A SCIENTOMETRIC REVIEW OF TECHNOLOGICAL APPLICATIONS IN OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT IN THE CONSTRUCTION INDUSTRY

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Poor safety performance has remained a significant concern in the construction industry worldwide. However, increased affordability and capabilities of emerging technologies could enable proactive OHS management. The paper presents a scientometric review of 151 peer-reviewed journal articles (2000-2021) on applications of various technologies in OHS management in construction projects. It identifies past and emerging research trends; primary research themes; collaborations among individuals; institutions; and countries; research gaps and future research directions. Most research has been conducted in the United States; followed by China and Hong Kong. Research was clustered around five major themes: (1) machine learning; sensors and wearable technologies; (2) virtual reality and experimental designs; (3) hazard identification and improved decision-making; (4) BIM and digital design; and (5) ergonomics. The review found less research in developing countries and a lack of discussion on legal; cybersecurity and ethical concerns surrounding technologies such as wearable devices and video surveillance.

Keywords: occupational; H&S; wearable devices; sensors; workers; scientometric

INTRODUCTION

Fatalities in the construction sector are historically high. As per the US Bureau of Labour Statistics, the annual fatalities in the construction industry increased by 13 per cent, from 937 to 1061 between 2015 and 2019 (BLS 2020). The construction industry accounts for 21% of all fatal accidents in the European Union nations (Eurostat 2016). Similarly, unhealthy lifestyles and work-related illness rates are prevalent among construction workers (Loudoun and Townsend 2017; HSE 2019). Health disorders such as hypertension and respiratory and cardiovascular diseases among construction workers were found at a rate higher than the general male population (Chung *et al.,* 2018). The high injury rates and poor health conditions affect construction workers, their families, organisations, and society.

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Consequently, occupational health and safety (OHS) is a widely researched topic in the construction management discipline. In addition to changes in worker behaviour and training, work design and work practices, several researchers have studied the application of emerging technologies in improving OHS in the construction industry (Adepoju and Aigbavboa 2021; Rivera *et al.,* 2021). For instance, researchers have studied design and construction OHS considerations using BIM (building information modelling) and applications of wearable sensors and devices to monitor critical health metrics to reduce workplace injuries and health disorders. Moreover, research on technological applications in OHS management has resulted in several focused research and collaboration networks among authors, institutions, and countries. However, a scientometric literature review of the current trends, research collaborations among countries and authors and cluster analysis of the major research themes is currently missing. Such an analysis could offer valuable insights into the existing research in this domain, facilitating future research efforts.

LITERATURE REVIEW

Scopus was selected as the source database for conducting a scientometric literature review on technological applications in OHS management in the construction industry. Scopus has a broader coverage of recent publications and a faster indexing process and lists (Abioye *et al.,* 2021). Moreover, it is widely used for systematic and scientometric reviews in construction management. The initial search for the relevant papers in the Scopus database was performed with the following search query:

(TITLE-ABS-KEY (("health" OR "safety") AND ("construction worker" OR "construction professionals" OR "construction personnel") AND ("technology" OR "wearable" OR "sensors"))

The period of the analysis was limited from 2000-2021. To filter out quality research outputs, the document type was refined to include only peer-reviewed journal articles, the rationale being that for science mapping purposes, journal articles represent research studies with a high impact (Wijewickrama *et al.,* 2021). After a round of manual screening of title, abstract and keywords to filter out irrelevant articles, 151 journal articles published in the English language were retained for further analysis.

Next, scientometric mapping was performed using *VOSviewer* because it provides easy mapping and visualisation of scientometric networks. It is increasingly used by researchers in the domain of construction management (Li *et al.,* 2021). The intention was to provide a preliminary evaluation of emerging themes in technological applications in OHS management in the construction industry and provide concise information on the existing research to undertake concentrated studies on emerging themes. The analysis also illustrated the major collaborative networks and research groups in this field. Additionally, it revealed information on researchers affiliated with institutions from different countries assisting research efforts in this field.

Wave of research on technological applications in OHS management in the construction industry

Fig. 1 depicts the wave of research on technological applications in OHS management in the construction industry. While very few articles were published annually between 2000-2010, the wave of research in this field has been steadily rising since 2015, with the highest number of articles (i.e., 42 articles) published on this topic in 2021. The publication trend could be explained by the increased affordability and availability of

various technologies in recent years resulting in broader applications in OHS management in the construction industry.

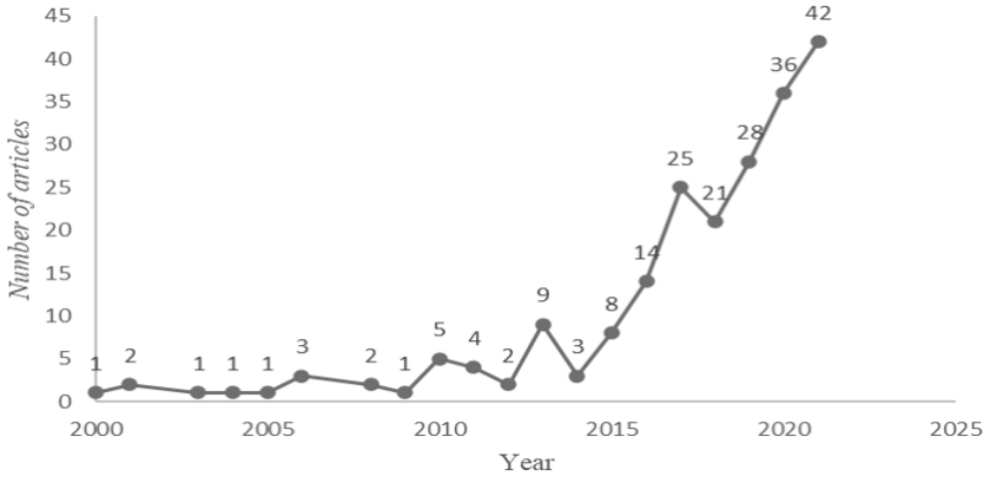

Figure 1: Year-wise publication trends on technological applications in OHS management in the construction industry (2000-2021)

The general distribution of the primary discipline source of the analysed articles revealed that most of the articles come from Engineering journals (41.6 %). Additionally, there are significant contributions from Business, Management and Accounting (10.5%), Medicine (10.2%), Computer Science (8%) and Social Sciences (8%), which demonstrate the multi-disciplinary nature of research in this field.

Leading institutes and countries

Among leading institutions illustrated in Figure 2, Hong Kong Polytechnic University, Hong Kong is the leading institute in this field with 28 publications, followed by the University of Michigan, Ann Arbor, USA, with 16 publications and Georgia Institute of Technology, USA, with 14 publications.

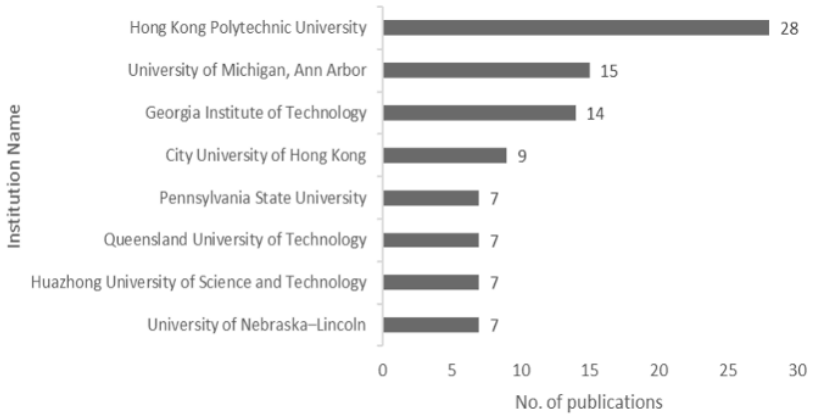

Figure 2: Prominent institutes

Among countries leading the research in this area, as illustrated in Figure 3, the US has the maximum number of publications (i.e., 97 publications), followed by China (43 publications) and Hong Kong (35 publications). It is observed that there are more academic contributions from developed countries than from developing nations which could be due to the limited financial capacity of construction organisations and the slow adoption of technological advances in developing countries (Iqbal *et al.,* 2021; Opoku *et al.,* 2021).

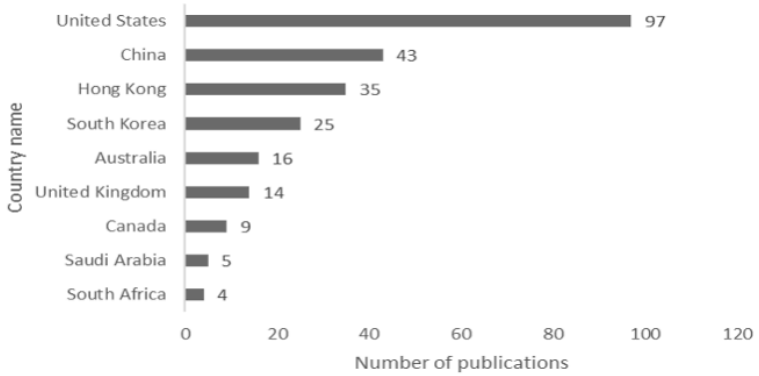

Figure 3: Prominent countries

Author collaboration networks

An analysis of author collaboration networks provided the results presented in Figure 4. For conducting this analysis in VOSviewer, the type of analysis was set to co-authorship, the unit of analysis was set to authors, and the counting method was fractional counting to determine the major authors. Of the 384 authors, 17 met the criteria of a minimum of 3 citations and a minimum of 5 documents per author.

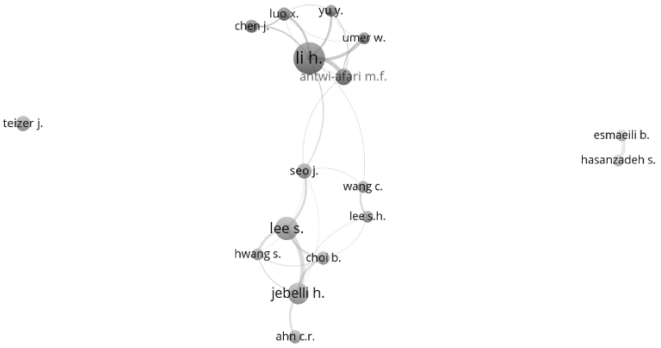

Figure 4: Author collaboration map shows the network map

Figure 4 shows the major author collaboration networks of 17 authors linked in 5 clusters through 30 links. Heng Li leads the authors in cluster 1 from Hong Kong Polytechnic University. Sang Hyun Lee from the University of Michigan, Ann Arbor leads author cluster 2, and Houtan Jebelli from Penn State University leads author cluster 3. These clusters are interconnected, which shows collaboration between authors of these clusters. Clusters 4 and 5 (isolated clusters) include authors who produced research work independently without collaboration.

Country collaboration networks

In VOSviewer, the type of analysis was set to co-authorship, the unit of analysis was countries, and the counting method was fractional counting to determine the major collaboration network between countries. Of the 25 countries, 9 met the criteria of a minimum of 3 documents and a minimum of 3 citations from a country. Figure 5 shows 9 countries grouped into 3 clusters with 19 links. One can also infer from Figure 3 and Figure 5 that the leading countries working on this topic are the United States, Hong Kong, and China. From a chronological analysis, it is observed that research on this topic has been going on in the US and Canada since 2017. A significant contribution by the United Kingdom, Hong Kong and Australia is noted after 2018. Vietnam and Saudi Arabia are relatively new in this field compared to other countries. The analysis shows 9 countries divided into 3 clusters based on their

network. Cluster 1 is the biggest cluster, with the United States having the most networks and comprises Canada, South Korea, and Vietnam. Cluster 2 comprises Australia, China and the UK, possibly due to the close collaboration between academic institutions. Cluster 3 comprises Hong Kong and Saudi Arabia, which could be due to the close economic relationship between these nations. Therefore, the close collaboration among these nations could be due to successful joint grants by the authors, independent research collaboration between the authors, or country-level research collaboration agreements.

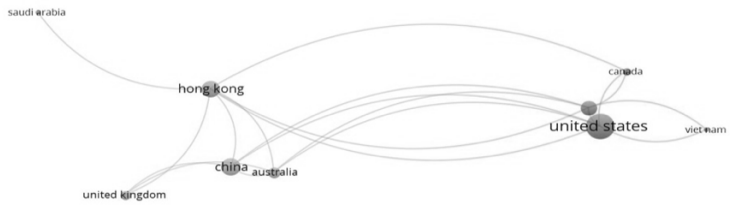

Figure 5: Country collaboration network

Keyword Cluster Analysis

For the keyword cluster analysis, the type of analysis was set to co-occurrence. The unit of analysis was set to all keywords. The counting method was set to full counting to form clusters in VOSviewer. Of 1690 keywords, 66 were selected when the minimum number of occurrences was set to 7. Some keywords were omitted due to being too generic or repetitive, such as construction industry, article, adult, humans, priority journal, construction work, construction, etc. The resulted final keyword network map was organised into five major clusters depicted in Figure 6.

Fig. 6: Text data overlay map of co-occurrence of research areas

Cluster 1: Machine learning, sensors and wearable technologies

Cluster 1 is denoted in red colour in the text data overlay map in Figure 6. This cluster contains keywords related to the application of digital technologies in OHS

management in the construction industry. Previous studies show that recent advancements in digital technologies have reduced OHS risks and increased industrial hygiene (Antwi-Afari *et al.,* 2022). Wearable sensors are now used to monitor construction workers' physical and mental health in many projects.

A strong focus has emerged on promoting industrial hygiene, especially when dealing with heavy machinery and critical construction equipment (Lippy *et al.,* 2021). For instance, electroencephalography determines the construction workers' physical and mental workload (Nguyen *et al.,* 2021). It also reveals the workers' emotional status (Noghabaei *et al.,* 2021). Additionally, deep learning and machine learning are used to analyse the physiological traits and data collected from the wearable sensors to improve OHS in the construction industry (Jeon and Cai 2021). For example, Shakerian *et al.,* (2021) propose a heat-stress risk-assessment process to evaluate heat strain based on the continuous measurement of workers' physiological signals using a wristband-type biosensor.

Cluster 2: Virtual reality and experimental designs

Cluster 2 is denoted by green colour in the text data overlay map in Figure 6. This cluster includes the keywords discussing accident prevention measures among construction workers. Previous studies show that technological applications in the construction industry have made human resource management and project management more efficient (Madubuike *et al.,* 2022). Experiments and controlled studies on construction workers have helped discover more efficient and alternative procedures to improve OHS in the construction industry (Yu *et al.,* 2021). Virtual and augmented realities have also helped make personnel training more effective. The experimental research designs act as a catalyst in implementing technology in the construction industry, highlighting their positive and negative repercussions (Harichandran *et al.,* 2021).

Cluster 3: Hazard identification and improved decision-making

Cluster 3 is blue in the text data overlay map in Figure 6. This cluster includes the keywords related to hazard identification and improved decision-making in construction sites. Innovative technologies have impacted the decision-making processes in selecting construction equipment and machinery in the construction industry (Tummalapudi *et al.,* 2022). They have also influenced risk perception in a positive way (Celik and Gul 2021). For example, timely hazard identification reduces occupational risks, prevents accidents, and increases total construction safety at construction sites (Hire *et al.,* 2022). Son and Kim (2021) proposed an integrated construction worker detection and tracking sensor-based scheme for real-time monitoring and safe operation of construction machines. Therefore, technologies used for hazard identification could significantly improve OHS management in the construction industry due to proactive risk management.

Cluster 4: BIM and digital design

Cluster 4 is yellow in the text data overlay map in Figure 6. This cluster comprises discussion regarding the use of BIM and digital design for promoting safety at construction sites (Lu *et al.,* 2021). Also, it facilitates the risk perception for different construction projects due to adequate planning for safety utilising principles of safety engineering (Park *et al.,* 2022). Hire *et al.,* (2021) discussed using BIM for planning, visualising, simulation of construction hazards, and on-site safety monitoring and control.

Cluster 5: Ergonomics

Cluster 5 is denoted in purple colour in the text data overlay map in Figure 6. This cluster consists of keywords focusing on the use of ergonomic studies on the musculoskeletal system disorders faced by the construction workers (Wahab *et al.,* 2022). Also, mitigation strategies to prevent this from developing into long-term diseases are discussed in the existing literature (Oakman *et al.,* 2022). A better understanding of ergonomics could help develop alternatives in the procedure and construction method to ensure construction activities do not stress the musculoskeletal system (Hire 2021). Technological applications, such as the inertial measurement unit (IMU), could reduce the chances of musculoskeletal disorders by early detection of improper body posture or poor work design that puts the load on the vulnerable body parts like the wrist, hips and back (Lee *et al.,* 2021). Chen *et al.,* (2021) proposed a novel posture coding scheme based on the worker's body part relative position information.

LIMITATIONS

The findings are to be considered against some limitations. First, the findings are limited by literature analysis ranging from 2000 to 2021. There might be a few studies published outside the research period considered for the analysis. Second, using Scopus as the search database has a few limitations. Using multiple databases could identify more relevant articles. A similar analysis could be conducted in databases like Web of Science, ScienceDirect or ProQuest to gauge the research trends in those indexing methods. Third, scientometric mapping suffers from certain limitations. Being a data-driven approach, it is an empirical and objective approach to analysing knowledge domains. However, there could be subjective biases while interpreting obtained results which could be minimised by consulting with independent domain experts (Li *et al.,* 2021). Finally, research quantity and other quantitative indicators used in scientometric mapping do not necessarily represent the quality of the research work. Therefore, quantity should not be considered the sole criteria for judging the research contributions of researchers and institutions active in this research area.

CONCLUSIONS

The present study aimed to enhance the understanding of the existing research on technological applications for OHS management in the construction industry. The outcomes of this study are expected to assist researchers and practitioners by providing valuable insights into research trends, collaborations, and research clusters. The study found that research on technological innovations and applications in OHS management in the construction industry is an emerging research area, as evidenced by increased research outputs in recent years. Current research in this field is attracting the attention of many researchers, as evidenced by 42 articles in 2021 alone. The multi-disciplinary nature of this field of enquiry was also observed in the analysis, indicating it is an important and relevant area of research across different disciplines. Moreover, five major collaborative clusters of researchers in this field were identified and mapped. The analysis also shows collaboration between researchers from different countries. The scientometric analysis further identified five major research clusters of technological applications in occupational health and safety management in the construction industry: (1) machine learning, sensors, and wearable technologies, (2) virtual reality and experimental designs, (3) hazard identification and improved decision-making, (4) BIM and digital design, and (5) ergonomics.

The review also identified a few gaps in the existing literature. For instance, research in developing countries such as South Asian and African nations are lacking. Since most construction workers reside in developing nations, improving OHS performance in these countries is essential and demands more attention and collaboration with researchers from developed countries. Similarly, studies on data privacy issues and ethical concerns while collecting and storing OHS data of construction workers are scarce. Recent cybersecurity breaches across different sectors suggest that similar incidents in the construction industry could have profound implications for workers and construction organisations. Moreover, most studies have examined the use of wearable sensors in controlled environments. Studies in the actual construction environment could offer more insights into user acceptance and the practical feasibility of these technologies for broader adoption.

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