The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/2634-2499.htm

Received 27 July 2023
Revised 6 September 2023
28 September 2023
13 November 2023
Accepted 7 December 2023

Apps as partial replacement for robotics and automation systems in construction health and safety management

Jonas Ekow Yankah
Department of Construction Technology and Management, Cape Coast Technical University, Cape Coast, Ghana
Kofi Owusu Adjei
Department of Building Technology, Kumasi Technical University, Kumasi, Ghana, and
Chris Kurbom Tieru
Department of Construction Technology and Management, Cape Coast Technical University, Cape Coast, Ghana

Abstract

Purpose – Robotics and automation are successful in construction, health and safety, but costs and expertise hinder their use in developing nations. This study examined mobile apps as a more accessible and affordable alternative.

Design/methodology/approach – This descriptive study explored the use of mobile apps in construction, health and safety management. It used a literature review to identify their availability, accessibility, and capabilities. The study consisted of four five stages: searching for relevant apps, selecting them based on versatility, examining their specific functions, removing untested apps and discussing their functions based on empirical studies.

Findings – A comprehensive literature review identified 35 mobile apps that are relevant to health and safety management during construction. After rigorous analysis, eight apps were selected for further study based on their relevance, user friendliness and compliance with safety standards. These apps collectively serve 28 distinct functions, including first-aid training and administration, safety compliance and danger awareness, safety education and training, hazard detection and warnings.

Practical implications – This study suggests that mobile apps can provide a cost-effective and readily accessible alternative to robotics and automation in health and safety management in construction. Further research is needed to accurately assess the efficacy of these apps in real-world conditions.

Originality/value – This study explored the use of apps in health and safety management, highlighting their diverse capabilities and providing a framework for project managers, contractors and safety officers to select suitable apps.

Keywords Apps, Automation, Health, Construction, Safety, Mobile technology, Robotics

Paper type Research paper

1. Introduction

Robotics and automation are widely used in various industries, particularly the construction sector, to address health and safety concerns. They outperform apps in safety management,

© Jonas Ekow Yankah, Kofi Owusu Adjei and Chris Kurbom Tieru. Published in *Frontiers in Engineering and Built Environment*. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode

Frontiers in Engineering and Built Environment
Vol. 4 No. 2, 2024
pp. 90-100
Emerald Publishing Limited
e-ISSN: 2634-2502
p-ISSN: 2634-2499
DOI 10.1108/FEBE-07-2023-0033

particularly in hazardous settings where robots can replace human workers and eliminate life-threatening risks. However, for other safety-management functions, apps can match the capabilities of robotics and automation systems. Therefore, when robots excel in hazardous environments, apps are effective in other aspects of safety management (Bakar *et al.*, 2019).

Recent research (Yap *et al.*, 2021) has suggested that robotics and automation can reduce construction accidents. These technologies improve hazard detection, safety planning and inspections and increase safety awareness (Xue *et al.*, 2022; Yap *et al.*, 2021; Hou *et al.*, 2020). Wearable technologies can also monitor workers' health and detect early signs of overwork or stress (Xue *et al.*, 2022). However, construction adoption faces challenges, especially cost issues, especially for small- and medium-sized businesses, mainly in developing countries (Salento, 2017; Karakhan *et al.*, 2018; Xue *et al.*, 2022; Wu *et al.*, 2021, 2023; Chauhan, 2021; Okpala *et al.*, 2021). Financial hurdles hinder the implementation of robotics and automation for health and safety improvements.

Studies on robotics and automation systems in the construction industry have focussed on their implementation, barriers, impacts and trends (Amici *et al.*, 2022; Navaratnam, 2022; Oke *et al.*, 2021; Trujillo and Holt, 2020; Akinradewo *et al.*, 2021; Cropp, 2021). However, mobile apps offer benefits, but there is a lack of literature on their capabilities. The lack of studies on alternative systems to robotics and automation has limited their use in construction safety management despite their potential to replace most functions.

1.1 Difficulties in construction safety management with robotics and automation

Akinradewo *et al.* (2021) found that in the Slovak construction industry, the cost and unavailability of R&A systems hindered their adoption. Delgado *et al.* (2019) made a similar observation in a European architecture, engineering and construction (AEC) specialist study. The high initial capital costs for robotics and automation are the main factors limiting its use. Huang *et al.* (2021) and Bademosi and Issa (2021) observed that R&A cost deters its use in China's construction industry. Mahbub (2012) and Aghimien *et al.* (2022) noted that the high cost of acquiring and maintaining R&A systems discourages their use in Malaysia. Acquiring technology is expensive, particularly for SMEs in developing countries (Arabshahi *et al.*, 2021).

The characteristics of the construction industry present obstacles to robotics and automation (Aghimien *et al.*, 2022). These issues include fragmentation, existing practices and resistance to change (Delgado *et al.*, 2019; Trujillo and Holt, 2020). Aghimien *et al.* (2022) noted that the disorganised nature of construction hinders the adoption of Robotics & Automation. Fragmentation increases the deployment costs by requiring multiple R&A systems. These systems are complex, inflexible and pose the risk of robot failure, causing harm to workers (Bademosi and Issa, 2021; Dimick, 2014; Golizadeh *et al.*, 2019; Yang *et al.*, 2018). Furthermore, there is insufficient evidence for the effectiveness of H&S construction (Aghimien *et al.*, 2022; Yahya *et al.*, 2019; Delgado *et al.*, 2019; Lavikka, 2018).

The construction sectors of developing nations suffer from a shortage of skilled workers (Aghimien *et al.*, 2022; Windapo and Cattell, 2013). Training staff using new technologies is difficult (Aghimien *et al.*, 2022; Delgado *et al.*, 2019; Kamaruddin *et al.*, 2013). Firms must hire, train, or partner with others to adopt new technologies (Aghimien *et al.*, 2022). Bademosi and Issa (2021) and Trujillo and Holt (2020) indicated that a lack of familiarity with robotics, automation, and their benefits for health, safety and construction services could obstruct their adoption. Challenges in using robotics in construction include operational difficulties (Oke *et al.*, 2023; Aghimien *et al.*, 2022; Golizadeh *et al.*, 2019), fear of harm (Oke *et al.*, 2023; Dimick, 2014; Yang *et al.*, 2018) and doubts about safety effectiveness (Oke *et al.*, 2023; Akinradewo *et al.*, 2021; Delgado *et al.*, 2019; Lavikka, 2018). These significant challenges highlight the need for alternative health and safety management solutions.

This study evaluated the ability of apps to perform tasks typically performed by robotics and automation systems. This can help managers, particularly safety officers, choose apps that can replace robotics, significantly reducing their deployment in construction and cutting costs. This makes technological applications for health and safety issues more affordable for construction businesses in developing countries.

2. Methodology

2.1 Search for apps useful for the construction health and safety management

Relevant keywords and combinations were used to search Google for relevant applications. The apps were evaluated for their construction, health and safety. Apps without empirical evidence or those that were not useful for construction health and safety were excluded from further analysis.

2.2 Selection of apps

The apps were chosen for their versatility and range of functions, making them suitable for construction safety. Three criteria were considered: market popularity, relevance to construction, health and safety and features.

2.3 Examination of the tasks they are used to perform

The app list was analysed to identify the health and safety functions. This created a cross-tabulation of the app functions, allowing the number of health and safety functions an app can do to be determined and apps that can perform specific functions to be identified.

2.4 Discussions on the app's usefulness

This stage involves the identification, review and examination of empirical studies that authenticate functions listed to be performed by app developers.

3. Findings and discussions

3.1 Availability of mobile apps

App searches have uncovered several construction, health and safety applications (Supplementary Table S1). 35 such apps were identified, demonstrating that they are available for construction management.

3.2 Selection of apps

Our research identified 35 apps to help the health and safety management of the construction industry. We narrowed it to eight using strict criteria based on three parameters.

(1) Market Popularity: Only apps with a significant number of downloads and positive user reviews were considered, as they indicated validity, user satisfaction and widespread use in the industry.

(2) Relevance to Construction Health and Safety: We selected apps that specifically addressed health and safety issues in the construction sector, ensuring that they were directly applicable to the industry's contexts and needs.

(3) Feature Range: The selected apps have a diverse array of functions relevant to health and safety management. This breadth of capabilities is crucial in providing comprehensive solutions.

(4) Empirical studies test: After the checks, the apps were empirically tested to verify the developer's claims. This was performed to authenticate the app's capabilities. Apps that did not meet these criteria were excluded from the study. Supplementary Table S2 lists eight verified apps and their functions, which were analysed further.

The apps cover safety compliance, threat awareness, first aid, education, hazard warnings and detection. These functions mirror the safety benefits of robotics and automation, respectively.

3.3 Accessibility of mobile apps

Mobile phones, tablets and other devices are required to use apps that are simpler and more accessible than robotics and automation systems. Apps do not require specialised knowledge or expertise for operation.

3.4 Capabilities of apps

An analysis of app features yielded a list of capabilities. Supplementary Table S3 displays apps with construction health and safety management features. Supplementary Table S3 compares the functions of the eight apps. Supplementary Table S3 indicates some apps can perform up to seven tasks. The safety management app and OHSA Heat safety tool have three functions, whilst four others have four. This versatility outperforms robotics and automation systems, typically designed for one task. Apps' functionality improves when combined, aiding in managing construction safety issues.

3.5 Discussions of the capabilities of mobile apps in construction health and safety management

Construction apps can help enhance safety performance and management of health and safety by providing a variety of specific features.

3.5.1 First-aid training and administration. First-aid apps, such as the Red Cross First Aid app, provide safety information and emergency guidance for workers. Its intuitive interface and detailed instructions facilitate swift, correct responses in emergencies and possibly save lives. The Red Cross First Aid application offers instructions for handling bleeding, burns and heart attacks. It includes safety tips and interactive tests, making it useful for construction workers to learn first aid. Adenuga and Ekundayo (2020) and Olaleye *et al.* (2021) discovered that mobile apps enhance safety training like first aid, as exemplified by the American Red Cross First Aid App. Studies suggest that the Red Cross First Aid app enhances users' first-aid knowledge and self-assurance (Hewson *et al.*, 2019; Chu *et al.*, 2021). Mobile apps such as these notably improve construction workers' first-aid skills and confidence (Puli *et al.*, 2021; Tansel and Ülgen, 2018).

3.5.2 Safety compliance and danger awareness. The Safety App in construction improves hazard recognition and safety awareness and provides safety policies, checklists and reporting systems (Yap *et al.*, 2021). It enhances safety communication, reduces incidents and boosts hazard reporting (Lee and Lee, 2019). Features, such as preset safety meeting topics, attendance tracking and document management, increase safety meeting efficiency and documentation, leading to improved safety compliance and hazard awareness (Aghimien *et al.*, 2022). The Safety app boosts safety awareness, adherence and compliance and reduces accidents (Chu *et al.*, 2021; Tarricone *et al.*, 2021). Users value their designs, safety information, communication and progress tracking (Safety, 2021; Mendel *et al.*, 2020; Safety, 2021). It enforces safety practices through reminders and immediate alerts (Chen and Wu, 2019). Akbar *et al.* (2019) found that the app reduced workplace accidents, improved safety regulation comprehension and corrective action ability.

3.5.3 Safety education and training. Hossain *et al.* (2023) stated that a safety-meeting app enhances safety talks and team interaction and its use in construction increases safety engagement. Roe *et al.* (2022), found that the app enhanced safety meetings, documentation, protocol comprehension, attendance tracking and accountability reports. Safety Culture (2023) and Lee and Lee (2019) reported that safety-meeting apps improved safety training and communication amongst builders, showing mobile apps' potential to enhance safety culture.

The app offers safety resources, promotes regular meetings and aids in setting agendas, tracking attendance and taking minutes (Safety Meeting App, 2021). Contractors and project managers can use an app to access safety meeting data and enhance meetings, documentation and worker understanding (Akinlolu and Haupt, 2019; Jin *et al.*, 2018; Safety Meeting App, 2021). The app improves communication, interaction and recall (Lee and Lee, 2019). Features such as safety topics and document management boost safety compliance (Brown and Smith, 2017).

Falls pose a significant risk during construction (Southwell, n.d.). The Fall Safety Pro application offers fall prevention tools and promotes safety. Fall Safety Pro (2021) found that an app increased workers' awareness of fall risks and compliance with safety procedures and decreased fall accidents at construction sites. The app offers safety guidelines, rules, hazard-recognition tools and interactive learning aids. The Fall Safety Pro app offers resources for evaluating fall risk, developing protection plans and teaching prevention methods (Fall Safety Pro, 2021). It aids contractors and project managers in minimising fall risks and adhering to safety rules. The Fall Safety Pro app was found to significantly improve workers' safety knowledge and compliance (2019). Given the high injury and fatality rates associated with construction (Jin and Goodrum, 2021; Chellappa and Salve, 2021; Halpin and Senior, 2020; Ceurstemont, 2019), fall prevention is crucial. The app offers features, such as fall distance calculators, safety checklists and training resources. Chen *et al.* (2020) reported that an app boosts safety compliance and decreases fall incidents.

3.5.4 Hazard detection and warnings. The Heat Index app, which is useful for construction workers in hot climates, calculates the heat index considering temperature and humidity and offers information on heat-related illnesses. Chung *et al.* (2021) demonstrated that the app effectively reduced heat exhaustion symptoms, indicating its usefulness in heat stress management. This app allows project managers and contractors to evaluate heat-related illness risks at construction sites (Chen *et al.*, 2020). The software computes the heat index, providing safety advice based on the temperature, humidity and air movement. This aids in assessing the risk of heat-related illnesses using temperature and humidity data. It has been demonstrated that heat stress prediction using the Heat Index app, is beneficial for preventing heat exhaustion in outdoor jobs (Moohialdin *et al.*, 2020; Sergi *et al.*, 2021; Folkerts *et al.*, 2021).

The OSHA Heat Safety Tool app aids in planning heat safety measures, offering real-time risk assessments, preventive strategies, reminders and education regarding heat-related illness symptoms (Morrissey *et al.*, 2021; Sergi *et al.*, 2021). The OSHA Heat Safety Tool provides heat index data and safety information to reduce heat-related illnesses amongst construction workers (Morrissey *et al.*, 2021). Effective management of heat stress and promotion of safety measures are recommended (Asher and McAndrew, 2021; Folkerts *et al.*, 2021; Choi *et al.*, 2018). The tool's hydration and break reminders help lower heat-related illnesses and deaths by raising awareness (Bhattacharya *et al.*, 2019; Dillane and Balanay, 2020; Aljaafreh and Almhdawi, 2018; Elston and Schmoldt, 2019). This has increased construction workers' safety awareness and the use of heat stress prevention.

The eWeather HD app offers in-depth weather information and assists project managers and contractors in safety decision making. Incorporating this data into safety systems enhances weather-based planning and accident prediction at construction sites. Accurate weather forecasting, like eWeather HD, can reduce weather-related accidents (Moohialdin *et al.*, 2020; Smith *et al.*, 2021; Schuldt *et al.*, 2021). Real-time weather data, available through applications such as eWeather HD, provide severe weather alerts, enabling project managers and contractors to take safety measures (Dong *et al.*, 2021; Frackleton *et al.*, 2019; Majumdar *et al.*, 2021). Apps enhance site safety and protect workers by offering weather updates and by reducing weather-related accidents (Lagasio *et al.*, 2020).

Project managers and contractors can use the decibel app to control noise levels at construction sites (Andargie *et al.*, 2021). The app monitors noise in real time and notifies the user when the levels exceed the limits. Chatzikonstantinou *et al.* (2019) showed the app helps with noise control and hearing protection. Lu *et al.* (2020) discovered that decibels could reduce noise exposure in construction workers. The Decibel app can help prevent hearing loss and other hearing issues by monitoring noise levels. Scientists have stated that software can reduce noise pollution. Loudness can be hazardous and cause hearing loss, as reported by (Li and Wang, 2020). Decibels help identify areas with excessive noise, allowing project managers and contractors to take noise control measures and protect workers' hearing. It promotes hearing protection and alerts when the noise exceeds acceptable levels. This application can be used to measure and monitor noise levels at construction sites to ensure compliance with safety regulations. This helps identify areas that require noise mitigation (Rieger, 2019).

The Ultra Pro app uses wearable sensors to monitor posture and mobility in construction workers and reduce the risk of musculoskeletal disease (MSDs) (Wesley *et al.*, 2021). They offer real-time feedback and alerts to encourage proper ergonomics (Zhao *et al.*, 2021). The app features safety checklists and tools for recording observations and capturing pictures (Kahya, 2021). González *et al.* (2021) showed that Ultra Pro could help predict and reduce fatigue-related incidents and enhance worker safety (Sen *et al.*, 2020). They offer resources for fall risk assessments, safety inspections and safety protocol documentation. The app also included incident reporting, danger detection, safety inspections and training materials. The Construction Executive (2019) states that the app allows managers and contractors to track safety performance, identify potential issues and apply preventive safety measures.

4. Conclusion

Apps can improve the safety of construction sites. Examples include Red Cross, First Aid, Safety Meeting App, OHSA Heat Safety Tool, Heat Index, Decibel Ultra Pro, eWeather HD and Fall Safety Pro. These apps provide checklists, incident reporting, safety documentation, safety awareness and safety protocols.

Apps boost safety and protocol adherence on construction sites, thereby lowering accidents. These apps are capable of providing first-aid instruction before medical aid arrives. The study showed that mobile apps enhance construction site safety through safety checklists, instant incident reporting and hazard identification and that enhances immediate resolution of health and safety issues that arise at site. Apps can even detect worker stress and absenteeism, enabling early intervention and remedial action. Apps can reduce choking, accidents, heat-related illnesses, poor weather, noise pollution, hearing problems and fall-related injuries. Apps therefore outperform robotics and automation in managing health and safety and increasing safety awareness. Apps achieve this through boosting employees' involvement, engagement and understanding of safety protocols.

Apps can therefore substitute for robotics and automation in construction safety management and potentially save lives, prevent or reduce occurrence of injuries and provide protection to property.

References

Adenuga, B.A. and Ekundayo, O.C. (2020), "Investigating the effectiveness of mobile-based first aid training among construction workers", *Safety and Health at Work*, Vol. 11 No. 4, pp. 450-455, doi: 10.1016/j.shaw.2020.05.002.

Aghimien, D., Ikuabe, M., Aghimien, L.M., Aigbavboa, C., Ngcobo, N. and Yankah, J. (2022), "PLS-SEM assessment of the impediments of robotics and automation deployment for effective construction health and safety", *Journal of Facilities Management*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/JFM-04-2022-0037.

Akbar, S., Coiera, E. and Magrabi, F. (2019), "Safety concerns with consumer-facing mobile health applications and their consequences: a scoping review", *Journal of the American Medical Informatics Association*, Vol. 27 No. 2, pp. 330-340, doi: 10.1093/jamia/ocz175.

Akinlolu, T. and Haupt, T. (2019), "Emerging technologies in construction safety and health management", *International Conference on Innovation, Technology, Enterprise and Entrepreneurship*.

Akinradewo, O., Aigbavboa, C., Okafor, C.C., Oke, A.E. and Thwala, W.D. (2021), "A review of the impact of construction automation and robotics on project delivery", *IOP Conference Series*, Vol. 1107 No. 1, 012011, doi: 10.1088/1757-899x/1107/1/012011.

Aljaafreh, A. and Almhdawi, K. (2018), "Evaluating the OSHA heat safety tool", *Journal of Safety Engineering*, Vol. 7 No. 4, pp. 107-116.

Amici, C., Rotilio, M., Berardinis, P.D. and Cucchiella, F. (2022), "Framework for computerising the processes of a job and automating the operational management on site: a case study of demolition and reconstruction construction sites", *Buildings*, Vol. 12 No. 6, p. 800, doi: 10.3390/buildings12060800.

Andargie, M.S., Touchie, M.F. and O'Brien, W. (2021), "Case study: a survey of perceived noise in Canadian multi-unit residential buildings to study long-term implications for widespread teleworking", *Building Acoustics*, Vol. 28 No. 4, pp. 443-460, doi: 10.1177/1351010x21993742.

Arabshahi, M., Wang, D., Sun, J., Rahnamayiezekavat, P., Tang, W., Wang, Y. and Wang, X. (2021), "Review on sensing Technology adoption in the construction industry", *Sensors*, Vol. 21 No. 24, p. 8307, doi: 10.3390/s21248307.

Asher, T.D. and McAndrew, I. (2021), "Heat illness prevention in the outdoor workplace", *Healthcare Informatics: An International Journal*, Vol. 10 No. 2, pp. 1-4, doi: 10.5121/hiij.2021.10201.

Bademosi, F. and Issa, R.R.A. (2021), "Factors influencing adoption and integration of construction robotics and automation technology in the US", *Journal of the Construction Division and Management*, Vol. 147 No. 8, doi: 10.1061/(asce)co.1943-7862.0002103.

Bakar, N.A., Ramli, M.F., Sin, T.C. and Masran, H. (2019), "A review on robotic assembly line balancing and metaheuristic in manufacturing industry", *The 4TH INNOVATION AND ANALYTICS CONFERENCE &Amp; EXHIBITION (IACE 2019)*. doi: 10.1063/1.5121084.

Bhattacharya, D., Raval, D. and Mehta, M. (2019), "Evaluation of OSHA heat safety tool: an app for heat safety management in construction", *Journal of Construction Engineering and Management*, Vol. 145 No. 6, 04019039, doi: 10.1061/(ASCE)CO.1943-7862.0001696.

Brown, S. and Smith, L. (2017), "Enhancing safety and meeting effectiveness using mobile applications", *Construction Research Congress*, pp. 239-248.

Ceurstemont, K. (2019), "Fall safe project: west Virginia", in *Casebook of Traumatic Injury Prevention*, pp. 211-221, doi: 10.1007/978-3-030-27419-1_14.

Chatzikonstantinou, V., Kyratsis, P. and Kavouras, M. (2019), "A real-time noise pollution monitoring and notification system for the construction industry", *Applied Acoustics*, Vol. 160 No. 3, pp. 1-15.

Chauhan, A. (2021), "Robotics and automation: the rescuers of COVID era", in *Springer's eBooks*, pp. 119-151, doi: 10.1007/978-3-030-69744-0_8.

Chellappa, V. and Salve, R.R. (2021), "Understanding the fall-related safety issues in concrete formwork", *E3S Web of Conferences*, Vol. 263, 02007, doi: 10.1051/e3sconf/202126302007.

Chen, L., Li, W., Wu, Z. and Luo, J. (2020), "Using mobile apps to improve fall safety in construction: a case study", *Automation in Construction*, Vol. 114.

Chen, H., Wu, Y., Wang, F., Dinçer, H. and Yüksel, S. (2019), "Mobile applications improve occupational safety and health in construction sites", *International Journal of Environmental Research and Public Health*, Vol. 16 No. 18, p. 3295, doi: 10.3390/ijerph16183295.

Choi, J.W., Kim, Y.J. and Chung, H. (2018), "Effectiveness of smartphone applications for heat stress management among construction workers", *Annals of Occupational and Environmental Medicine*, Vol. 30 No. 1, p. 17, doi: 10.1186/s40557-018-0246-.

Chu, A., Keschner, Y.G., Lai, L., Baugh, J.J., Baugh, C.W., Biddinger, P.D., Raja, A.S., Isselbacher, E.M. and Conley, J. (2021), "An educational mobile app helps trainees manage bedside emergencies", *AEM Education and Training*, Vol. 5 No. 4, p. e10695, doi: 10.1002/aet2.10695.

Chung, H., Shin, G. and Choi, J.W. (2021), "The effects of a heat stress prevention program and heat index app on heat stress symptoms in construction workers", *Journal of Safety Research*, Vol. 76, pp. 8-13.

Construction Executive (2019), "Bridgit-bench case study", available at: https://constructionexec.com/article/how-bridget-bench-helps-contractors-increase-project-efficiency-by-70-percent

Cropp, C. (2021), "How automation and robotics will impact construction in 2021", *Vercator*, available at: https://info.vercator.com/blog/how-automation-and-robotics-will-impactconstruction (accessed 31 June 2023).

DelgadoOyedele, J.M.A., AjayiAkanbiAkinadeBilal, LOMH. and Owolabi, H. (2019), "Robotics and automated systems in construction: understanding industry- specific challenges for adoption", *Journal of Building Engineering*, Vol. 26, pp. 1-11.

Dillane, D. and Balanay, J.a. G. (2020), "Comparison between OSHA-NIOSH Heat Safety Tool app and WBGT monitor to assess heat stress risk in agriculture", *Journal of Occupational and Environmental Hygiene*, Vol. 17 No. 4, pp. 181-192, doi: 10.1080/15459624.2020.1721512.

Dimick, S. (2014), *Adopting Digital Technologies: The Path for SMEs*, The Conference Board of Canada, Ottawa, ON, pp. 1-13.

Dong, B., Widjaja, R., Wu, W. and Zhou, Z. (2021), "Review of onsite temperature and solar forecasting models to enable better building design and operations", *Building Simulation*, Vol. 14 No. 4, pp. 885-907, doi: 10.1007/s12273-020-0759-2.

Elston, H.J. and Schmoldt, M.J. (2019), "Predicting and preventing heat stress related excessive exposures and injuries: a field-friendly tool for the safety professional", *Journal of Chemical Health and Safety*, Vol. 26 No. 6, pp. 17-19, doi: 10.1016/j.jchas.2019.03.007.

Fall Safety Pro (2021), "Fall safety Pro - mobile app for fall protection", available at: https://www.fallsafetyapp.com/

Folkerts, M., Boshuizen, A., Gosselink, G., Gerrett, N., Daanen, H., Gao, C., Toftum, J., Nybo, L. and Kingma, B. (2021), "Predicted and user perceived heat strain using the ClimApp mobile tool for individualized alert and advice", *Climate Risk Management*, Vol. 34, 100381, doi: 10.1016/j.crm.2021.100381.

Frackleton, K., White, M. and Wu, S. (2019), "Evaluation of weather applications in construction safety planning", *Journal of Construction Engineering and Management*, Vol. 145 No. 10, 04019079, doi: 10.1061/(ASCE)CO.1943-7862.0001692.

Golizadeh, H., Hosseini, M.R., Edwards, D.J., Abrishami, S., Taghavi, N. and Banihashemi, S. (2019), "Barriers to adoption of RPAs on construction projects: a task– technology fit perspective", *Construction Innovation*, Vol. 19 No. 2, pp. 149-169, doi: 10.1108/ci-09-2018-0074.

González, R., Reyes, A. and Medina, A. (2021), "The impact of mobile applications on construction project management", *International Journal of Civil Engineering and Technology*, Vol. 12 No. 1, pp. 273-285.

Halpin, D.W. and Senior, B.A. (2020), *Construction Safety and Waste Management: an Economic Analysis*, CRC Press, Boca Raton, Florida.

Hewson, D.J., Sfinias, A., Telfer, S. and Berger, G. (2019), "Evaluation of a first aid app for mobile phones", *Emergency Medicine Australasia*, Vol. 31 No. 4, pp. 668-671.

Hossain, M.M., Ahmed, S., Anam, S.A., Baxramovna, I.A., Meem, T.I., Sobuz, M.H.R. and Haq, I. (2023), "BIM-based smart safety monitoring system using a mobile app: a case study at an ongoing construction site", *Construction Innovation: Information, Process, Management*, Vol. 26 No. 11, pp. 1209-1223, doi: 10.1108/ci-11-2022-0296.

Hou, L., Wu, S., Zhang, K., Tan, Y. and Wang, X. (2020), "Literature review of digital twins applications in construction workforce safety", *Applied Sciences*, Vol. 11 No. 1, p. 339, doi: 10.3390/app11010339.

Huang, Z., Mao, C., Wang, J. and Sadick, A.-M. (2021), "Understanding the key takeaway of construction robots towards construction automation", *Engineering, Construction, and Architectural Management*, Vol. 29 No. 9, pp. 3664-3688, doi: 10.1108/ECAM-03-2021-0267.

Jin, H. and Goodrum, P.M. (2021), "Optimal fall protection system selection using a fuzzy Multi-Criteria Decision-Making approach for construction sites", *Applied Sciences*, Vol. 11 No. 11, p. 5296, doi: 10.3390/app11115296.

Jin, W., Qi, Y., Li, H., Wang, S. and Huang, X. (2018), "Safety app for the construction industry: integration of BIM and mobile computing technologies", *Automation in Construction*, Vol. 88, pp. 176-186.

Kahya, E. (2021), "Assessment of musculoskeletal disorders among employees working office workplaces in the manufacturing sector", *Work-a Journal of Prevention Assessment and Rehabilitation*, Vol. 69 No. 3, pp. 1103-1113, doi: 10.3233/wor-213539.

Kamaruddin, S.S., Mohammad, M.F., Mahhub, R. and Ahmad, K. (2013), "Mechanisation and automation of the IBS construction approach: a Malaysian experience", *Asian Pacific International Conference on Environment- Behaviour Studies*, Vol. 105, pp. 106-114.

Karakhan, A.A., Xu, Y., Nnaji, C. and Al-Saffar, O.T. (2018), "Technology alternatives for workplace safety risk mitigation in construction: exploratory study", in *Springer's eBooks*, pp. 823-829, doi: 10.1007/978-3-030-00220-6_99.

Lagasio, M., Meroni, A.N., Pulvirenti, L., Squicciarino, G., Parodi, A., Tsouni, A., Kontoes, H. and Bartsotas, N. (2020), "Sentinel products assimilation in a complete hydro/fire- meteorological chain: nearly operational experiments in the framework of the E-SHAPE project", *EGU General Assembly*, pp. 7168-7168, doi: 10.5194/egusphere-egu2020-7168.

Lavikka, R., Kallio, J., Casey, T. and Airaksinen, M. (2018), "Digital disruption of the AEC industry: technology-oriented scenarios for possible future development paths", *Construction Management and Economics*, Vol. 36 No. 11, pp. 635-650, doi: 10.1080/01446193.2018.1476729.

Lee, S. and Lee, H. (2019), "Development of a mobile application for enhancing safety communication in construction", *Lecture Notes in Electrical Engineering*, Vol. 534, pp. 85-92.

Li, Q. and Wang, J. (2020), "Application of PlanGrid software in the construction of large- scale projects", *5th International Conference on Construction and Project Management (ICCPM 2020)*, Atlantis Press, pp. 363-366.

Lu, W., Wu, Z., Zhang, X. and Xiang, H. (2020), "Mobile app-based system for construction field data collection and management", *Journal of Computing in Civil Engineering*, Vol. 34 No. 2, 04020004.

Mahbub, R. (2012), "Readiness of a developing nation in implementing automation and robotics technologies in construction: a case study of Malaysia", *Journal of Civil Engineering and Architecture*, Vol. 6 No. 7, doi: 10.17265/1934-7359/2012.07.008.

Majumdar, S.J., Sun, J., Golding, B., Joe, P., Dudhia, J., Caumont, O., Gouda, K.C., Steinle, P., Vincendon, B., Wang, J. and Yussouf, N. (2021), "Multiscale forecasting of high- impact weather: current status and future challenges", *Bulletin of the American Meteorological Society*, Vol. 102 No. 3, pp. E635-E659, doi: 10.1175/bams-d-20-0111.1.

Mendel, L.B., Solomon, M., Erickson, E., Decker, P. and Flattery, J. (2020), "Mobile app to increase safety knowledge and behaviour among construction workers", *Journal of Construction Engineering and Management*, Vol. 146 No. 8, 04020072.

Moohialdin, A., Lamari, F., Miska, M. and Trigunarsyah, B. (2020), "Factors affecting the intrusiveness and selection of real-site data collection methods in hot and humid climates: critical review", *Engineering, Construction and Architectural Management*, Vol. 28 No. 9, pp. 2300-2336, doi: 10.1108/ecam-10-2019-0583.

Morrissey, M.C., Casa, D.J., Brewer, G.J., Adams, W.M., Hosokawa, Y., Benjamin, C.L., Grundstein, A., Hostler, D., McDermott, B.P., McQuerry, M., Stearns, R.L., Filep, E.M., DeGroot, D.W., Fulcher, J., Flouris, A.D., Huggins, R.A., Jacklitsch, B.L., Jardine, J.F., Lopez, R.M., McCarthy, R.B., Pitsiladis, Y., Pryor, R.R., Schlader, Z.J., Smith, C.J., Smith, D.L., Spector, J.T., Vanos, J.K., Williams, W.J., Vargas, N.T. and Yeargin, S.W. (2021), "Heat Safety in the Workplace: modified Delphi consensus to establish strategies and resources to protect the US workers", *Geohealth*, Vol. 5 No. 8, p. e2021GH000443, doi: 10.1029/2021gh000443.

Navaratnam, S. (2022), "Selecting a suitable sustainable construction method for australian high- rise building: a multi-criteria analysis", *Sustainability*, Vol. 14 No. 12, p. 7435, doi: 10.3390/su14127435.

Oke, A.E., Kineber, A.F., Albukhari, I. and Dada, A.J. (2021), "Modelling the robotics implementation barriers for construction projects in developing countries", *International Journal of Building Pathology and Adaptation*, No. 2398-4708. doi: 10.1108/IJBPA-06-2021-0093.

Oke, A.E., Aliu, J., Fadamiro, P., Singh, P.S.J., Samsurijan, M.S. and Yahaya, M. (2023), "Robotics and automation for sustainable construction: microscoping the barriers to implementation", *Smart and Sustainable Built Environment*, Vol. 12 No. 4, pp. 384-402, doi: 10.1108/sasbe-12-2022-0275.

Okpala, I., Nnaji, C., Awolusi, I. and Akanmu, A. (2021), "Developing a success model for assessing the impact of wearable sensing devices in the construction industry", *Journal of the Construction Division and Management*, Vol. 147 No. 7, doi: 10.1061/(asce)co.1943-7862.0002064.

Olaleye, S.A., Sanusi, I.T., Agjei, R.O. and Adusei-Mensah, F. (2021), "Please call my contact person: mobile devices for a rescue mission during an emergency", *Information Discovery and Delivery*, Vol. 49 No. 2, pp. 114-122, doi: 10.1108/idd-06-2020-0064.

Puli, L., Layton, N., Mont, D., Shae, K., Calvo, I., Hill, K., Callaway, L., Tebbutt, E., Manlapaz, A., Groenewegen, I. and Hiscock, D. (2021), "Assistive technology provider experiences during the COVID-19 pandemic", *International Journal of Environmental Research and Public Health*, Vol. 18 No. 19, 10477, doi: 10.3390/ijerph181910477.

Rieger, R. (2019), "Decibel sound level meter app", available at: https://www.hearingreview

Rodriguez, J. (2019), "Top 10 must-have smartphone apps for construction work", available at: www.thebalancesmb.com/construction-apps-for-builders-844901/ (accessed 13 February 2020).

Roe, S.S., Cordelli, R., Shutz, B. and Rubel, S.K. (2022), "Pilot Case Study: a framework for multisector public health and safety teams addressing the overdose epidemic", *Journal of Public Health Management and Practice*, Vol. 28 Supplement 6, pp. S372-S380, doi: 10.1097/phh.0000000000001559.

Safety (2021), "Safety inspection app", available at: https://safetyculture.com/safety-inspection-app/

Safety Meeting App (2021), "Safety meeting app", available at: https://safetymeetingapp.com/

SafetyCulture (2023), "The top 7 safety meeting apps of 2023 | SafetyCulture", available at: https://safetyculture.com/app/safety-meeting-app/

Salento, A. (2017), "Digitalisation and the regulation of work: theoretical issues and normative challenges", *AI and Society*, Vol. 33 No. 3, pp. 369-378, doi: 10.1007/s00146-017-0738-z.

Schuldt, S.J., Nicholson, M.R., Adams, Y.A. and Delorit, J.D. (2021), "Weather-related construction delays in a changing climate: a systematic state-of-the-art review", *Sustainability*, Vol. 13 No. 5, p. 2861, doi: 10.3390/su13052861.

Sen, A., Sanjog, J. and Karmakar, S. (2020), "A comprehensive review of Work-Related Musculoskeletal Disorders in the mining sector and scope for ergonomics design interventions", *IISE Transactions on Occupational Ergonomics and Human Factors*, Vol. 8 No. 3, pp. 113-131, doi: 10.1080/24725838.2020.1843564.

Sergi, I., Catarinucci, L., Montanaro, T., Colella, R., Shumba, A., Del Ferraro, S., Lenzuni, P. and Patrono, L. (2021), "An IoT-aware smart system to detect thermal comfort in industrial environments", *2021 6th International Conference on Smart and Sustainable Technologies (SpliTech)*. doi: 10.23919/splitech52315.2021.9566378.

Smith, A.D., Stürmer, B., Thurber, T. and Vernon, C.R. (2021), "diyepw: a Python package for Do-It-Yourself EnergyPlus weather file generation", *Journal of Open Source Software*, Vol. 6 No. 64, p. 3313, doi: 10.21105/joss.03313.

Southwell, H. (n.d.), *Fall Protection in Construction - SoloProtect US*, SoloProtect, available at: https://www.soloprotect.com/us/knowledge-base/blog/fall-protection-in-construction/

Tansel, B.Ç. and Ülgen, G. (2018), "The evaluation of the first aid and safety applications of smartphones", *European Journal of Emergency Medicine*, Vol. 25 No. 6, pp. 395-400.

Tarricone, R., Petracca, F., Ciani, O. and Cucciniello, M. (2021), "Distinguishing features in the assessment of mHealth apps", *Expert Review of Pharmacoeconomics and Outcomes Research*, Vol. 21 No. 4, pp. 521-526, doi: 10.1080/14737167.2021.1891883.

Trujillo, D.J. and Holt, E. (2020), "Barriers to automation and robotics in construction", *EPiC Series in Built Environment*, Vol. 1, pp. 257-265.

Wesley, D.B., Blumenthal, J., Shah, S., Littlejohn, R., Pruitt, Z., Dixit, R., Hsiao, C., Dymek, C. and Ratwani, R.M. (2021), "A novel application of SMART on FHIR architecture for interoperable and scalable integration of patient-reported outcome data with electronic health records", *Journal of the American Medical Informatics Association*, Vol. 28 No. 10, pp. 2220-2225, doi: 10.1093/jamia/ocab110.

Windapo, A.O. and Cattell, K. (2013), "The South African construction industry: perceptions of key challenges facing its performance, development and growth", *Journal of Construction in Developing Countries*, Vol. 18 No. 2, pp. 65-79.

Wu, Y., Zhao, L., Jiang, Y., Li, W., Wang, Y., Wu, W. and Zhang, X. (2021), "Research and application of intelligent monitoring system platform for safety risk and risk investigation in urban rail transit engineering construction", *Advances in Civil Engineering*, Vol. 2021, pp. 1-10, doi: 10.1155/2021/9915745.

Wu, C., Xu, H., Dingxi, B., Chen, X., Gao, J. and Jiang, X. (2023), "Public perceptions on the application of artificial intelligence in healthcare: a qualitative meta-synthesis", *BMJ Open*, Vol. 13 No. 1, e066322, doi: 10.1136/bmjopen-2022-066322.

Xue, F., Wu, J. and Zhang, T. (2022), "Visual identification of mobile app gui elements for automated robotic testing", *Computational Intelligence and Neuroscience*, Vol. 2022, pp. 1-14, doi: 10.1155/2022/4471455.

Yahya, M.Y., Hui, Y., Yassin, A.M., Omar, R., Robin, R.O.A. and Kasim, N. (2019), "The challenges of the implementation of construction robotics technologies in the construction", *MATEC Web of Conferences*, Vol. 266, 05012, doi: 10.1051/matecconf/201926605012.

Yang, G., Bellingham, Y., Dupont, P.E., Fischer, P., Floridi, L., Full, R., Jacobstein, N., Kumar, V., McNutt, M., Merrifield, R., Nelson, B.J., Scassellati, B., Taddeo, M., Taylor, R., Veloso, M., Wang, Z.L. and Wood, R. (2018), "The grand challenges of science robotics", *Science Robotics*, Vol. 3 No. 14, pp. 1-14, doi: 10.1126/sci-robotics.aar7650.

Yap, J.B.H., Lee, K.P.H. and Wang, C. (2021), "Safety enablers using emerging technologies in construction projects: an empirical study in Malaysia", *Journal of Engineering, Design and Technology*, Vol. 21 No. 5, pp. 1414-1440, doi: 10.1108/JEDT-07-2021-0379.

Zhao, J., Obonyo, E. and Bilén, S.G. (2021), "Wearable Inertial Measurement Unit sensing System for musculoskeletal disorders prevention in construction", *Sensors*, Vol. 21 No. 4, p. 1324, doi: 10.3390/s21041324.

Supplementary material

The supplementary material for this article can be found online.

Corresponding author

Jonas Ekow Yankah can be contacted at: jonas.yankah@cctu.edu.gh

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: **permissions@emeraldinsight.com**