Leading Technologies Adoption in Construction Safety Management

Yash Kumar Mittal
Malaviya National Institute of Technology Jaipur, Jaipur, India
yash.arch@mnit.ac.in

Pooja Tripathi
Malaviya National Institute of Technology Jaipur, Jaipur, India
2021rar9008@mnit.ac.in

Abstract

Existing research reveals that by adopting leading technologies in the construction industry, worker's safety could be maximized. Presently, the application of technologies to promote safety in the construction sector is limited. The data for accident cases on the construction sites are very limited. Many tools and techniques have been created to increase worker safety on construction sites by designing and implementing good safety plans. A bibliometric and scientometric approach was used to identify the most prominent technologies in construction safety management. The data was retrieved from WOS database, and the analysis of the study is based on using VOS viewer to visualize the domain-specific knowledge. This study helps in the identification of emerging digital technologies such as Building Information Modelling (BIM), IT applications, Augmented Reality (AR) and Virtual Reality (VR), its application, and barriers in adoption during safety management. This study also highlights critical factors that promote technology adoption in construction safety management. This research also traces the current trends, future directions and supports crucial knowledge on safety technology to construction researchers and practitioners.

Keywords: Construction industry; Technology adoption; Digital technologies; Safety Management

1 Introduction

The construction industry constitutes one of the most hazardous sectors around the world. The incident rates which measure the frequency of illness and injuries, in the construction sector are much higher than in any other industry (Jin *et al.*, 2019). Despite strict health and safety rules, there has been a noticeable increase in the incidence of building accidents. The most frequent causes of injuries and fatalities on construction sites include defective equipment, hazardous workplaces, and unsafe working conditions(Haupt, Akinlolu & Raliile, 2019). Safety planning is more difficult in an unstructured construction environment. Loss of life is the most severe effect of poor safety planning and implementation (Zhang *et al.*, 2013). Traditional safety planning is labour-intensive, time-consuming, and highly ineffective because it frequently relies on manual observations(Guo, Yu & Skitmore, 2017). In light of these, numerous technologies and interventions have been developed to reduce worker accidents and injuries and improve safety on construction sites. Modern technologies help clarify the work process and its applications in the virtual world. As a result of the expanding use of digital technologies in the building industry, researchers have been using BIM (Building Information Modelling), AR (Augmented reality), VR (Virtual reality), IOT (Internet of things), ICT (Information and Communication technologies) to improve safety management, planning and site monitoring in

the recent years (Hu & Zhang, 2011; Skibniewski, 2014; Guo, Yu & Skitmore, 2017; Park, Kim & Cho, 2017).

This review-based study used the science mapping approach by examining journal publications that have been published in the field of construction safety. The goals of this study are to (1) use science mapping to analyse the related journals, keywords, scholars, and articles in the field of construction safety; (2) analyse work on leading technology adoption in construction safety; (3) discuss the shortcomings and applications of the technologies in the construction safety domain and suggest directions for future research in sub-themes within the domain of construction safety.

2 Research Methodology

A bibliometric and scientometric approach was adopted to address the study's objective. The approach consists of a bibliometric analysis followed by scientometric analysis of the literature available on the concerned subject.

2.1 Biblio Metric Analysis

The bibliometric analysis is done using the Web of Science (WOS) database to examine research trends relevant to the use of technology in construction safety management. The search term is entered in the "Advanced search" field: “Construction Site”, “Safety Management”, and “Technology” are all represented by the acronyms “TO”. Without using filters, 292 papers in the years 2010 and 2022 are found. Filters are utilised in order to obtain more pertinent and concentrated literature results published in English. Review papers and articles are reviewed before being eligible for examination. The final list excludes documents containing meeting abstracts, conference proceedings, and editorial content. After applying all the filters, 236 papers related to the use of technology for safety management in the construction industry are found.

2.2 ScientoMetric Analysis

The scientifically retrieved data is mapped using scientometric analysis to identify themes and dynamic data properties, allowing the processing of a wide range of data. Current technology adoption patterns in the construction industry, gaps, key sources, organizations, and authors are studied using VOS viewer. This study performs a scientometric analysis using “mappings based on text data”. The most frequent terms in the title and abstract are then discovered using a “Co-Item Analysis”.

3 Results

3.1 Density of Publications

The yearly publishing history from 2002 to 2023 is depicted in Figure 2. It also demonstrates the yearly publications about the use of technology in construction safety management growing exponentially. The cumulative publications and exponential growth in publishing pattern are also shown and presented in the Figure 2. The graph shows that the number of articles on “Technology adoption in construction safety management” is rising. There has been a noticeable increase in number of publications between 2019 and 2022. Additionally, the deployment of technology is seen as being widely accepted, and there are ample evidences of studies and publications that highlight the need of using technology to manage construction safety.

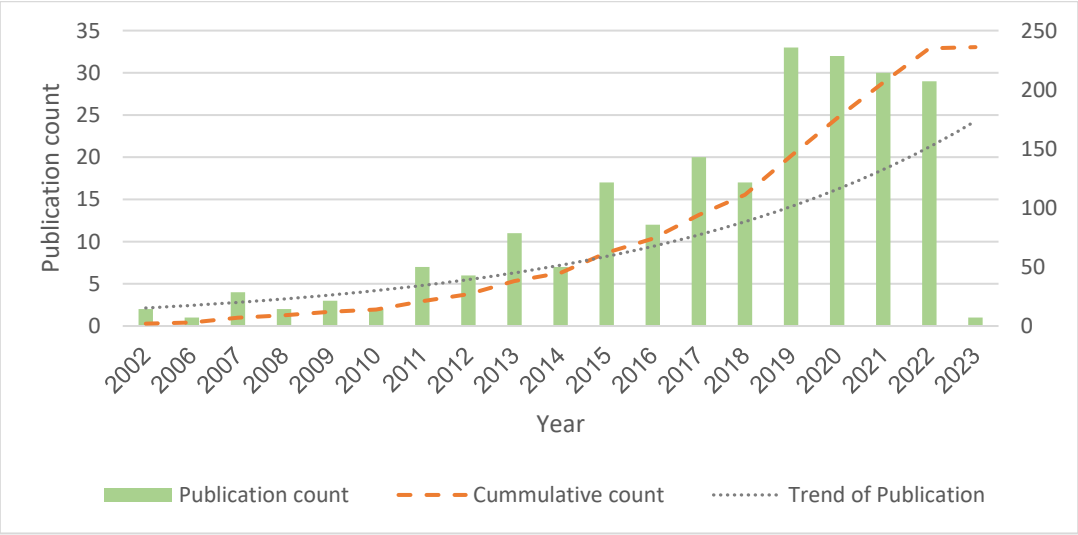

Fig. 1: Trend of Annual Publication

3.2 Most Occurring Keywords

Keyword identification in VOS Viewer is facilitated by choosing the data type and mapping the phrase "Co-Item" based on bibliographic data. The title and abstract fields are explored for words, and full counting is adopted as the counting mode. Out of 299 terms, 39 met the cut-off when the minimum number of occurrences of a term was set at 3. Figure 2 highlights the mapping of the most occurring keywords in the construction safety domain.

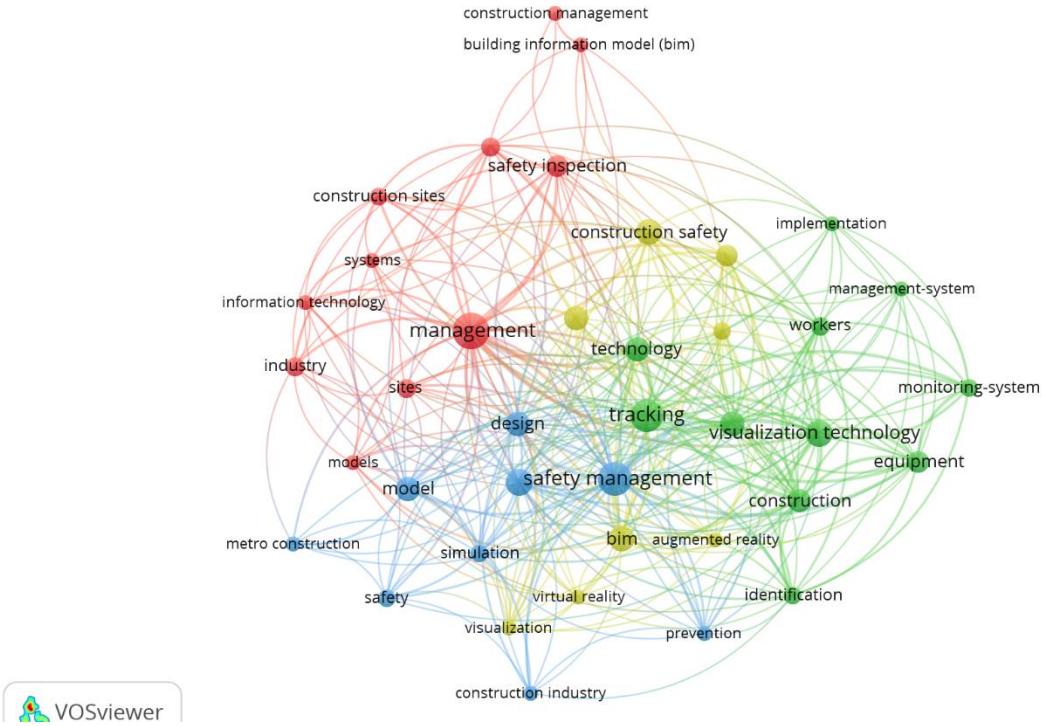

Fig. 2: Most Occurring Keywords

From the VOS viewer analysis, it is identified that Tracking (14), BIM (9), Visualization Technology (10), Augmented Reality (3), Virtual Reality (3), and Information Technology (3) are some mostly occurred keywords related to the construction safety domain. Four different clusters were generated from VOS viewer where blue colour indicates safety management with modelling

and simulations, green colour highlights monitoring of work process and hazards with the help of visualization technology, red colour shows safety management with inspection and information management system, while yellow colour shows different technology adoption in hazards prevention and mitigation.

3.3 Top Journal in Construction Safety Management

Figure 3 displays the top publications where technology adoption in the construction sector is addressed, with "Automation in Construction" receiving the most citations (1077). A table of published documents, citations, overall link strength, and scopus quartile is created based on the relevant journals.

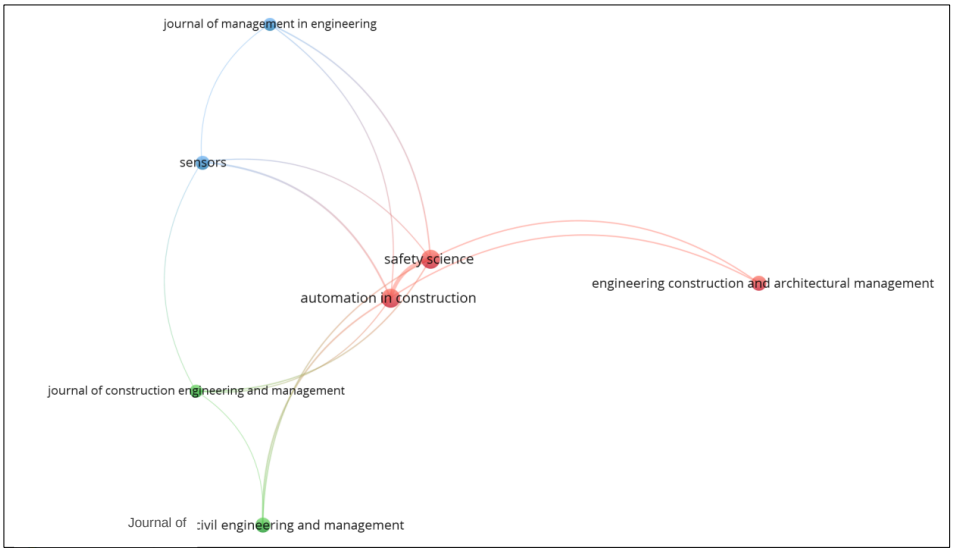

Fig. 3: Most Influential Journal in Construction Safety Management Domain

Table 1 shows that the most of the documents belong to the first and second quartile, indicating that they are the most acknowledged and frequently cited papers in the field of technology adoption in construction safety management. The Total Link Strength (TLS), which is automatically provided by VOS viewer upon mapping the research activity of chosen regions, was used to demonstrate the strength of international research collaboration. The degree of international research collaboration is inversely correlated with the TLS, with a higher TLS value indicating more collaboration (Sweileh, 2020).

Table 1 : Mapping of Journals as per Citation

S. No.	Source	Document	Citation	Total link strength	Quartile
1	Automation in Construction	13	1077	40	Q-1
2	Safety science	12	534	38	Q-1
3	Sensors	3	137	9	Q-2
4	Journal of construction engineering and management	2	137	7	Q-1
5	Engineering construction and architecture management	4	101	6	Q-2
6	Journal of management in engineering	2	18	6	Q-1
7	Journal of civil engineering and management	4	102	8	Q-2

4 Discussion: Digital Technologies and Trends in the Construction Safety Management

Big data, technological innovation, and construction have recently enhanced worker safety on construction sites. The usage of technology continues to receive attention as new technologies are

being developed. Various technologies have been designed to help contractors attain safety on their construction projects. BIM, VR, AR, drones, sensing and warning systems have been highlighted in numerous studies as useful for accident prevention and safe project delivery (Shen & Marks, 2016; Fan *et al.*, 2021; Tian *et al.*, 2021). The following sections provide a detailed examination of these technologies.

4.1 Building Information Modelling (BIM)

A cutting-edge technology in the development of the construction industry, building information modelling (BIM) combines various types of construction information into a 3D digital model. It can be used in all project lifecycle phases, including planning, design, construction, operation, and maintenance (Cheung, Lin & Lin, 2018). The current focus of construction site management systems is primarily on how to apply artificial neural networks, expert systems, and other numerical methods to improve the on-site management of uncertainty or optimize problems of space utilization (Hu & Zhang, 2011).

BIM technology can be used for 'facility maintenance', 'accident investigations', 'worker safety training', 'design for safety', and 'safety planning'. Visual evaluation of construction sites and the detection of potential dangers are made possible by BIM. The creation of safety training movies for site employees to help them better grasp the conditions on the jobsite is made possible by using BIM in construction activities (Akinlolu & Haupt, 2021). Innovative technologies were suggested to pair with BIM to improve its resolution and keep track of construction schedules (Tian *et al.*, 2021).

4.2 Virtual Reality (VR)

VR is an artificial, computer-generated experience of a real-life situation or environment (Haupt, Akinlolu & Raliile, 2019). In the construction demonstrates new ways of working using immersive displays to see, review, and alter virtual projects for all stages of the development cycle when integrated with BIM. Several authors have examined the benefits of using VR for construction safety instruction. VR enables the realistic simulation of many types of construction machinery for learning its operation and instructing employees about operational safety (Serrano, La Rivera & Valero, 2021). The user can enter a simulated construction site with the associated activities using immersive VR technologies. They can help a more efficient evaluation of the building plans, schedules and identify or assess relevant risks by improving real-scale spatial perception (Getuli *et al.*, 2020). VR is one powerful visualization tool used to advance state-of-the-art safety management practices (Park & Kim, 2013).

4.3 Augmented Reality (AR)

In contrast to VR, which simulates real-world situations with computer-generated visuals, augmented reality employs technology to improve reality (Zhao, 2017).It has been identified that the communication between the project team became difficult for safety manager while doing manual inspection with the help of site photos and checklists. By enhancing essential activities with digital content, AR technology can expand the scope of human recognition and reasoning (Park & Kim, 2013). Numerous researchers have investigated AR, creating systems and prototypes to assess its potential to enhance safety levels in construction. The System for Augmented Virtual Environmental Safety (SAVES) is one such system that was introduced to solve the shortcomings of the pre-existing training materials. Incorporating educational and performance-based tasks improves safety training (Shafiq & Afzal, 2020).

4.4 Internet of Things (IOT)

The Internet of Things (IOT) is described as the "interconnection of sensing and actuating devices offering the capacity to share information across platforms through a unified framework, generating a common operating picture for allowing creative applications" (Tang *et al.*, 2019). In collaboration with data transmission tools like Wi-Fi, Bluetooth, and 5G, IOT-related technologies like radio frequency identification (RFID), Unnamed Aerial Vehicles (UAVs), sensors, and laser scanners can be used to create seamless connectivity between physical devices on the construction site (Wang *et al.*, 2022). Researchers have used BIM and O technology to design a construction safety management system of deep foundation pits, as safety is related to accurate location tracking and real-time on-site monitoring (Fan *et al.*, 2021). IOT not only supports the BIM technology that provides safety incident warnings but also facilitates using various sensors to monitor hazardous factors at construction sites. In order to better achieve the integrated functional advantage of IOT technologies and correctly address potential safety hazards, various construction safety systems based on identifying and responding to dangers have been developed (Wang *et al.*, 2022). Figure 3 shows the interaction of the relevant covered technologies.

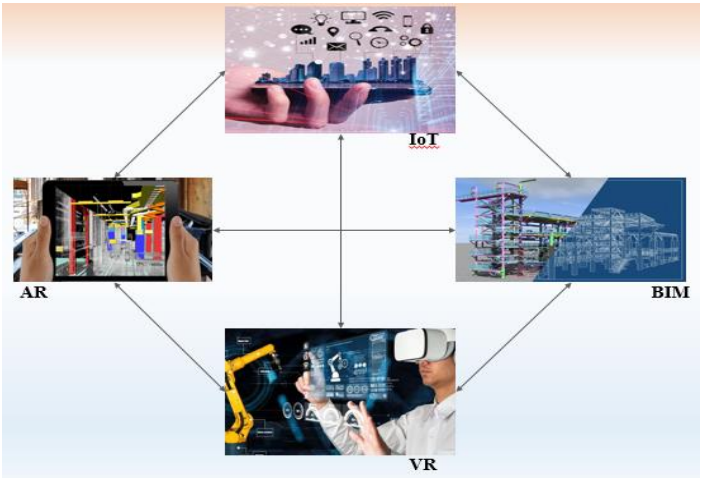

Fig. 4: Interaction of Digital technologies

A review of identified literature justifies that interaction of these technologies is an important decision-making tool. From site monitoring to virtual site planning, all critical decisions can be made possible with the help of technology implementation. Table 2 includes the summary of the existing literature review.

Table 2: Summary of Literature Review

S. No.	Technologies Integration	Application of Technology	Reference	Year
1	BIM and IOT	To improve construction and operational efficiencies by incorporating real time data streams	Tang et al. 2019	2019
2	BIM and VR	Safety training protocol based on BIM- enabled VR activity simulations	Getuli et al. 2020	2020
3	4D BIM	4D BIM tool for construction planning efficiency	Martins et al. 2020	2020
4	AR	Safety training module by AR technologies	Shafiq & Afzal 2020	2020
5	4D BIM	4D BIM simulation to prevent severe injuries and fatalities on building sites caused by spatial-temporal situations	Manzoor et al. 2021	2021

6	BIM and IoT	To improving the safety management efficiency of deep foundation pit construction sites	Fan et al. 2021	2021
7	4D BIM and VR	Effectiveness of (4-D) BIM and VR in simulating job-site safety instructions for a multilingual construction crew at a project	Afzal & Shafiq 2021	2021

5 Barriers in Adopting Digital Technologies

Digital technologies have a huge potential to enhance the efficacy of construction projects during design, construction, and maintenance phases. Despite this, several factors are limiting the advancement of technology adoption in the construction safety management. It was analyzed from numerous studies that there are various barriers in adopting technology for construction safety management purposes (Nnaji & Karakhan, 2020; Yap *et al.*, 2022):

- Costly investment associated with new technology.
- Workers training limitations.
- Lack or no government regulations for the implementation.
- Lack of legislations.
- Lack of decision support tools.
- Incompatibility of technology with current practices and current construction operations.
- Lack of professional knowledge.
- Technology performance concerns.

6 Conclusion

This study has offered a thorough review of earlier works on using technology in construction safety management. The use of different types of technology in construction safety issues, such as site safety education with training, safety communication and site monitoring and control, has been the subject of numerous research studies. A significant increase in innovation has occurred recently across several industries, creating numerous prospects for enhancing operational flexibility, efficiency, and safety. Many researchers have highlighted that the latest technology has more potential to address the issues of construction safety management. Latest technologies like BIM, AR, VR and IOT have significantly improved safety management on construction sites. In contrast to other businesses, the construction sector is slow in adopting technological improvements. Costly investments, lack of skilled staff and undefined government regulations are some significant barriers to adopting digital technologies. The study is limited to assessment of the safety management scenario in relation to technology implementation at various levels whereas occupational safety behaviors are not covered in the study. The study's findings would guide the construction stakeholders in formulating certain legislative recommendations that might significantly affect the adoption of digital technologies for construction safety management. The future scope of work includes practical implications of integrating technologies with the real-time construction process for managing safety.

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