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Performance of Emerging Technologies on Construction Safety: A Review

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Abstract. The construction industry is far behind many industries when it comes to the adoption of digitalization. The construciton industry is facing issues like low production rate, lower profitability, and higher cost overruns due to its low adoption of emerging technologies. Also, the situation is even worse when it comes to safety. The issues this industry currently has are a high number of accidents, high fatality rates, absence from work, and many others. Recently, a term construction 4.0 has emerged as a remedial to lower digitalization adoption in this industry. It includes various recent technologies, including Artificial Intelligence, and Computer Vision and, Building Information Modeling. Every other advanced technology has its different role in safety. There are various benefits of the adoption of recent technologies, which can work for the advancement of the construction industry as well betterment of safety. This study has included a thorough literature review regarding the impact of these recent technologies on the safety performance of the construction industry. This study will provide a comprehensive review of the current adoption, absence of these technologies, and how many benefits this industry can get with the implementation of digital technologies.

Keywords: Digitalization; construction industry; Bim; computer vision; artificial intelligence

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INTRODUCTION

Building construction can progress towards enhanced production efficiency, innovative business models, and optimised value chains due to the advent of the Fourth Industrial Revolution (4IR) and the associated Industry 4.0 (I4.0) framework [1]. The integration of existing and developing technologies within the Industry 4.0 paradigm enables such a change [2]. Construction 4.0 is a notion derived from Industry 4.0. It encompasses the combined use of several trends and technologies, both digital and physical, intended to transform the design and construction of built environment assets [3].

The presence of risk in construction industry is high very high, and organisations are continually searching for measures to improve their safety performance. Among these, using technology into health and safety practices leads to better safety performance [4]. Due to the complex and on-site nature of construction projects, the construction sector is very susceptible to significant safety hazards. Therefore, construction researchers have been actively

exploring ideas, techniques, and instruments that utilize emerging technologies to enhance the management of construction safety. The swift digitization of construction work procedures is creating chances to enhance safety in the construction sector [5].

Construction work is commonly performed in dangerous, disorderly settings and under substandard and unsanitary working conditions. [6]. The issue of safety on construction job sites has emerged as a paramount concern for construction businesses globally. Construction labor is commonly perceived as hazardous, exposing workers to significant risks of injury and disease. Utilizing technology is seen as a highly effective method for enhancing the health and safety conditions of site workers and ensuring overall construction safety management. [7]. The adoption of digital technologies is very limited in construction. According to the New South Wales report [8], from FIGURE 1, it can be seen that only 28% combined designers and builders use digitization in their routine work, while 48% of designers and 57% of builders are still relying on basic Microsoft software.

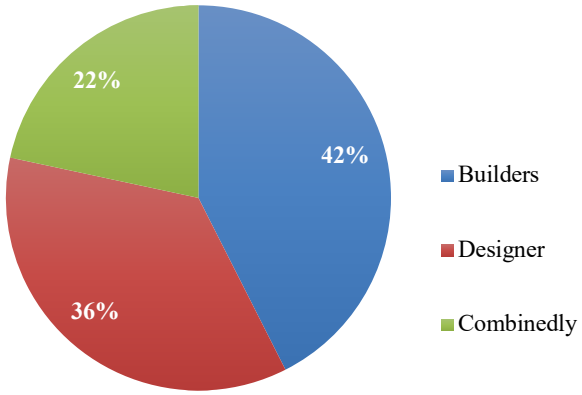

FIGURE 1. Adoption of Digitalization

Study also reveals that 70% respondents found achieving accuracy, 66% found improvements in quality, 61% found on time delivery of the project and better communication and 43% found competitive advantage, which can also be seen in FIGURE 2. When it comes to safety, as it can also be ssen from FIGURE 2, which reveals that only 18% of the firms using advance softwwares while 60% still relying on basic softwares.

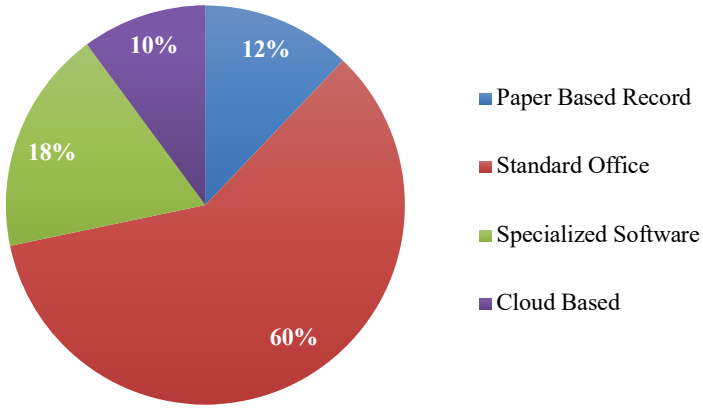

FIGURE 2. Safety Adoption in C.I

The subject of construction safety management has attracted considerable focus in both scholarly research and practical application in recent years, primarily owing to the disturbing occurrence of fatalities and mishaps in construction industry [9]. Construction safety is greatly impacted by the use of new technologies in the current wave of technology adoption. Applying cutting-edge technologies like wearables, Building Information Modeling (BIM), virtual reality, and artificial intelligence greatly improves safety performance [10]. The deployment of digital technology has the capacity to significantly enhance the safety and productivity of construction projects. The construction industry is quickly embracing cutting-edge technological innovations to enhance current construction methods, such as the utilization of Virtual Design and Construction (VDC) tools [5]

Utilizing VDC can enhance the overall quality of design, enhance construction safety, and ultimately lead to cost reduction and time savings [12]. Moreover, it possesses the capacity to improve productivity and project outcomes by promoting knowledge exchange among stakeholders. These digital instruments, frequently referred to as VDC technologies, comprise an array of IT-driven solutions that improve the effectiveness of traditional processes through digital or visual techniques. The technologies mentioned in this area include BIM, Virtual Reality, Augmented Reality, and Geographic Information System [13].

RESEARCH METHOD

Systematic review has been adopted as a methodology for writing this paper. The Scopus database has been used to find the relevant studies and the details of the literature are discussed below:

Literature Review

A comprehensive literature review has been performed in the domain impact of emerging technologies of constructions safety performance. The Scopus database has been used to search for literature. The timeline was set from 2010 to 2024, and the keywords were "Technologies" "Construction", and "Safety". After doing the search, the following details have been found.

Yearly Publications

It was found out that 382 articles were published in 2023, and 395 recorded in 2024 which is the highest compared to any other year. A better comparison of years can be seen in FIGURE 3.

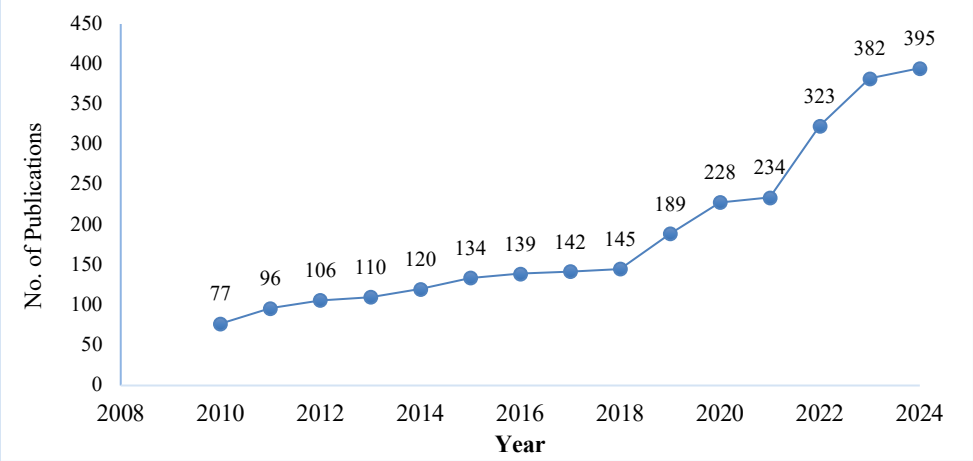

FIGURE 3. Yearly Number of Publications

Country-Wise Publication

Most of the articles were published by China, which were 998, followed by the USA, which has 630, as can also be seen from FIGURE 4.

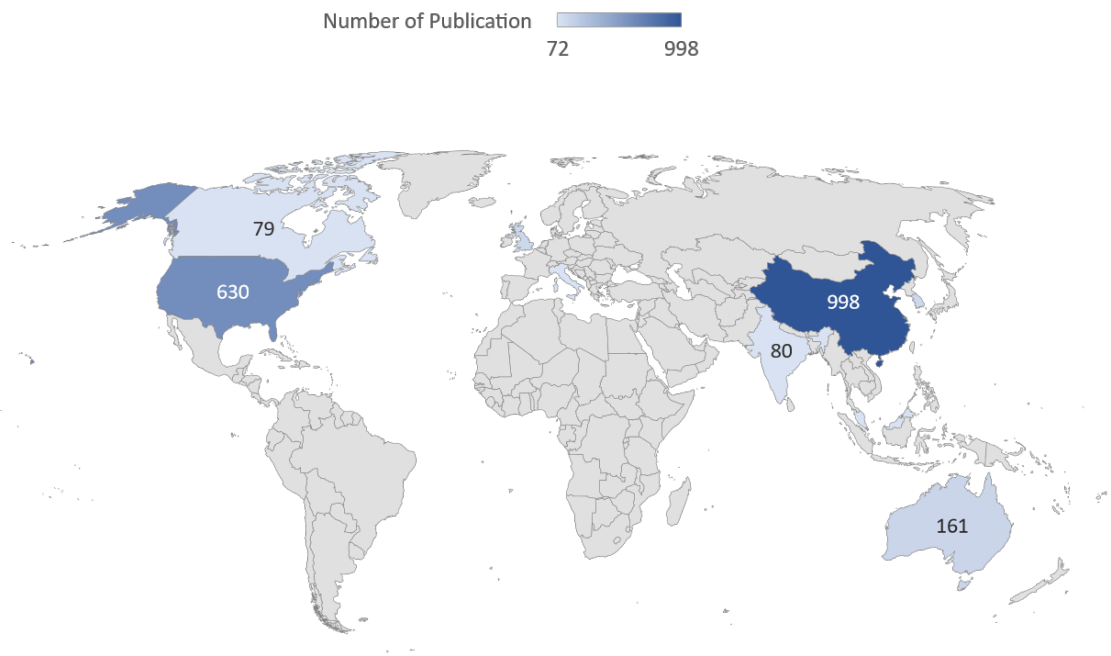

FIGURE 4. Country wise Publications

Keywords Analysis

Most repeated keywords from relevant studies have been found using VOSviewer. The **FIGURE 5** shows various clusters and the number of links in between them. The most repeated keywords were: construction industry, which has an occurrence of 101, and followed by emerging technologies, which has an occurrence of 68.

LITERATURE

The use of digital tools and technologies to enhance construction health and safety management has grown during the past 20 years [14]. Digital technologies include a variety of examples, such as Building Information Modeling. (BIM), technology for tracking and location, Artificial Intelligence and computer vision. The potential of these digital technologies to enhance safety planning, hazard management, and safety education and training is clear.

Artificial Intelligence

The use of AI is a powerful technology with numerous potential applications that are just starting to emerge across a variety of industries. Furthermore, there are very minimal analyses that look at the factors impacting the adoption of minimal AI in the construction industry. Artificial intelligence (AI) has started to become apparent in many industries, but its popularity is much lower in the construction industry as compared to other industries [15]. Due to this low performance, different sectors have started to include AI in different processes to increase their productivity. This inclusion can provide many benefits, fewer overruns, better safety, increased productivity, and efficiency [16]. Also, AI improves automated systems, providing a competitive edge. Several types of AI-based technologies are being used in the construction industry. According to Bigham et al., [17] Artificial intelligence can be employed to optimize equipment utilization, improve construction management by streamlining information flow, and enhance construction safety. Increment in job site secutiry, improvement in safety protocols, and, reduction in safety hazards canbe enhance with the implementation of AI [18].

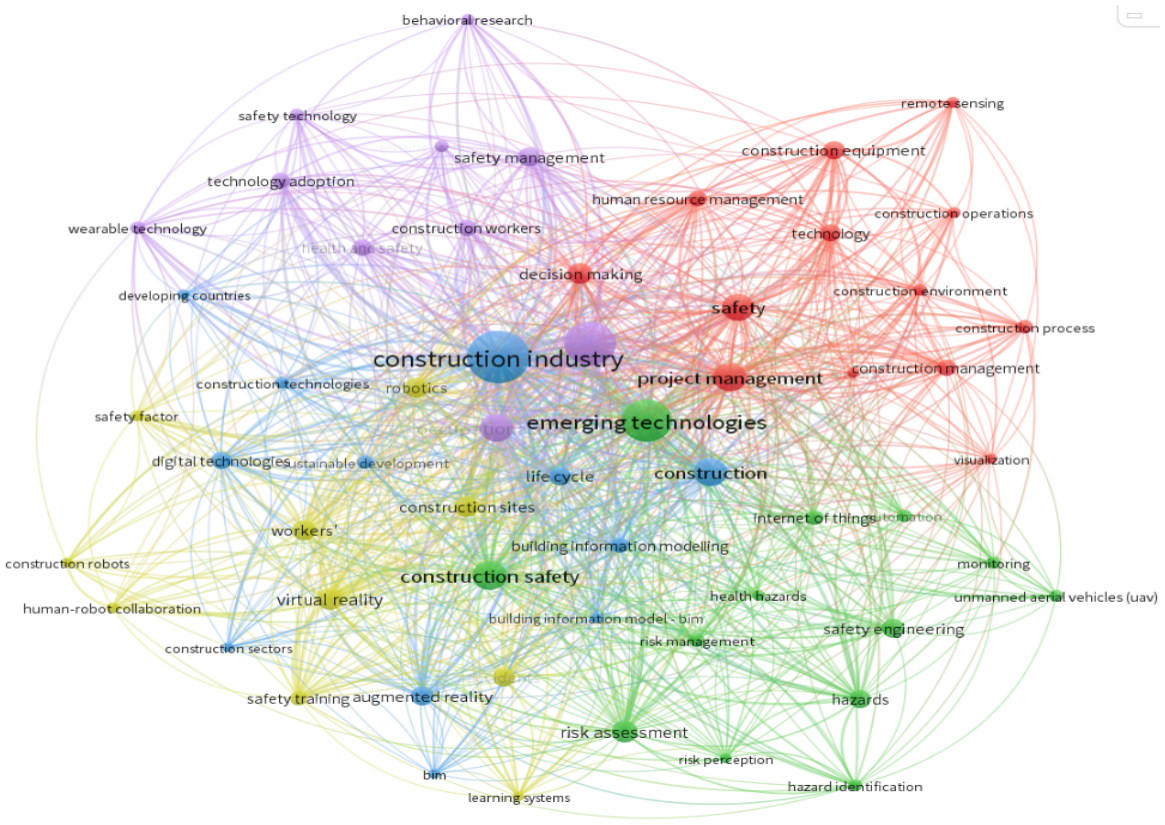

FIGURE 5. Keywords Analysis

It is widely used for the improvement in safety management [4], proper usage of PPE [19], safe monitoring of construction equipments [20], reduce number of accidents due to falling [21]. Promising possibilities for AI in construction safety management include analyzing photos and videos to identify possible safety violations, such as workers not utilizing personal protective equipment (PPE). Moreover, researchers have developed various machine-learning algorithms to serve as leading indicators. Tixier et al., [22] employed machine-learning methods, including natural language processing (NLP), to discern tendencies that result in certain safety results. The integrated AI can assist in resolving engineering challenges and making safety-related determinations, such as establishing work-related safety risk levels [23].

Building Information Modeling for Safety

Another way to handle building site safety is via Building Information Modelling (BIM) [24]. Utilizing a BIM-based safety-planning technique, which involves digitally designing and visualizing onsite circumstances, can assist safety managers in developing more effective plans. Azhar, [25] confirmed the effectiveness of utilizing BIM for generating virtual simulations to facilitate safety planning and management. Throughout our investigation, BIM demonstrated substantial efficacy in the control of cranes, mitigation of excavation risks, provision of fall safety during work on leading edges and roofs, and facilitation of emergency-response planning. Safety managers can create more efficient plans by using a BIM-based safety-planning technique, which involves digitally creating and visualising onsite conditions. The usefulness of using BIM to create virtual simulations to support safety planning and management was validated by Azhar [25], and they concluded that, BIM showed significant effectiveness in crane control, excavation risk mitigation, fall safety during work on roofs and leading edges, and emergency response planning. An automated safety tracking mobile app, a web interface for site safety visualisation and monitoring, and a cloud-based BIM system for worker tracking visualisation on a virtual construction site are all used by M. Hossain et al., [26] to find potentially hazardous regions on construction sites. According to Shukri et al, [27] BIM is a state-of-the-art method for improving safety management. It does this by improving visualisations, scheduling, cost estimation, teamwork, and clash detection.

Additionally, it offers a complete structure for managing and sharing information, with a high capacity to store vast quantities of data in BIM models [28]. By incorporating BIM into safety risk assessment, designers may effectively identify possible safety risks and develop design strategies to mitigate and decrease risk levels. This approach provides a clear framework for key activities that need to be taken during the construction process. BIM was employed to identify secure working areas and boundaries within a structure using automated inspection based on predefined rules. These data can be further examined to mitigate worker accidents [29]. The construction sector has extensively studied safety, yet it still falls short in terms of performance in this management area. Utilising BIM can effectively solve safety concerns. BIM has the potential to improve project delivery results by minimising errors, conflicts, and omissions, while also offering enhanced business development opportunities. Safety management is a critical issue within the construction sector, and research has validated the advantages of Building Information Modelling (BIM) for assurance of safety [30]. BIM-driven automation, particularly via safety information modelling, may greatly enhance safety protocols; [31] identified numerous efficient BIM features for safety management, including 3D modelling and visualisation, 4D simulation, hazard assessment tools for proposed designs, and data exchange.

Computer Vision in Safety

The multidisciplinary study area of computer vision (CV) focuses on how to teach a machine to "see." CV technology tracks, measures, and recognises using cameras and computers rather than human eyes. It converts graphics into pictures that are easier for people to view with their eyes or send to detection devices [32,33]. Growing interest has been observed in the development and application of CV technology to address safety issues in the construction sector in recent years. Additionally, there has been an increase in interest in computer vision applications in recent years to address issues facing the architecture, engineering, and construction (AEC) sector [34]. Seo et al., [35] examined CV methods for monitoring the health and safety of construction projects. The goal of the study was to assess risky behavior from both a technological and a practical standpoint. Different CV technologies must be utilised at construction sites because to their unique characteristics and the variety of dangerous conditions and behaviour. Object detection, object tracking, and action recognition are the three main types of CV-based approaches.

By utilising these techniques, construction sites may be intelligently monitored for hazardous behaviour and situations [36]. Normally, CV works in two main domains for safety. One is recognition of personal protective equipment (PPE) and unsafe behavior recognition. The unsafe behavior of workers is the leading factor behind accidents in the construction industry [37,38]. Workers' unsafe behavior is the main reason for construction accidents [39]. Unsafe behaviors are the reason for 80% construction accidents. Moreover, unsafe behavior will not only keep the person himself but other those who work with him [40]. Guo et al., [34] focused on the safety management system using CV, it highlighted the safety management system in three levels. L1 object detection, Level 2 object assessment, Level 3 object prediction.

A study conducted by Liu et al., [36] highlighted the latest usage and issues in using computer vision for construction safety purposes. This study found that occlusion is one of the biggest problem in using CV for safety, and it needs to be overcome by a more efficient system. This paper also highlighted various techniques for PPE detection, posture detection, interaction of workers, and other construction activities to avoid collisions. By thoroughly looking at the past studies, it can be stated that computer vision technology is the smartest technology in terms of automated safety in construction [41].

DISCUSSION

To deal with the many issues surrounding construction safety, a wide range of technologies have been utilised. Problems arise when trying to evaluate and compare the accuracy, reliability, and performance outcomes of the many safety technologies used in the various categories of construction. Guidelines are required for the prevalent application of technologies in addressing specific construction safety domains. The construction industry is far behind in adopting digital technologies, and this industry is also facing various issues of its safety. This study highlighted some recent technologies that have a significant impact on construction industry safety performance. From the literature, it was found that after 2021, the number of publications significantly increased. Three recent technologies have been discussed in this study: Artificial Intelligence, BIM, and computer vision.

Starting with AI, as this is the era of Industry 4.0, AI is one of the most predominant technologies for this advancement. Particularly for construction safety. Artificial Intelligence uses its intelligence with other available technologies to provide the expected outcomes. It can work with BIM, CV, and other available technologies for safety purposes. The problems in safety that can be resolved by AI are the detection of PPEs, the detection of unsafe conditions in construction sites, accident prevention due to falling, due to collision with equipment, and many others. It can be stated that with the help of AI, the overall safety management of a construction site can be improved significantly.

BIM is also one of the primary technologies during this era in advancing the construction activities, particularly in construction safety. It has been utilized in various scenarios, including Peng & Chua, [42] created a model for crane information that is used to enhance safety on construction sites. To make it easier to apply safety procedures during the building of subterranean metro rails, Malekitabar et al.,[43] developed a method for identifying safety concerns and issuing early alerts. This system utilizes BIM models. S. Zhang et al., [44] developed a method to automatically identify possible safety accidents and suggest actions to reduce their impact). It was also developed as a safety-management framework that integrated the construction timeline, a BIM model, and risk evaluation [45]. Implementing suitable precautions during the design process can help prevent many building mishaps. The limited knowledge of construction safety by designers challenges their capacity to anticipate safety concerns during the construction phase and facility management [46]. An automated safety-checking approach utilising BIM was created by Kim et al., [47]and integrated into a safety-planning platform. Using BIM helps fix a lot of issues with construction safety.

Talk about CV, nowadays it is the most practised technology in construction safety. Its methods have shown effective in quickly and efficiently retrieving relevant data from construction sites, such as the identification and monitoring of workers, supplies, and machinery [48]. It can mitigate the risk of fatalities and accidents by utilising visual data acquired from job sites [49,50]. It gained focus in construction due to its use in automating various construction jobs, monitoring construction sites, and facilitating safety and quality checks [51,52]. It can additionally automate operations that the human visual system cannot execute [53]. It can facilitate the automation of several construction management processes that presently necessitate significant human intervention for visual assessment [54]. It utilizes images and videos and then applies different techniques to generate expected outputs. Including: image classification, object detection [55], and recognition and , object tracking [56]. It can be stated that these three technologies, including AI, BIM, and CV, have potential impacts and can enhance the safety performance of construction.

CONCLUSION

This study reviewed the impact of emerging technologies on construction safety performance, with particular emphasis on AI, BIM, and CV. The findings indicate that these technologies can improve safety planning, hazard identification, risk assessment, site monitoring, and the early detection of unsafe conditions and behaviors. AI supports intelligent decision-making, predictive safety analysis, and the automation of safety-related processes. BIM facilitates the visualization of construction activities, identification of potential hazards during the design and planning stages, and improved coordination among project stakeholders. Computer vision enables automated and real-time monitoring of workers, equipment, personal protective equipment, and unsafe behaviors using images and videos.

The increasing number of publications in recent years demonstrates growing research interest in technology-enabled construction safety. However, the practical adoption of advanced digital technologies remains limited across the construction industry. Increased industrial investment, workforce training, organisational preparedness, and the creation of workable implementation frameworks are therefore necessary. Future research should focus on integrating AI, BIM, and CV into comprehensive safety-management systems and evaluating their effectiveness in real construction environments. Overall, emerging technologies have significant potential to support proactive, efficient, and data-driven construction safety management.

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