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A BIBLIOMETRIC REVIEW OF TRENDS IN CONSTRUCTION SAFETY TECHNOLOGY RESEARCH

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This paper provides a bibliometric review of technologies for safety on construction sites to explore the evolution and research trends on digital technologies for the management of construction safety. A comprehensive bibliometric review adopting a two-step literature selection method was conducted to compile relevant publications from the Scopus database. In total, 240 related papers were examined. VOSviewer was used to develop a co-occurrence network based on the bibliographic data obtained. The analysis focused on the trend of research topics on technologies for construction safety. Emerging trends in construction safety technologies research were project safety design and planning, visualization and image processing for construction projects, digital technologies for project monitoring, information management and Internet of Things, automation and robotic systems, safety and accident prevention, and structure evaluation. This study provides insights into technology development and application and identifies trends for future research, which is crucial for the construction health and safety stakeholders to share and access research findings.

Keywords: Bibliometrics, Construction industry, Digitalization, Digital Technologies, VOSviewer.

1 INTRODUCTION

Regardless of the countless efforts made by safety authorities and government agencies to improve safety standards in construction sites, worker's injuries and fatalities continue to occur (Azmy and Zain 2016). Defective machinery, poor working conductions, and unhealthy working practices are reported as frequent causes of accidents and deaths in building sites (Hinze and Teizer 2011, Li 2015). Consequently, diverse technologies and strategies have been introduced to reduce injury, incidents, and increase occupational safety (Zhou *et al.* 2011, Welch *et al.* 2015, Dodge Data and Analytics 2017).

There has been a rapid increase in the use of emerging technological innovations to enhance safety on job sites in recent years. Numerous studies have found with the advent of new technology that the introduction of these technologies may offer a sustainable solution to construction safety issues (Zhou *et al.* 2013, Zhang *et al.* 2017). A bulk of research has focused on the use of emerging technology, such as internet libraries, Geographic Information Systems (GIS), and Building Information Modelling (BIM), Unmanned Aerial Vehicle (UAV), Augmented Reality(AR), 4D Computer-Aided Design (4D CAD), robotics and automation, laser scanning,

Virtual Reality (VR) photogrammetry and sensor-based technologies to prevent accidents and onsite injuries (Zhou *et al.* 2011, Dodge Data and Analytics 2017).

Utilizing emerging technologies provide significant prospects to improve construction health and safety management and ensure efficiency in construction work (Zhou *et al.* 2013, Teizer 2015). Therefore, investing in novel technologies also improves construction site safety.

Numerous studies have been conducted and published on technologies for construction safety, creating a background for the promotion of effective safety practices on construction sites. A systematic review of literature on technology applications for construction safety is essential for major construction stakeholders to comprehend, share ground-breaking research findings and capture emerging trends that may positively impact construction safety in the long run (Zhou *et al.* 2013, Liang *et al.* 2018). While numerous studies reviewing construction health and safety technologies have been conducted, limited studies have performed an analysis utilizing a variety of selection criteria and samples. This study conducts further research compared to other reviews by providing a comprehensive bibliometric analysis of published research on construction safety technologies by examining the publication trend of research topics.

2 METHODOLOGY

Due to its completeness and representation of documents from diverse fields, the Scopus database was chosen as the source of data for this analysis (Hong *et al.* 2012, Hosseini *et al.* 2018).

The database and retrieval strategy were initially selected to create a data source with sufficient accuracy and robustness. A two-step screening was conducted to filter relevant documents from the retrieval results based on publication types and other criteria. A co-occurrence and frequency analysis were conducted to examine publications in terms of country/ region, the number of publications annually, publication year, publication type, and source. Keyword co-occurrence analyses were then conducted to identify the trend of research topics. Gaps and trends for future research were discussed to guide research directions on the adoption of digital technologies for safety on construction sites.

An online retrieval was carried out, and 3189 data records were obtained. A keyword search was conducted to retrieve all related documents from the Scopus database. The specific keywords adopted for the study were "Safety" AND "Digital Technologies" AND "Construction." The literature selection focused on journal articles and conference proceedings published in construction. In the first selection stage, book reviews and editorial materials were excluded from the data set. After filtration, a total of 3133 relevant publications were used for the second stage of literature selection. A preliminary review was further conducted by reviewing the titles, abstracts, and keywords of the 3133 publications. To further select and eliminate irrelevant documents, four filter criteria were applied to select documents that aligned with the research topic and theme. After conducting the two-stage literature selection, a total of 240 publications remained, including 84 journal articles and 156 conference papers.

This study analyzed statistical data obtained from the data source, focusing on the co-occurrence of keywords. The VOSviewer software was used to conduct the analysis and develop a co-occurrence map. VOSviewer is a software tool used for the construction and visualization of graphical and bibliometric maps. The software contains features that are able to display large bibliometric networks that can be easily interpreted (Van Eck and Waltman 2014).

3 RESULTS AND DISCUSSIONS

3.1 Co-occurring Network of Keywords

A co-occurrence network was derived from a total of 2970 keywords using the VOSviewer software. With a minimum number of 5 co-occurrence keywords, 52 keywords met the threshold, and 7 significant keyword clusters were identified. According to Liang et al. (2018) the degree of co-occurrence is determined by the closeness of keywords to each other and similarity of keywords. Figure 1 presents a network visualization map of the 7 co-occurring keyword clusters.

Cluster #1, labeled in red, had 12 keywords, such as architectural design, computer aided design, digital avionics, digital technologies, human computer interaction, laws and legislations, real time systems, research, security of data, construction projects, and virtual reality. This cluster can be further be summarized as 'Project Safety Design and Planning (PSDP)'.

Cluster #2, presented in green, had 9 members with keywords, such as augmented reality, cameras, data handling, image processing, life cycle, maintenance, photogrammetry, reliability, and 3D. Keywords in this cluster can be summarized as 'Visualization and Image Processing for Construction Projects (VIPCP)'.

Cluster #3, labeled in blue, had 9 members with keywords, such as computer simulation, decision making, digital instruments, information technology, monitoring, sensors, technology, virtual instrument, and virtual instrument technology. This cluster was summarized as 'Digital technologies for Project Monitoring (DTPM)'.

Cluster #4, shown in yellow, had 7 items, such as digital storage, hazards, information management, internet, internet of things, remote control, and safety engineering. This cluster can be summarized as "Information Management and Internet of Things (IMIoT).

Cluster #5, labeled in purple, had 5 members with keywords, such as automation, computer software, digital control systems, digital devices, electronic power systems, and standards. This cluster was summarized as 'Automation and Robotic Systems (ARS)'.

Cluster #6, shown in green, had 6 items showing keywords, such as accident prevention, digital radiography, non-destructive examination, risk assessment, safety, and safety testing. This cluster was grouped as 'Safety and Accident Prevention (SAP)'.

Cluster #7 was represented in orange and had 3 keywords, such as cracks, image analysis and strain measurement. This cluster was summarized as 'Structure Evaluation (SE).'

Findings from the co-occurrence of keywords analysis indicate that studies on digitalization in construction safety have majorly focused on the application of digital technologies for safety design and planning, implementing visualization and image processing for construction projects, application of digital technologies for project monitoring, application of information and internet of things to construction projects, automation and robotics for construction safety and the evaluation of structures to enhance construction safety. These findings support claims by Zhou et al. (2011), Zhou et al. (2013), Azmy and Zain (2016) that a variety of digital technologies have been widely applied within the construction industry to enhance safety in the construction environment. Evidence from these studies revealed a wide focus on digitalization for construction safety management.

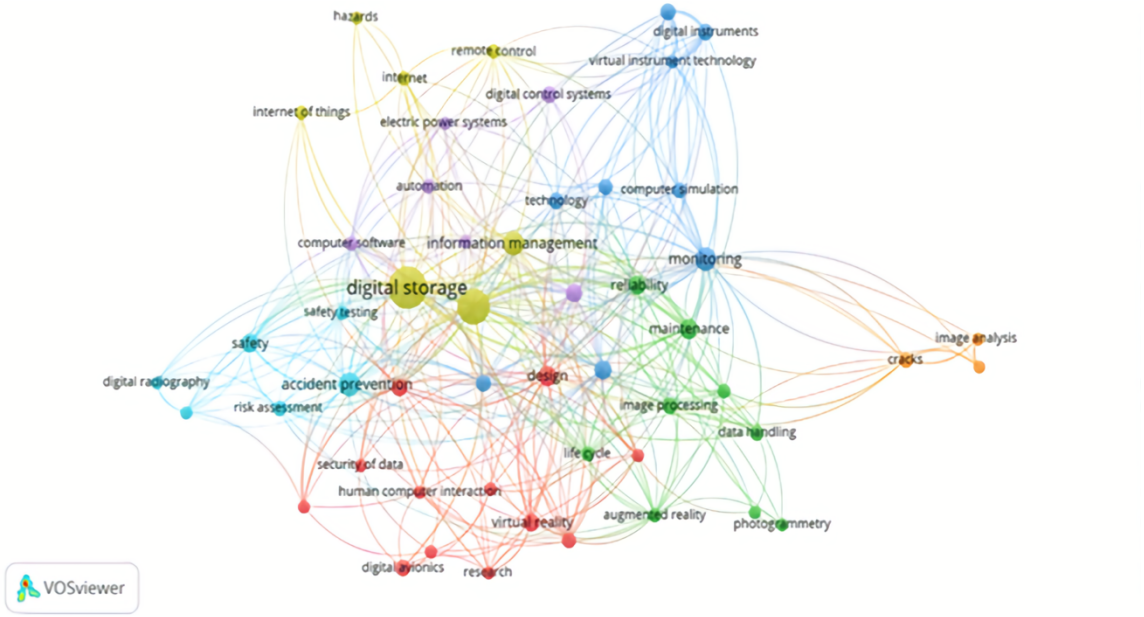

Figure 1. Cluster Visualization Map for co-occurring keywords.

3.2 Analysis of Trends of Research Topic Analysis

Figure 2 presents an overlay visualization network generated from VOSviewer, showing the trend of research topics in terms of co-occurring keywords over a ten-year period (2010-2019). With a co-occurrence of 5 keywords, starting from 2012, there was a trend of research on topics related to virtual instruments, digital instruments, computer simulation, and sensors.

From the generated network and links, it is evident that in 2013 there was an increase in publications on topics, such as digital avionics, cameras, design, hazards, and digital control systems. This implies that during this year, numerous studies emphasized on the use of digital avionics systems such as drones and the design of digital control systems for construction safety hazards. In 2014, keywords with strong co-occurrences were identified as reliability, monitoring, safety testing, automation, image processing, information technology, and remote control. This indicates that in 2014, research on digitalization concentrated on the use of automation and information technology for construction site safety and safety monitoring. In 2015, researchers focused on robotics and automation for accident prevention and intensified on issues of safety engineering and risk assessment. Keywords such as digital storage, safety engineering, accident prevention, risk assessment, human-computer interaction and digital devices were identified. From 2016, keywords such as architectural design, life cycle, image analysis, cracks, strain measurement, law and legislation, and decision making were found to co-occur. In this last period, innovative design and sustainable concepts for the evaluation and analysis of structures received more attention from researchers. It is also evident that studies in this period intensified on decision making and safety laws and legislations in the construction industry.

Findings from this study indicate that research on digital technologies for construction safety has evolved from the incorporation of digitalization of construction safety through the application of digital control systems, information technology, robotics and automation, and digital design. Subsequent research has concentrated on decision making processes on the adoption of digital

technologies for safety in construction and the development of laws and legislations that promote of digitalization for construction safety.

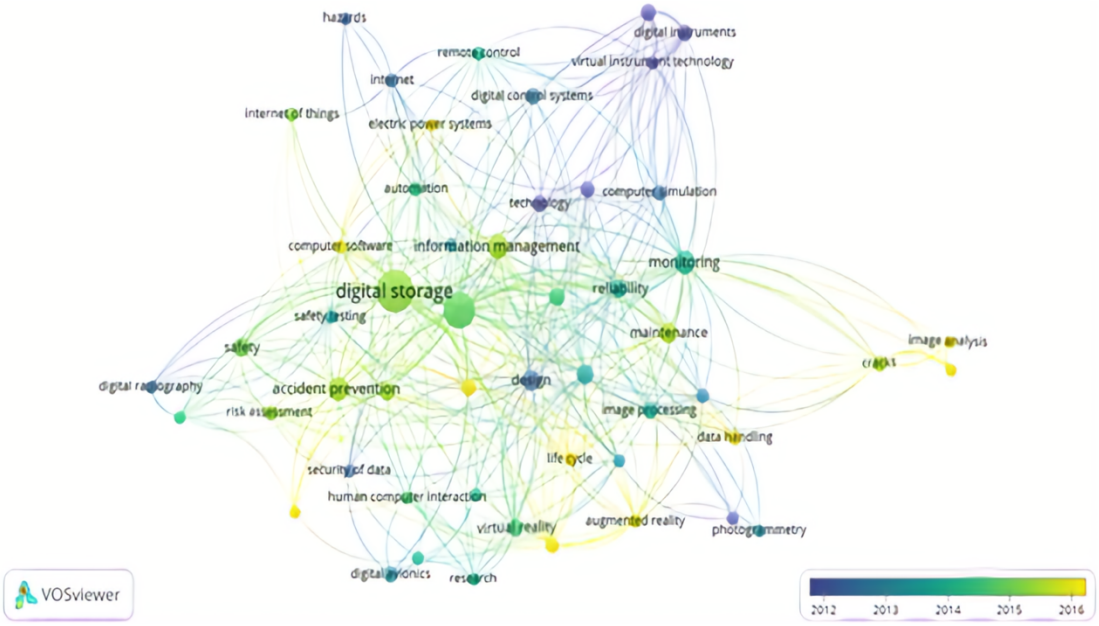

Figure 2. Overlaying visualization network of research topics.

4 CONCLUSION

Globally, the concept of digitalization and technology for construction safety has received wide attention. It has been found that with the application of digital technologies, the efficacy of safety management at construction sites improved significantly. The study presented a bibliometric review of technologies for construction safety by conducting a comprehensive bibliometric review of 240 relevant publications from the Scopus database. A co-occurrence analysis was conducted to identify publication trends on construction technology safety research. The study presented the evolution of research topics through a cluster of existing topics, providing researchers with a trend of existing literature directions to guide future research on construction safety technologies. Publication trends over the past decade and the distribution of publications across different countries and regions were identified. The co-occurrence of keywords analysis identified 7 main research topics evolving from research on construction safety technologies from 2009 to 2019. Consequently, 5 emerging trends were identified. Since Scopus was considered as a source of data for the study and selected only documents published in English, the report suggests future research using a mixture of databases and documents written in other languages.

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