document identifies that smart shoe for roofing work, smart glasses for dust particles and smart helmets for working at heights are the most prioritised wearable technologies in the Sri Lankan construction industry for enhancing OSH practices. In addition, this study provides insights into how essential it is to introduce wearable technology, from the point of view of overall safety and health implantation practices in the Sri Lankan construction industry and emphasises the importance of a systematic implementation approach suited to the needs and challenges of this region.

Keywords: *Construction Works; Occupational Health and Safety; Personal Protective Equipment; Sri Lanka; Wearable Technology.*

1. INTRODUCTION

OSH is a cross-disciplinary area concerned with protecting the safety, health and welfare of people engaged in work or employment (Jain et al., 2018). OSH has evolved to not

[1] Undergraduate, Department of Building Economics, University of Moratuwa, Sri Lanka, dilanikaneshapalan@gmail.com

[2] Lecturer, Department of Facilities Management, University of Moratuwa, Sri Lanka, isuru.mapa@uom.lk

[3] Lecturer, Ritsumeikan University, Japan, gy_kaushi@yahoo.com

[4] Lecturer, Department of Facilities Management, University of Moratuwa, Sri Lanka, samarakoonk@uom.lk

only prevent workplace illnesses and accidents but also to actively manage overall health and well-being in the workplace (Yilmaz & Yildiz, 2021). The construction sector may contribute significantly to economic development yet associated with a large number of fatal accidents. In particular, the construction sector is recognised as one of the most dangerous industries (Kamoli et al., 2022).

Wearable technology encompasses clothing and accessories that have sensors and electronics embedded within them, enabling real-time continuous monitoring of physiological and environmental parameters (Choi et al., 2017). The construction industry has seen technological innovations such as Wearable Safety Devices (WSD) as one of the solutions to their OSH challenges (Awolusi et al., 2018). Effectively resolving OSH concerns requires teaching and educating construction workers on the use of digital technology (Ahn et al., 2019). WSDs give employees a way to proactively check their OSH, which might help mitigate hazards.

There are many benefits to using wearable technology in construction as opposed to standard Personal Protective Equipment (PPE) (Awolusi et al., 2018). This allows them to monitor environmental and physiological data which can be a precursor of possible OSH hazards. Construction Wearables promotes improved coordination and communication between construction workers (Okpala et al., 2019). Construction work is made safer and more efficient by the smooth integration of wearable technology with PPE (Awolusi et al., 2018). Hence, to address these hazards in the best way possible and lessen them effectively, the construction industry must implement wearable technologies that aid safety procedures while making operations more productive (Al-Sahar et al., 2021).

Although WSDs have positive effects on OSH, there are drawbacks as well, including maintenance costs, operational costs, training and managerial obstacles (Didehvar et al., 2018; Young et al., 2011). The potential for technology adoption to improve OSH practices needs to be explored in Sri Lanka, where there is a lack of technological awareness (Aghimien et al., 2019). Technology is given less weight in OSH research conducted in poor nations. There is a lack of knowledge regarding the benefits of technology adoption in the construction sector of developing countries (Moshood et al., 2020).

In conclusion, the findings of this study emphasise the pressing need to address OSH issues in the construction industry, highlighting higher work-related accident rates and the importance of safety rules (Ajayi et al., 2021). It advocates an integrated approach using modern technologies such as WSDs to be effective in reducing hazards (Papazoglou & Heuvel, 2007). The extant literature, based on the construction industry of different countries, provides numerous studies that focus on the adoption and benefits of wearable technology in improving work safety. The primary aim of this study is to fill this gap in the literature by determining the types of wearable technology best suited to Sri Lankan construction workers to cater to their needs in terms of safety and considering the unique challenges faced by these workers in a contextual context.

For this reason, this study looks further into the methods of utilising wearable technologies to improve OSH for construction workers in Sri Lanka. In this context, the objectives of the study are to review existing knowledge on wearable technologies in OSH practices and their validity for use in the industry in Sri Lankan construction sector, set up a detailed implementation strategy and develop applications for using these wearables within Sri Lankan construction sites and identify strategies to overcome the constraints and support worker acceptance when integrating wearable technology devices.

2. LITERATURE REVIEW

2.1 OCCUPATIONAL SAFETY AND HEALTH ON CONSTRUCTION SITE

In the building industry, OSH ensures the physical, mental and social well-being of workers in all companies in all categories of employment at work (Patel & Jha, 2015). Cost is one of the greatest impediments to the adoption of OSH practices by small construction companies. Their financial standing often prevents them from attending to basic safety measures, such as hiring safety personnel and procuring PPE, which in other words affects the overall safety of construction activities on sites (Ying et al., 2015). A company can protect its productivity and efficiency, as well as the health of its employees, by taking care of these health threats. One of the essential OSH practices in the construction industry is the use of PPE.

2.2 PERSONAL PROTECT EQUIPMENT

PPE is fundamental in the construction industry, where technical and managerial control can be challenging to implement (Ahmad et al., 2016). The lack of PPEs has led to workers being fairly careless when it comes to OSH, in that if the workers do not wear them appropriately, the workers may be subject to multiple OSH hazards whereby all of which may have a serious impact on human health (Balkhyour et al., 2019). PPEs are highly crucial for safety purposes as they help to decrease the extent of human suffering, financial losses related to reduced productivity fines and occupational injuries and accidents (Lu et al., 2015). The construction industry now uses various technologies to address these barriers. This research aims to provide a comprehensive understanding of wearable technology usage in construction work.

2.3 WEARABLE TECHNOLOGY

In the construction sector, technology covers solutions that are adapted to address a specific challenge or to a specific device and machinery in use to meet project objectives. This set includes hand and excavation tools, as well as digital devices and space-geographic analysis systems that are used to execute the entire life cycle of a construction project from design to deconstruction. A wearable device is designed to be worn and the consumer can carry it or wear it using an accessory (Ercan & Timur, 2020). The adoption of wearable technology has grown explosively across various sectors (Seneviratne et al., 2017). As the sector faces worsening statistics in terms of OSH, more construction businesses are turning to technological advancements as a remedy (Awolusi et al., 2018). WSDs are small wearable devices designed with sensors that continuously monitor a worker’s OSH. (Okpala et al., 2020). WSD can facilitate real-time monitoring and preventive practices, implying that mitigating any OSH hazard can be achievable in construction (Ahn et al., 2019). There are numerous advantages to using wearable technology in the OSH context.

2.4 WEARABLE TECHNOLOGY AN IMPLEMENTATION PLAN FOR CONSTRUCTION SITE

This represents the initial step towards implementing wearable technologies for OHS in construction through requirements assessment (Okpala et al., 2020). Based on this needs assessment, a methodology is provided to the construction industry to identify the most appropriate wearable technologies for construction sites (Aksut et al., 2024). Then, the wearable technologies that are chosen should be able to handle the hazards and obstacles that arise on construction sites (Junior et al., 2021). After selecting the appropriate wearables, it is critical to conduct pilot testing in a controlled setting or on a small-scale building site (Brandt et al., 2018). Train staff and OHS specialists in the operation of the selected wearable devices in detail (Arana-Landín et al., 2023). The next step is the implementation of wearable technologies on construction sites with a guarantee that wearable technologies are being used appropriately and efficiently, continuously monitoring their performance and utilisation (Awolusi et al., 2018). Finally, the efficacy of wearable technologies will be evaluated, and any necessary modifications or alterations will be implemented as per evaluation outcomes to maximise their impact on OHS practices.

2.5 COMMON BENEFITS OF WEARABLE SAFETY DEVICES IN CONSTRUCTION

WSDs provide several advantages to the construction sector, boosting overall job performance, monitoring worker health and promoting worker safety (Nnaji et al., 2021). Connected to wearables and smartphones, these sensors enable real-time monitoring of potentially dangerous environments, including temperature, fine dust, gas concentrations and noise (Nnaji & Awolusi, 2021). Inertial Measurement Units (IMUs) and motion sensors improve workers' awareness of their movements by identifying irregular gaits, awkward postures, and fall risks (Okpala et al., 2021). Clearing up misconceptions, WSD use in the construction industry can lead to a significant reduction in mortality, accidents and lower costs related to workplace mishaps (Mahmud et al., 2022). WSDs offer the advantage of preventive action, allowing potential risks to be recognised early and avoided (Arabshahi, 2021). WSDs provide several advantages to the construction sector, boosting overall job performance, monitoring worker health and promoting worker safety (Nnaji et al., 2021). WSDs, such as wearable Electroencephalography (EEGs), record brain wave patterns to monitor stress levels, mental fatigue and emotional states.

2.6 CHALLENGES IN THE ADOPTION AND IMPLEMENTING WEARABLE TECHNOLOGY IN CONSTRUCTION SITE

The prohibitively high initial cost is the main drawback of adopting WSDs (Alemu et al., 2020). Critical elements, including the type of organisation, its size and its past WSD experience, are necessary for the successful adoption of WSDs, such as worker education, customised WSDs and ongoing assessment strategies (Nnaji & Awolusi, 2021). Construction workers express serious worries about privacy and security confidentiality, particularly when it comes to wearable technology (Choi et al., 2017). Moreover, end-users must accept and trust IoT-based solutions in OSH deployments (Haikio et al., 2020). Some of the key technical challenges relate to how to select the appropriate sensors, overall data storage and wireless communication and connectivity protocols. Social barriers arise due to intellectual property rights, privacy and interoperability problems (Abuwarda et al., 2022).

2.7 SOLUTION TO OVERCOME CHALLENGES

Contractors prioritise technologies that have demonstrated their ability to perform, stressing the value of accurate information sharing via thorough assessments and repeatable procedures (Okpala et al., 2019). Client or owner involvement is essential for technology adoption in OSH management (Shen et al., 2015). When undertaking construction projects with fewer resources, training should encompass end-to-end processes from the start, as well as include upgrades (Tang, 2019). Management support significantly influences employees' intentions to adopt new systems. Managerial involvement at various stages of technology adoption decisions, along with interactions among managers, engineers, operational crews, and fitters, facilitates a joint decision-making process. Construction wearable promotes improved coordination and communication between construction workers (Okpala et al., 2019). It is in keeping with a philosophy that rewards contractors who have developed safety programs and adopted more expedient technologies that reduce the potential for accidents and project delays (Karakhan et al., 2018).

3. RESEARCH METHODOLOGY

Survey-eligible participants were recruited via a convenience sample that focused on construction industry professionals. A convenience sample of 40 construction industry professionals (contractors, site engineers, safety officers, technical officers and quantity surveyors) was used to ensure data quality. Surveys were conducted online through WhatsApp and Zoom platforms. Questionnaire survey questions are created based on the literature review. Before conducting the survey, information sessions were held where participants were informed about wearable technologies and their importance. A series of awareness sessions were held, leading to more thoughtful responses as attendees learned about the value and potential applications of wearable technologies in construction. To increase responses and reduce unwanted biases, they were assured of their anonymity and the confidentiality of their answers. Trained interviewers were available to help with any questions and to corroborate that the survey was answered completely and correctly. The main issue in conducting the survey was whether Sri Lankan construction workers had adequate knowledge about wearable technologies.

Questionnaires were administered to a large sample of construction workers, providing quantitative data on the application of wearable technology in construction work. When considering the structure of the questionnaire, two sections were dedicated to collecting information about the usage of wearable technologies on Sri Lankan construction sites and to obtaining respondents’ perspectives on implementing wearable technologies in the Sri Lankan construction industry. There are nine questions in Section 2 categorised by categories of wearable technology, using a Likert scale to measure the suitability of wearable technology necessary for certain construction work. Five points of the Likert scale indicate that: 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, and 5=strongly agree. Content analysis techniques, including code-based and manual approaches, were used to analyse data. For content that was code-based, SPSS (Statistical Package for the Social Sciences) software specifically was employed. Given the limitation of SPSS software for code-based analysis, hence was chosen to conduct simple descriptive statistic tests on base group demographics using statistical techniques. SPSS is an easy-to-use tool that can scale to large datasets with a high level of precision and reliability.

4. RESEARCH FINDINGS AND RESULTS

4.1 APPLICATION OF WEARABLE TECHNOLOGY IN CONSTRUCTION SITE

By categorising and interpreting responses from the questionnaire, content analysis provided insights into stakeholders' preferences and perceptions, identifying trends in technology adoption across different construction tasks (refer to Table 1).

Table 1: Application of wearable technology in construction site

Type	Usage of construction work
Exoskeletons	Exoskeletons can be used to support particular body parts, such as the shoulders, back or entire body (Pillai et al., 2020). Back support exoskeleton example can reduce physical strain in rebar work by supporting back muscles during activities, as well as assistive moments at the hip or lower spine (Zhang & Huang, 2018). Exoskeletons may help, but they could also create new effects and OSH risks, especially for back-supporting exoskeletons.
Smart helmet	Smart helmets can become attractive for the construction sector as they enable productivity and safety communication (Choi & Kim, 2021). The use of smart helmets with sensors allows critical vital signs to be monitored in real-time, which makes the necessary action for accident situations or health problems reliable and speedy (Singh et al., 2019). Smart helmets are fitted with accelerometers that can detect sudden movements that could be associated with a crash, for example, a fall (Wang et al., 2020).
Smart vest	Smart vests containing lots and lots of sensors are used to locate trackers, gyroscopes, accelerometers, etc. (Chan et al., 2012). While this data includes the positioning of workers, it further includes details of posture, movements and surroundings (Cheng et al., 2013). Most of the time, these smart vests can be integrated with project management systems so that they can be more effective in their respective industry (Landaluce et al., 2020). This enables real-time data to be integrated into wider project analytics and allows resource usage, efficiency and safety performance to be assessed in more detail (Ferreira et al., 2021).
Smartwatch	It is more likely for elderly people to own such gadgets as they are too small to wear (Dehghani et al., 2018). It gets complicated in the course of activities when the vibrations might interfere with prospective usability (Alpert et al., 2020). Because the information can only be displayed at a small level and requires drivers to divide their attention between the screen and their surroundings (close to multitasking), it is difficult to deal with. This limitation also makes it particularly challenging for elderly users to recognise and understand information on small screens (Kim et al., 2019).
Smart Glasses	In construction, smart glasses are supposed to offer ease of interacting with digital models and machinery in a hands-free manner using digital twins (Lombardi et al., 2019). Safety smart glasses with capabilities such as monitoring Building Information Management (BIM) data, providing the ability to see real-time onsite conditions (Sadhu et al., 2023).
Hearing Protection Devices	Workers at construction sites are subjected to high noise levels, thus they must wear appropriate hearing protection to avoid ear damage (Hong et al., 2013). It might be difficult to strike a balance between protection and awareness when using traditional options, such as earplugs, which frequently impair Auditory Situational Awareness (ASA). Earplugs and other conventional hearing

Type	Usage of construction work
	protection devices prevent ASA, which impairs response to important noises (Elelu et al., 2022).
Smart Shoes	Smart shoes are classified as measurement-oriented and passive devices that track metrics including steps walked, calories burnt and sleep efficiency (Al-Sahar et al., 2021). Without actively altering physiological states, these gadgets offer insightful data on physical activity (Steptoe et al., 2009).
Smart Hard Hats	To enable automatic identification of hard hat use and heart rate monitoring of the worker, the modification entails moving the sensor from the arm to the hard hat chin strap (Kim et al., 2021). For hard hats to be functional, headband and chin strap criteria must be followed (Fung et al., 2014).
Smart Wristband	Wristbands offer a practical solution for continuous Heart Rate (HR) monitoring without interference, making them better suited to continuous HR monitoring in situations where physical exertion is required (Sevil et al., 2020). The reading of blood flow rates is obtained through Photoplethysmography (PPG) sensors used with automatic wristband-based heart-rate monitors. The performance of ECG sensors proves their ability the monitor HR wristband-based using construction environments with accurate HR data (Anwer et al., 2021).

For quantitative data analysis, it used SPSS to calculate the RII and rank the usability of wearable technology with weighting based on cumulative response frequency. This means that SPSS was used for the necessary statistical calculations and to visualise results statistical gradients overlay these statistical factors to ensure a rigorous end-point of quantitative validation of qualitative findings. Together, these methodologies allowed for a comprehensive assessment of wearable technology implementation, integrating qualitative insights with quantitative data to inform strategies for enhancing safety and productivity in Sri Lanka's construction industry. This study aimed to examine the perspectives of these experts on the adoption priorities and the type of work roles and tasks in the construction site that are suitable for using wearable technology. Data were analysed by the responses to the questionnaire of the respondents and the final ranking of its application of wearable technology in Sri Lankan construction sites was done using the RII value.

$$\textit{Relative Importance Index (RRI)} = \frac{\sum (Wn)}{AN} \qquad \textit{(Eq. 01)}$$

Where,

- W = constant expressing the weighting given to each response.
- N = frequency of responses
- A = highest weighting
- N = total number in the responses

Table 2 indicates the top 20 RII value and ranks based on wearable technology usage priority.

Table 2: RII rate of wearable technologies

Wearable Devices	Construction works	Respondent scores					Total	W	RII	Rank
		1- Stongly disagee	2- Disagree	3- Nuetral	4- Agree	5- Stongly agree				
Exoskeletons	Heavy lifting and carrying	1	2	12	7	18	40	159	0.795	4
	Demolition and excavation	4	6	11	10	9	40	134	0.670	17
Smart helmet	Fixed objects like low pipes and beams	2	3	8	10	17	40	157	0.785	6
	Work in Heights	2	4	6	8	20	40	160	0.800	3
Smart vest	Welding and construction crew	3	1	15	10	11	40	145	0.725	14
	Inspection and surveying	3	2	8	13	14	40	153	0.765	11
Smartwatch	Site inspections and surveying	3	3	11	8	15	40	149	0.745	13
	Inventory management and logistics	4	5	8	13	10	40	140	0.700	16
Smart Glasses	Dust particles	2	0	11	9	18	40	161	0.805	2
	Chemicals	2	4	7	11	16	40	155	0.775	9
	Bright or harmful light rays	2	3	7	12	15	39	152	0.779	8
Hearing Protection Devices	Demolitions	2	4	7	10	17	40	156	0.780	7
	Loud machine use	0	3	10	11	16	40	160	0.800	3
Smart Shoes	Dangling electrical wires	2	2	9	13	14	40	155	0.775	9
	Roofing Work	1	2	8	11	18	40	163	0.815	1
	Concrete Pouring	1	4	6	14	15	40	158	0.790	5
Smart Hard Hats	Electrical and plumbing work	1	3	11	11	14	40	154	0.770	10
	Work in Heights	1	2	11	11	15	40	157	0.785	6
Smart Wristband	Site inspections and surveying	3	3	9	10	15	40	151	0.755	12
	Inventory management and logistics	3	1	13	15	8	40	144	0.720	15

As a result, the majority of respondents concurred that the most usable wearable technology in the Sri Lankan construction industry is smart shoes for roofing work (RII=0.815; R=1). This is followed by smart glasses for dust particles (RII= 0.805; R=2), smart helmets for working at heights and hearing protection devices for using loud machinery (RII=0.800; R=3). However, employing exoskeletons for excavation and demolition (RII=0.670; R=17) scored lowest in the respondents' opinions. In general, the results have indicated wearable technology has the potential to enhance safety and productivity in many construction operations in Sri Lanka.

5. DISCUSSION

The study underscores the critical imperative regarding OSH issues in the construction industry and reveals the importance of protocols for individual protection and accident rate (Ajayi et al., 2021). It promotes a comprehensive approach with a combination of modern technologies to minimise hazards (Papazoglou & Van Den Heuvel, 2007). The use of WSDs is one of the most crucial construction risk mitigation strategies (Nnaji et al., 2021). Wearable technology can help enhance the awareness of workers and the real-time monitoring of construction businesses hence decrease the risks stemming from unsafe working conditions (Awolusi et al., 2018). The paper suggests strategies for addressing challenges related to initially high costs and privacy concerns by emphasising comprehensive training programs and stakeholder participation. The authors of the study should, therefore, consider their practical recommendations to work with technology providers and continue to evaluate the effectiveness of the technology as likely to be well-placed to support stakeholders in the adoption and implementation of wearable technology to support safety in Sri Lanka's construction sector. The findings highlight the positive implications of wearable devices on improving safety practices within the industry in Sri Lanka, contributing towards better worker welfare and improving construction project performance.

6. CONCLUSIONS

It is feasible to enhance OSH practices of the Sri Lankan construction sector, via integrating wearable technologies. Through an exhaustive literature review, the nine most relevant wearable technologies are identified in this study. Wearable safety devices leverage the power of real-time monitoring combined with hazard identification and prevention to protect the construction industry from accidents. A structured approach that incorporates needs assessment, pilot testing, comprehensive training and continuous evaluation should help to ensure the successful adoption of wearable technologies. Moreover, the research's empirical basis is reinforced by the methodology used in the study, which used a questionnaire survey to determine participants' preferences and wearable technology applicability in the construction industry. Through the methodical data analysis and the calculation of RII, the study offers important insight relating to the wearable technology applications required in Sri Lankan construction sites. This research assists Sri Lankan construction enterprises to assess safety concerns, improve OSH processes and provide safer workplaces for their workers by implementing wearable technology.

7. REFERENCES

Abuwarda, Z., Mostafa, K., Oetomo, A., Hegazy, T., & Morita, P. (2022). Wearable devices: Cross benefits from healthcare to construction. *Automation in Construction*, *142*, 104501. https://doi.org/10.1016/j.autcon.2022.104501

Aghimien, D., Aigbavboa, C., & Oke, A. (2019). A review of the application of data mining for sustainable construction in Nigeria. *Energy Procedia*, *158*, 3240–3245. https://doi.org/10.1016/j.egypro.2019.01.996

Ahmad, I., Sattar, A., Nawaz, A., & Professor, A. (2016). Occupational health and safety in industries in developing world. *Gomal Journal of Medical*, *14*, 4. https://gjms.com.pk/index.php/journal/article/view/694/690

Ahn, C. R., Lee, S., Sun, C., Jebelli, H., Yang, K., & Choi, B. (2019). Wearable sensing technology applications in construction safety and health. *Journal of construction engineering and management*, *145*(11). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001708

Ajayi, S. O., Adegbenro, O. O., Alaka, H. A., Oyegoke, A. S., & Manu, P. A. (2021). Addressing behavioural safety concerns on Qatari Megaprojects. *Journal of Building Engineering*, *41*, 102398. https://doi.org/10.1016/j.jobe.2021.102398

Aksüt, G., Eren, T., & Alakas, H. M. (2024). Using wearable technological devices to improve workplace health and safety: An assessment on a sector base with multi-criteria decision-making methods. *Ain Shams Engineering Journal*, *15*(2), 102423. https://doi.org/10.1016/j.asej.2023.102423

Alemu, A. A., Yitayew, M., Azazeh, A., & Kebede, S. (2020). Utilization of Personal Protective Equipment and associated factors among building construction workers in Addis Ababa, Ethiopia, 2019. *BMC Public Health*, *20*, 794. https://doi.org/10.1186/s12889-020-08889

Alpert, J. M., Manini, T., Roberts, M., Kota, N. S. P., Mendoza, T. V., Solberg, L. M., & Rashidi, P. (2020). Secondary care provider attitudes towards patient-generated health data from smartwatches. *Npj Digital Medicine*, *3*(1). https://doi.org/10.1038/s41746-020-0236-4

Al-Sahar, F., Przegalińska, A., & Krzemiński, M. (2021). Risk assessment on the construction site with the use of wearable technologies. *Ain Shams Engineering Journal*, *12*(4), 3411–3417. https://doi.org/10.1016/j.asej.2021.04.006

Anwer, S., Heng Li, P., Fordjour, M., Umer, W., & Yu Lok Wong, A. (2021). Evaluation of physiological metrics as a real-time measurement of physical 1 fatigue in construction workers: State-of-the-Art Reviews. *Journal of Construction Engineering and Management*, *147*(5), 03121001. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002038

Arabshahi, M. (2021). *Developing a governance framework to assist with the adoption of sensing technologies in construction*. [Doctoral thesis, Curtin University] Curtin Theses. http://hdl.handle.net/20.500.11937/84210

Arana-Landín, G., Laskurain-Iturbe, I., Iturrate, M., & Landeta-Manzano, B. (2023). Assessing the influence of industry 4.0 technologies on occupational health and safety. *Heliyon*, *9*(3). https://doi.org/10.1016/j.heliyon.2023.e13720

Awolusi, I., Marks, E., & Hallowell, M. (2018). Wearable technology for personalized construction safety monitoring and trending: Review of applicable devices. *Automation in Construction*, *85*, 96–106. https://doi.org/10.1016/j.autcon.2017.10.010

Balkhyour, M. A., Ahmad, I., & Rehan, M. (2019). Assessment of Personal Protective Equipment use and occupational exposures in small industries in Jeddah: Health implications for workers. *Saudi Journal of Biological Sciences*, *26*(4), 653–659. https://doi.org/10.1016/j.sjbs.2018.06.011

Brandt, M., Madeleine, P., Samani, A., Ajslev, J. Z., Jakobsen, M. D., Sundstrup, E., & Andersen, L. L. (2018). Effects of a participatory ergonomics intervention with wearable technical measurements of physical workload in the construction industry: Cluster randomized controlled trial. *Journal of medical internet research*, *20*(12), e10272. https://doi.org/10.2196/10272

dehg, M., Estève, D., Fourniols, J. Y., Escriba, C., & Campo, E. (2012). Smart wearable systems: Current status and future challenges. *Artificial Intelligence in Medicine*, *56*(3), 137–156. https://doi.org/10.1016/j.artmed.2012.09.003

Cheng, T., Migliaccio, G. C., Teizer, J., & Gatti, U. C. (2013). Data fusion of real-time location sensing and physiological status monitoring for ergonomics analysis of construction workers. *Journal of computing in civil engineering*, *27*(3), 320–335. https://doi.org/10.1061/(ASCE)cp.1943-5487.0000222

Choi, B., Hwang, S., & Lee, S. H. (2017). What drives construction workers' acceptance of wearable technologies in the workplace? Indoor localization and wearable health devices for occupational safety and health. *Automation in Construction*, *84*, 31–41. https://doi.org/10.1016/j.autcon.2017.08.005

Choi, Y., & Kim, Y. (2021). Applications of the smart helmet in applied sciences: A systematic review. *Applied Sciences*, *11*, 5039. https://doi.org/10.3390/app11115039

Dehghani, M., Kim, K. J., & Dangelico, R. M. (2018). Will smartwatches last? factors contributing to the intention to keep using smart wearable technology. *Telematics and Informatics*, *35*(2), 480–490. https://doi.org/10.1016/j.tele.2018.01.007

Didehvar, N., Teymourifard, M., Mojtahedi, M., & Sepasgozar, S. (2018). An investigation on virtual information modeling acceptance based on project management knowledge areas. *Buildings*, *8*(6), 80. https://doi.org/10.3390/buildings8060080

Elelu, K., Le, T., & Le, C. (2022). Augmented hearing of auditory safety cues for construction workers: A systematic literature review. *Sensors*, *22* (23), 9135. https://doi.org/10.3390/s22239135

Ercan, I. P., & Timur, S. (2020). Changing terminology of definition and design of wearable technology products. *Online Journal of Art and Design*, *8*(3), 90-106. http://www.adjournal.net/articles/83/837.pdf

Ferreira, J. J., Fernandes, C. I., Rammal, H. G., & Veiga, P. M. (2021). Wearable technology and consumer interaction: A systematic review and research agenda, *Computers in Human Behavior*, *118*, 106710. https://doi.org/10.1016/j.chb.2021.106710

Fung, I. W. H., Lee, Y. Y., Tam, V. W. Y., & Fung, H. W. (2014). A feasibility study of introducing chin straps of safety helmets as a statutory requirement in the Hong Kong construction industry. *Safety Science*, *65*, 70–78. https://doi.org/10.1016/j.ssci.2013.12.014

Guk, K., Han, G., Lim, J., Jeong, K., Kang, T., Lim, E. K., & Jung, J. (2019). Evolution of wearable devices with real-time disease monitoring for personalized healthcare. *Nanomaterials*, *9*(6), 813. https://doi.org/10.3390/nano9060813

Haikio, J., Kallio, J., Mäkelä, S.-M., & Keränen, J. (2020). IoT-based safety monitoring from the perspective of construction site workers. *International Journal of Occupational and Environmental Safety*, *4*(1), 1–14. https://doi.org/10.24840/2184-0954_004.001_0001

Hong, O. S., Kerr, M. J., Poling, G. L., & Dhar, S. (2013). Understanding and preventing noise-induced hearing loss. *Disease-a-Month*, *59*(4), 110–118. https://doi.org/10.1016/j.disamonth.2013.01.002

Jain, A., Leka, S., & Zwetsloot, G. I. J. M. (2018). Work, health, safety and well-being: Current State of the art. In *Managing health, safety and well-being. Aligning perspectives health, safety and well-being.* (pp. 1–31). Springer, Dordrecht. https://doi.org/10.1007/978-94-024-1261-1_1

Jeferd, E., Saong, E., Babaran, A. L., Dale, G., & Balaho, A. (2021). Assessment of the awareness and safety practices in mitigating hazards of silica dust exposure among construction workers. *International Journal of Engineering Applied Sciences and Technology*, *5*(10), 60-65. https://www.ijeast.com/papers/60-65,Tesma510,IJEAST.pdf

Kamoli, A., Adul Hamid, R., & Hendra Binmahmud, Y. (2022). Roles of construction organizations in revitalizing occupational health and safety of the Nigerian construction industry. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *26*(1), 97–104. https://doi.org/10.37934/araset.26.1.97104

Karakhan, A. A., Rajendran, S., Gambatese, J., & Nnaji, C. (2018). Measuring and evaluating safety maturity of construction contractors: a multicriteria decision-making approach. *Journal of Construction Engineering and Management*, *144*(7). https://digitalcommons.cwu.edu/cotsfac

Kim, J. H., Jo, B. W., Jo, J. H., Lee, Y. S., & Kim, D. K. (2021). Autonomous detection system for non-hard-hat use at construction sites using sensor technology. *Sustainability*, *13*(3), 1–11. https://doi.org/10.3390/su13031102

Kim, J. W., Lim, J. H., Moon, S. M., & Jang, B. (2019). Collecting health lifelog data from smartwatch users in a privacy-preserving manner. *IEEE Transactions on Consumer Electronics*, *65*(3), 369–378. https://doi.org/10.1109/TCE.2019.2924466

Landaluce, H., Arjona, L., Perallos, A., Falcone, F., Angulo, I., & Muralter, F. (2020). A review of IoT sensing applications and challenges using RFID and wireless sensor networks. *Sensors*, *20*(9), 2495. https://doi.org/10.3390/s20092495

Lombardi, M., Cammarota, A., & Refoyo, J. (2019). Development, applications and benefits of the network digital twin. In *CIRED 2019, Madrid, Spain*, 3-6 June 2019. (2149). AIM. http://dx.doi.org/10.34890/974

Lu, L., Shi, L., Han, L., & Ling, L. (2015). Individual and organizational factors associated with the use of Personal Protective Equipment by Chinese migrant workers exposed to organic solvents. *Safety Science*, *76*, 168–174. https://doi.org/10.1016/j.ssci.2014.11.025

Mahmud, D., Bennett, S. T., Zhu, Z., Adamczyk, P. G., Wehner, M., Veeramani, D., & Dai, F. (2022). Identifying facilitators, barriers and potential solutions for adopting exoskeletons and exosuits in construction workplaces. *Sensors*, *22*(24). https://doi.org/10.3390/s22249987

Moshood, T. D., Nawanir, G., Sorooshian, S., Mahmud, F., & Adeleke, A. Q. (2020). Barriers and benefits of ICT adoption in the Nigerian construction industry. A comprehensive literature review. *Applied System Innovation*, *3*(4), 1–19. https://doi.org/10.3390/asi3040046

Nnaji, C., & Awolusi, I. (2021). Critical success factors influencing wearable sensing device implementation in the AEC industry. *Technology in Society*, *66*, 101636. https://doi.org/10.1016/j.techsoc.2021.101636

Nnaji, C., Awolusi, I., Park, J. W., & Albert, A. (2021). Wearable sensing devices: Towards the development of a personalized system for construction safety and health risk mitigation. *Sensors*, *21*(3), 1–25. https://doi.org/10.3390/s21030682

Okpala, I., Nnaji, C., & Awolusi, I. (2019). Emerging construction technologies: state of standard and regulation implementation. *Computing in Civil Engineering 2019: Data, Sensing and Analytics - Selected Papers from The ASCE International Conference on Computing in Civil Engineering 2019*, 153–161. https://doi.org/10.1061/9780784482438.020

Okpala, I., Nnaji, C., Awolusi, I., & Akanmu, A. (2021). Developing a success model for assessing the impact of wearable sensing devices in the construction industry. *Journal of construction engineering and management*, *147*(7). https://doi.org/10.1061/(ASCE)CO.1943-7862.0002064

Okpala, I., Nnaji, C., & Karakhan, A. A. (2020). Utilizing emerging technologies for construction safety risk mitigation. *Practice periodical on structural design and construction*, *25*(2), 04020002. https://doi.org/10.1061/(ASCE)sc.1943-5576.0000468

Papazoglou, M. P., & Van Den Heuvel, W. J. (2007). Service-oriented architectures: Approaches, technologies and research issues. *VLDB Journal*, *16*(3), 389–415. https://doi.org/10.1007/s00778-007-0044-3

Patel, D. A., & Jha, K. N. (2015). A neural network model for the prediction of safe work behaviour in construction projects. *Journal of construction engineering and management*, *141*(1), 04014066. https://doi.org/10.1061/(ASCE)co.1943-7862.0000922

Pillai, M. V., Van Engelhoven, L., & Kazerooni, H. (2020). Evaluation of a lower leg support exoskeleton on the floor and below hip height panel work. *Human factors: The Journal of the Human Factors and Ergonomics Society*, *62*(3), 489–500. https://doi.org/10.1177/0018720820907752

Sadhu, A., Peplinski, J. E., Mohammadkhorasani, A., & Moreu, F. (2023). A review of data management and visualization techniques for structural health monitoring using BIM and virtual or augmented reality. *Journal of Structural Engineering*, *149*(1). https://doi.org/10.1061/(ASCE)ST.1943-541X.0003498

Seneviratne, S., Hu, Y., Nguyen, T., Lan, G., Khalifa, S., Thilakarathna, K., Hassan, M., & Seneviratne, A. (2017). A survey of wearable devices and challenges. *IEEE Communications Surveys and Tutorials*, *19*(4), 2573–2620. https://doi.org/10.1109/COMST.2017.2731979

Sevil, M., Rashid, M., Askari, M. R., Maloney, Z., Hajizadeh, I., & Cinar, A. (2020). Detection and characterization of physical activity and psychological stress from wristband data. *Signals*, *1*(2), 188–208. https://doi.org/10.3390/signals1020011

Shen, Y., Koh, T. Y., Rowlinson, S., & Bridge, A. J. (2015). Empirical investigation of factors contributing to the psychological safety climate on construction sites. *Journal of construction engineering and management*, *141*(11), 04015038. https://doi.org/10.1061/(ASCE)co.1943-7862.0001021

Singh, V., Chandna, H., & Upadhyay, N. (2019). Smart PPM: An Internet of Things-based smart helmet design for potholes and air pollution monitoring. *EAI Endorsed Transactions on Internet of Things*, *5*(18), 163833. https://doi.org/10.4108/eai.13-7-2018.163833

Soares Junior, G. G., Satyro, W. C., Bonilla, S. H., Contador, J. C., Barbosa, A. P., Monken, S. F. de P., Martens, M. L., & Fragomeni, M. A. (2021). Construction 4.0: Industry 4.0 enabling technologies applied to improve workplace safety in construction. *Research, Society and Development*, *10*(12), e280101220280. https://doi.org/10.33448/rsd-v10i12.20280

Steptoe, A., Dockray, S., & Wardle, J. (2009). Positive affect and psychobiological processes relevant to health. *Journal of Personality*, *77*(6), 1747–1776. https://doi.org/10.1111/j.1467-6494.2009.00599.x

Tang, K. N. (2019). Beyond employability: Embedding soft skills in higher education. *The Turkish Online Journal of Educational Technology*, *18*(2), 1-9. https://eric.ed.gov/?id=EJ1211098

Wang, C., Kim, Y., Kim, D. G., Lee, S. H., & Min, S. D. (2020). Smart helmet and insole sensors for near fall incidence recognition during the descent of stairs. *Applied Sciences (Switzerland)*, *10*(7), 2262. https://doi.org/10.3390/app10072262

Yilmaz, M., & Yildiz, S. (2021). The importance of occupational health and safety (OHS) and OHS budgeting in terms of social sustainability in the construction sector. *Journal of Building Material Science*, *2*(1). https://doi.org/10.30564/jbms.v2i1.2591

Ying, J., Wong, Y., Gray, J., & Sadiqi, Z. (2015). Barriers to good occupational health & safety (OHS) practices by small construction firms. *Journal of Constriction Management*, *30*, 55-66. https://eprints.qut.edu.au/87062/

Young, D. A., Haas, C. T., ASCE, F., Goodrum, P., ASCE, M., Caldas, C., & ASCE, A. M. (2011). Improving construction supply network visibility by using automated materials locating and tracking technology. *Journal of Construction and Engineering Management*, *137*(11), 976-984. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000364

Zhang, T., & Huang, H. H. (2018). A lower-back robotic exoskeleton: Industrial handling augmentation used to provide spinal support. *IEEE Robotics and Automation Magazine*, *25*(2), 95–106. https://doi.org/10.1109/MRA.2018.2815083