A critical review on BIM for construction safety management

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ABSTRACT

The earlier so-called "brick and mortar" industry is entering the digital era. Digitization in the construction industry gives efficient and effective ways to manage several construction aspects such as scheduling, cost, quality, information, and documentation leading to improved productivity. Along with these aspects, safety management also needs special attention in terms of digitalization, for a safer, more efficient, and productive work environment on construction sites. The Indian construction industry is known as labour intensive industry, which employs approximately 32 million of labour. The cost spent on the labour is 30% to 50% of the total project cost. Still, the labours are given the least attention in the construction sector. The bar of onsite construction accidents in India is rising at a rapid pace and it shows that current safety practices are insufficient. To manage the smooth and safer working of labour force and to reduce on-site accidents, conventional safety practices need to be replaced with advanced and digitalized safety practices. Building Information Modeling (BIM) is believed as the most prominent process that is supported by various tools, technologies for digital representations of physical and functional characteristics of a construction project. This study explores the comprehensive review of existing literature in the line of work of utilization of BIM for site safety. For the selection of literature, a well-defined methodology is adopted. It includes scientometric analysis followed by screening of the obtained results to review the most relevant literature in BIM for safety. Outcome of undertaking an extensive review would help to understand potentials of BIM for safety management, prerequisites needed to implement BIM for safety, its adoption process and also identify areas where additional research will benefit the future integration of BIM and site safety

KEYWRODS

BIM, Construction, Safety, Hazards, and Accidents

INTRODUCTION

Construction safety is one of the most critical parameters which affect the overall construction productivity. Despite being an important parameter, it is still one of the highly ignored areas in construction project management. Nowadays, automation has been observed in several construction aspects such as for effective cost management, time management, quality management; but automation for safety management is the least priority by many construction firms. Construction accidents are the most widespread issue faced by construction industries of both developing and developed countries. However, developed countries are adopting advanced technologies for reducing the rate of construction accidents. Considering developing countries like India, the rate of construction accidents is rapid. OSHA estimated that every year one in ten construction site employees get injured. The OSHA also says falling hazards are the leading cause of injury at building sites. According to the Bureau of Labor Statistics, around 150,000 injuries from construction sites occur every year. These statistics are increasing and witness insufficient traditional safety practices.

Nowadays, BIM has been considered as the most flourishing technology in the construction sector. BIM, according to the worldwide authority (http://buildingsmart.org/) stands for “A digital representation of a facility's physical and functional features (Joblot et al. 2017) Different construction phases can be procured with the utilization of BIM, such as stages of programming, design, preconstruction, development, and post-construction (Azhar, Khalfan, and Maqsood 2012).

The wide applications of BIM with dimensions ranging from 3D to nD include visual representation, clash detection, scheduling, cost management, energy consumption, collaboration and communication, facility management, safety management and to name a few (Bongiorno et al. 2019). Most of the surveys conducted for BIM awareness and adoption reported that Indian construction firms have not fully explored the potential benefits of BIM (Ahuja et al. 2020). It is also reported that the adoption of BIM in India is limited to design purposes only (CB 2020). Hence for the understanding of how BIM can be utilized for safety management, an extensive literature review is carried out. This review examines worldwide studies in the area of BIM adoption for safety management, its statistics such as leading countries, leading authors, and also summarizes with a critical review of these publications.

To recognize the functions and novelties of BIM for construction safety management, this study aims to examine recent research on the exploitation of BIM to enhance the safety of construction. The outcome of undertaking an extensive review help to understand the potentials of BIM for safety management, prerequisites needed to implement BIM for safety, integration of other technologies with BIM for safety, and its adoption process. This research also discusses areas where the potential integration of BIM and site safety will benefit from additional research.

METHODOLOGY

A significant body of literature on the subject of the application of BIM for construction safety has been reviewed. Various online platforms are used for the collection of the most relevant papers in the selected domain. Along with this, the Scopus database has been used to keep the search precise and limiting only to safety and BIM. For this search, four different keywords namely "BIM" OR "BIM" AND "Construction" AND "Safety" were used and results are refined to get the most relevant papers in the field [Figure 1]. This study includes the most recent literature on the subject published in top-ranked construction management journals. To obtain the most recent research in the field, the review time frame was limited to five years (2015 to 2021) of publication.

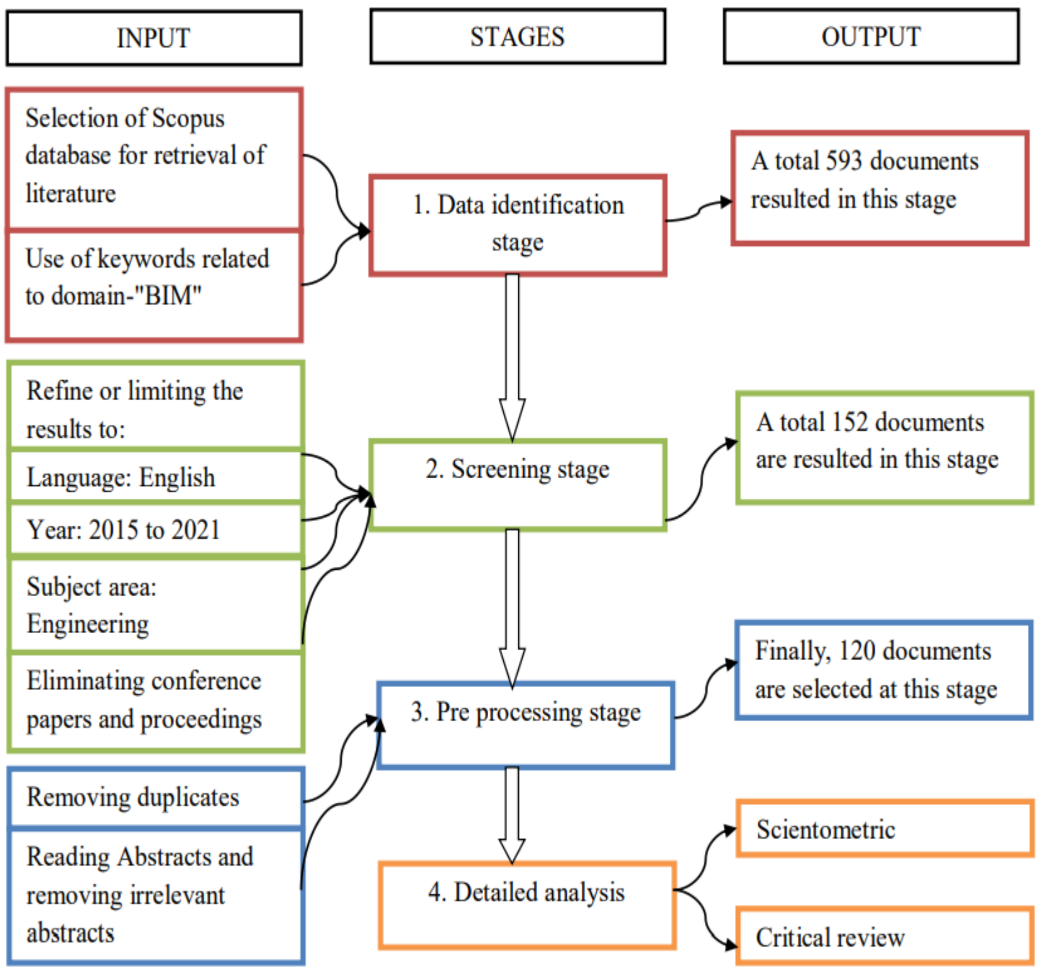

Figure 1: Methodology for selection of literature or research papers

SCIENTOMETRIC ANALYSIS OF RESULTS

The search process resulted in the most relevant documents in the selected domain. This study not only reviews the literature based on BIM for safety but also studies the scientometric analysis for resulted literature. The scientometric analysis helps to understand leading countries, leading authors, top journals in the selected domain. It examines past areas covered in the selected field and also signifies the need and scope for research in the selected domain

Leading countries in BIM and safety-based publications: A total of 120 documents are observed in the area of BIM adoption for safety management. Leading countries in this domain are the United States, China followed by the United Kingdom [Figure 2]. On the other hand a developing country such as India is in 17th position with only 3 publications. It shows that Indian researchers have a huge scope for studying the research domain under consideration.

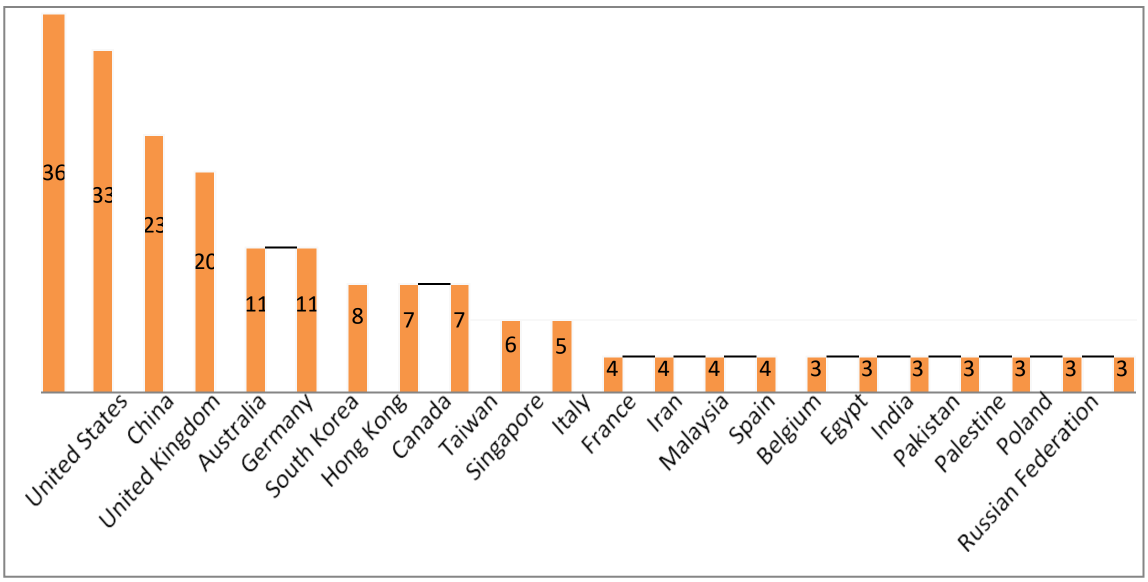

Figure 2: Country-wise publications in the BIM for safety domain (Information source: www.scopus.com)

Leading journals in BIM and Safety publications: Journals are the platforms for publishing research and are widely accessible over the internet. Papers published in peer- reviewed journals are likely to remain a very critical way of communicating research findings. This analysis also helps in identifying the productive journals that have published documents on construction safety. A network diagram is prepared for journals using tool VOSviewer [Figure 3]. Journals that appear with bigger font sizes are likely to have a maximum number of publications as compared with journals with lesser font sizes and the topmost journals can be quickly assessed by visual inspection of the changing font size. Figure 3 illustrates that 'Automation in Construction' has been observed as the topmost journal with the highest i.e. 38 number of publications. Further, the 'Safety Science' journal is in second-highest position followed by 'Engineering Construction and Architectural Management' with 13 and 08 publications. Citation wise 'Automation in Construction' journal remains on the first rank with 1135 citations followed by 'Engineering Construction and Architectural Management' and 'Safety Science' with 638 and 71 citations.

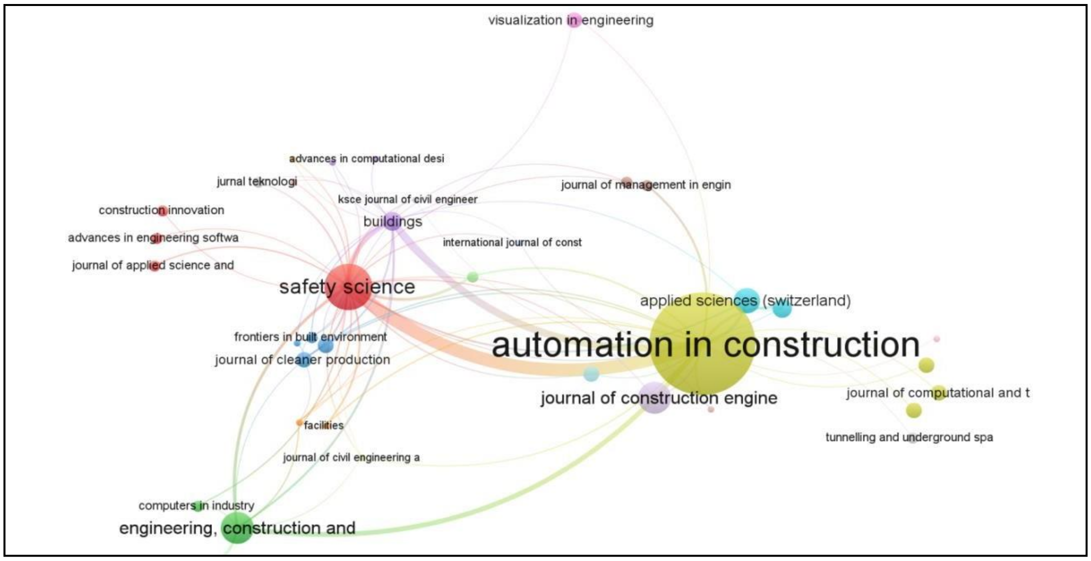

Figure 3: Network of journals that publish research on BIM for construction safety

Leading authors in BIM and safety-based publications: Researchers play an important role in leading research and some have more prominence in a subject area than others. Visualization of authors in the proposed domain is shown in Figure 4. Author names that appear with bigger font sizes are likely to have the maximum number of publications as compared with author names with lesser font sizes. Teizer has been observed as a leading author with 08 publications followed by Zhang & Kim with 06 and 05 publications. However, this list does not consider the co-authorship between these publications. Some of the documents may be co-authored by authors appearing in the same figure. In such cases, these common publications appear as individual documents for each author. For example, out of the 06 publications by Zhang and 03 publications by Eastman, 02 documents are common and jointly co-authored by Zhang and Eastman. Thus, two common publications appear in search results (by the number of documents) of Zhang as well as Eastman, as their publications. These authors have explored the adoption of BIM for safety (some with the co-authorship).

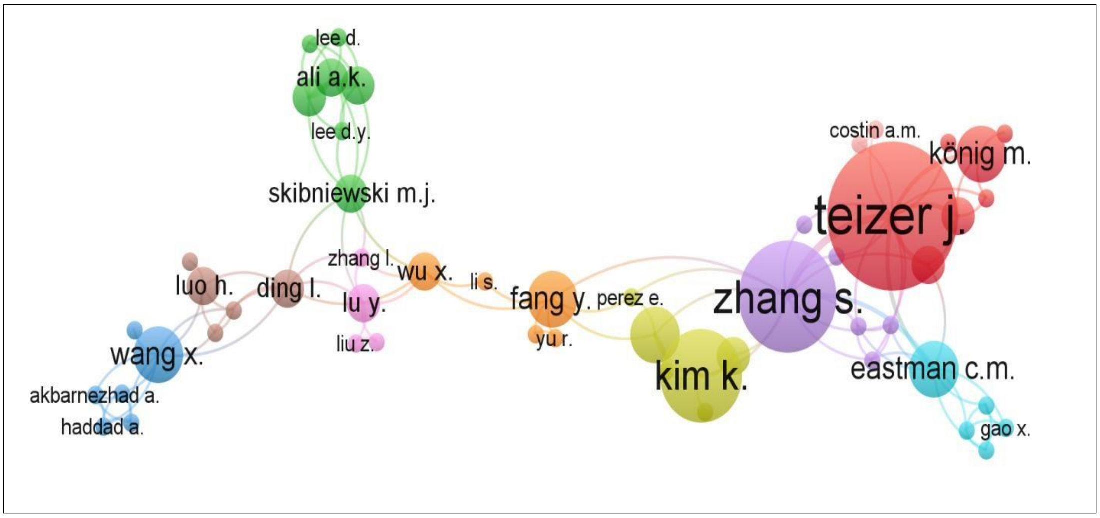

Figure 4: Network of authors name in the research of BIM for construction safety

CRITICAL REVIEW OF BIM AND SAFETY LITERATURE

BIM has been adopted widely around the globe for different construction activities. The very first publication of general adoption of BIM is observed in the year 2004 (www. scopus.com). Further, publication on the adoption of BIM for safety is firstly observed in the year 2007 (www. scopus.com). For this particular study, documents ranging from the year 2015 to date are considered. Literature retrieved from scopus database is examined and categorized according to its application. For instance, BIM for overall risk assessment, fire safety, fall safety, workspace planning, workers behavior & tracking, and also the review & survey studies. The studies show that all the categories are somehow interlinked with each other.

BIM for fall safety: Every year, as per OSHA, the largest number of deaths in the construction industry are consistently accounted for by falls. Falls also includes a variety of variables, including uneven working surfaces, misuse or inability to use fall safety systems and human error. The most frequent causes of falls from height are fallen from scaffolding (Smolarz 2019). Improper placement of scaffolding, incompetent supervisor, unsound, and insufficient scaffolds to carry their weight can lead to failure of scaffolds. With automated design, planning and drawing of scaffolding systems for building, BIM may solve these problems (Hara et al. 2019). The design method includes precise amounts of scaffold materials which helps to reduce the design effort and the cost estimating processes. Kim et al. 2018 establish a scaffolding decision-making process that produces stable scaffolding tactics with no unnecessary physical effort and compromises for other critical construction objectives, such as cost and time. This framework produces multiple scaffolding tactics automatically and assesses them in terms of protection, expense, and duration quantitatively. Kim et al. 2016 with the incorporation of job series and provisional structures into safety planning, created BIM-based automated scaffolding-related hazard detection and prevention. The algorithms were introduced as a plug-in and tested with a real-world construction project in a commercially available BIM app. Further, Zhang et al. 2015 suggested a BIM-based method of detection and avoidance of fall hazards for building safety planning. This study investigates latent fall risks that are naively introduced into the construction schedule can be recognized and prevented in the planning phase. Next, there is a discussion of a study of studies on building security and BIM. A system involving automated BIM security rule-checking algorithms were then developed. BIM-based construction safety management of buildings can analyze the problems that appeared in the management of progress early warning. Combine with the case study, the BIM constructs a visual safety management platform, 4D construction simulation, and collision detection technology. Dynamically rehearse construction progress and manage the hidden dangers such as falling and collision during actual construction progress (Xiong and Tang 2017). Excavations are also a major cause for falls on site. These falls happen due to a lack of safety warning signs around the trench or lack of barricades around the trench. To avoid these excavation hazards, Khan et al. 2019 developed a series of rules-based algorithms using a visual programming language (VPL) in commercially available software, this automatically creates geometric conditions in BIM and visualizes the construction, along with their take-off quantity and optimized positions of possible risks and security tools.

BIM for fire safety: Fires present an extreme threat to human safety, and over the past few years, several dramatic fires have been reported in under-built buildings. The majority of construction sites rely only on fire extinguishers, as there is no everlasting fire safety system in under-built buildings. A reasoned approach to preparing the installation of firefighting equipment on the construction site is missing in conventional safety planning. Fires can spread rapidly during construction. A BIM-based automated code-checking technique for fire protection in tall timber construction is developed and on the real project onset of fire regulations, it is validated (Kincelova et al. 2020). Shi et al. 2019 conducted a study on Industry Foundation Classes (IFC)-And Fire Dynamics Simulator (FDS)-based knowledge sharing for building fire safety. A quick and accurate approach to data distribution between BIM functions and broadly used fire simulation tool for fire safety research has been successfully implemented. A visual language solution implemented for the conversion of rules and a multi-agent simulation of fire safety preparation for construction. This technique has the potential to benefit designers through its simplicity and ease, although it may be beneficial for practical use in the field (Khan et al. 2020). Using a simulation of fire dynamics and agent-based modeling, Mirahadi, et al. 2019 developed an IFC-centric performance- based assessment of construction evacuations, which provides a more comprehensive measurement of safety success compared to the existing safety indices and measures of the industry.

BIM for struck by an object hazard: Around 25 percent of all fatal building workplace incidents in many developing countries contribute to the unnecessary proximity of pedestrian workers to construction machinery or hazardous materials. Golovina et al. 2019 developed advanced positioning technology that records trajectory data, while computational algorithms produce preceding inaccessible information automatically to near-miss events. The determined data is set in improved mathematical data models that can be recuperated, effectively deciphered, and adjusted by clients on a building site in current preventive risk recognizable proof and control measures.

BIM for seismic hazards: Ground damage risks from earthquakes pose a major risk to infrastructure, lifelines, and houses. To be able to reduce the risk of earthquakes, hazard detection, awareness, vulnerability, and risk assessment, mitigation and preparedness are critical. Vitiello et al. 2019 suggested a BIM-based approach to cost-optimizing existing structures with seismic retrofit strategies. A disentangled system based on a quasi-probabilistic methodology is modified in a BIM model to determine the monetary yield and financial misfortunes of a framework faced with seismic risk. BIM has likewise utilized seismic harm to building roofs and furniture for the virtual scene plan (Xu et al. 2019). First, for the consequent structural Time-History Analysis (THA) and scene building, a modeling system is developed based on BIM to construct compatible structural and scene models. The result of this study offers all-around established seismic harm scenes for indoor nonstructural segments for virtual quake wellbeing drills to be led.

BIM for workers behavior-based hazards and tracking: Existing studies indicate that hazardous activities of worker movement are one of the key causes for fatalities in construction sites resulting in severe collisions with site objects and machinery (Arslan, Cruz, and Ginhac 2019)**.** The need to enforce the construction protocol is becoming more important as construction worksites become larger and more complex. Getting a real-time monitoring system installed on a job site for materials, equipment and staff will help project managers improve safety, safety, quality control, worker logistics, and maintain a construction project's local regulations. A real-time tracking system is used to identify potentially dangerous areas by comparing workers' current paths to their optimal paths (Costin et al. 2015). Using a Real-Time Position Tracking System (RTLS) based on RFID, where RFID tags are placed on staff's hard hats, location tracking is performed (Asadzadeh et al. 2020). Lee et al., 2019 sets up a checklist for Behavior-based Safety (BBS) observation and tracks the unsafe conduct of employees. Similarly, Arslan, Cruz, and Ginhac 2019 researched BBS for worker protection by visualizing intrusions in complex building environments. The building locations where there have been intrusions using the BIM system are demonstrated. The developed framework provides a combination of systems from the data attainment stage to the simulation of hazardous job activities in the analysis of superior employee movements. Intrusion, which is unauthorized entry to unsafe areas on a building site, is one of the most significant rule-breaking practices (Shuang et al. 2019). This research examined how age and gender have an effect on different types of construction site intrusion behaviors. The study shows that male site workers were more resistant than females to intrusion. Middle-aged workers had substantially greater intrusion frequency for both genders than younger and older employees.

BIM for workspace planning: Due to congested site conditions, safety and productivity performances are often low. Parn et al. 2019 researched the digitization of work safety management in enclosed spaces. The goal of this paper is to report on the further creation of a BIM-entitled confined space security monitoring framework plug-in for a hybrid Application Programming Interface (API). Further, Zhang, et al. 2015 presented a model with workplace position monitoring to visualize and evaluate workplace specifications in BIM. This approach uses remote sensing and workspace modeling technologies to create automated workspace visualization in BIM and is an important component of building safety planning. The hard hats of a work crew building cast-in-place concrete columns were connected to the Global Positioning System (GPS) data loggers. By simulating a building process using both interactive virtual reality and BIM technologies, BIM has also been adopted for building workspace planning (Getuli et al. 2020).

BIM for safety risk management: Risk management is the recognition, measurement and choice for risk reduction (Reddy 2015). Considering safety, the earliest detection of hazards will minimize loss of life, property, and save time and expense as well. Before commencement of construction, risks can be recognized, primarily through the planning and design phase (Li, Yu, and Liu 2018). Kim, et al. 2020 for automating construction site risk assessment, developed a methodology for BIM-based hazard identification and evaluation. This research analyses the stage-wise tasks needed for more automated BIM-based construction safety planning. Many of the associated hazards are identified in the risk analysis stage and the associated risks are analyzed and quantified. The identification of risk can be through the design as well (Yuan et al. 2019). The concept of Prevention through Design (PtD) helps to focus onthe safety of the workers in the life cycle during the project's design phase. Documentation, construction unsafe conditions and their pre-control steps were identified and gathered in a PtD knowledge base about current safety laws. Similarly, during the design process, Jin et al. 2019 , built a system for evaluating construction risks using 4D BIM. This approach has the potential to determine the safety risk and forecasts the safety risk in a particular period, workspace, and mission before construction for an entire high rise project. It allows designers to conduct risk assessments and select alternatives for safety-related architecture. Cortés-Pérez, et al. 2020 developed the methodology for integration in the design process in compliance with the criteria stipulated by the Spanish health and safety regulations.

BIM for safety training, inspection and monitoring: Safety education and training are vital tools for training individuals and managers about workplace risks and controls so that they can function more quickly and more effectively. However, another role for education and training is to give employees a better understanding of the safety and health program itself, so that they can contribute to its growth and implementation. Training with advanced teaching methods such as visualization and simulation will allow employees to better understand danger conditions than conventional teaching methods (Clevenger, et al. 2015). Ahn et al. 2020 examined two unlike types of safety training methods, representing the actual site's hazard status. It was stated that employees trained through BIM simulation showed a greater degree of understanding than the group of employees who were conventionally trained. To recognize hazardous conditions and protect workers from possible injuries and catastrophic events, sites need to be constantly monitored in light of safety inspection and surveillance. BIM can regulate the safety of construction sites (Wu, Lu, and Hsiung 2015). In the construction site performance evaluation, integrated systems with Bluetooth Low-Energy (BLE)-based position tracking technology, BIM-based hazard identification and a cloud-based communication network will assist and potentially improve site safety (Park, Kim, and Cho 2017). Similarly, the Wireless Sensor Network (WSN) and BIM have been implemented as a groundbreaking feature that enables the construction site to visually control the safety status via a visual, coloured interface and remove any dangerous gas automatically (Cheung et al., 2018). Along with this, Unmanned Arial Vehicles (UAV) and BIM can also used for safety monitoring on different construction projects (Alizadehsalehi et al. 2018)

Review and survey based studies on BIM adoption for safety: This category describes the review studies and surveys held in the domain of BIM for safety. Review papers are very significant in terms of research as it helps to understand past studies available, different methodologies and approaches adopted by various authors, need and scope for the study in the domain in single research paper. In this context. Fargnoli et al., 2020 reviewed different literature available in the proposed domain and categorized it into knowledge-based systems, automated safety regulation, safety design, information scheduling, resolution of overlaps and disputes, safety preparation, as well as expectations of stakeholders.Similarly, a science mapping approach (R. Jin et al. 2019; Akram et al. 2019; Sadeghi et al. 2016) was adopted for exploring the review of BIM for construction safety. To gain a deeper understanding of research advances in safety initiatives. Martínez et al., 2018 studied a systematic review in the proposed domain. It has also conducted a scientometric analysis followed by review of available studies. Available studies were categorized according to their utilization in different construction phases [Figure 5]. Maximum study, mainly in the construction process, was documented to concentrate on the adoption of BIM for protection. The key results suggest that the rising introduction of BIM in the AEC sector is changing the approach to defense. It is possible to automatically classify potential safety hazards and use an automated approach to implement appropriate preventive methods.

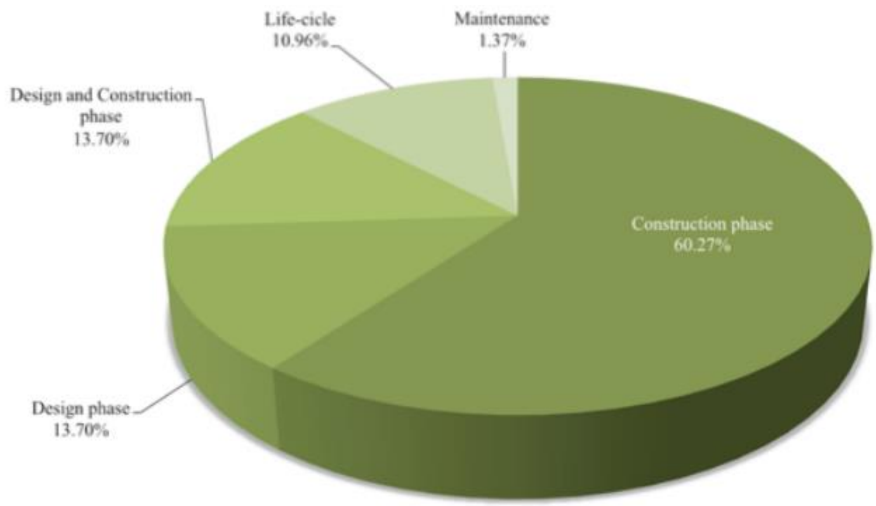

Figure 5: Percentage of publications of adoption of BIM for safety as per project phases [45]

As explained in the section of BIM for risk management, risk can be identified through design. In this context, Hossain et al. 2018 conducted a systematic review of studies on design-for-Safety knowledge library for BIM-integrated safety. Similarly, on BIM and BIM-related technologies for risk management, Zou, et al., 2017 conducted a systematic review. It offers an overview of traditional risk management and a detailed and systematic review of published literature on existing risk management strategies using technologies such as BIM, automated control of regulations, knowledge-based systems, information technology-based reactive and proactive security systems. The search tool used for this research indicates that a large number of studies are based on the survey questionnaire. These studies collect perceptions of stakeholders, employees(Han et al. 2019), students (Swallow and Zulu 2019b) and various construction professionals on applications, barriers, benefits and awareness of BIM for safety in different countries (Marefat, Toosi, and Mahmoudi Hasankhanlo 2019; Swallow and Zulu 2019 . Enshassi, et al., 2016 , conducted a survey in the Gaza strip on the adoption of BIM for the improvement of construction security, including its visibility, applications and barriers. In order to improve safety, the scarcity of widespread use in the construction industry and the insufficient availability of training are the main obstacles to the implementation of BIM in construction.

CONCLUSION AND FUTURE SCOPE:

This review study adopted a scientometric approach to identify the most relevant researches in the field of utilization of BIM for safety. According to the review of literature, it can be stated that BIM can be used for construction safety management with a variety of applications in different kind of hazards such as for fall safety, fire safety, struck by an object hazard, seismic hazards, workers behavior-based hazards and tracking, workspace planning, overall safety risk management including identification of risk at the design stage, safety training, inspection, and monitoring. This study also examined past reviews and survey-based studies on BIM adoption for safety. It can be stated that BIM has the capability for identification of hazards, automatic safety checking, simulation, and information management, and to name a few. One of the major advantages of BIM for safety is that it can identify the hazards at the design stage, i.e. before construction. It saves time and cost also reduces rework. It has all the capabilities that cover the insufficiencies of traditional practices. It is a single platform for information management which is most critical for sharing the risk information to different people involved in the process. With its collaboration and communication applicability, it helps for better decision making. It is also observed that various technologies such as GPS, GIS, sensor-based technologies, safety rules have been integrated with BIM for construction safety management. One of the benefits of these integrations is that with a combination of two or more different technologies, a single system can be formed that can provide better safety solutions on a common platform.

Looking at the scientometric data from Scopus, it is observed that very negligible studies are available in India for the utilization of BIM for safety. Despite having major applications for safety, it's not fully explored in India. Indian construction firms have adopted BIM majorly for design and drawing purposes only, and need to take a step forward in implementing BIM for safety as well. It can be reported that there are a need and scope for Indian authors to research in the domain. This need is not only limited to conducting research but also implementing it practically to the sites to reduce the number of construction accidents.

Falls being the major cause of accidents on construction site, majority of the studies on BIM- based safety planning are focused on fall safety management. It is necessary to utilize BIM benefits for other types of accidents occurring on a typical construction site. For effective life cycle management, application of BIM-based safety planning should not be limited to the pre-construction phase only. It should be adopted for construction as well as post-construction phase. For future work, designing BIM-based safety solutions for real-time accidents can be considered.

Most of the review studies also show that lack of awareness of BIM benefits along with return on investments, lack of expertise, lack of training, and lack of BIM standards are the barriers in BIM adoption as well as practicing safety using BIM applications. Indian firms require standard guidelines and mandates by the government that can majorly contribute to successful BIM adoption. The study also revealed that more realistic BIM implementations are required, with a focus on safety training and education in particular. It should be noted that the current review is constrained to selected literature published in the Scopus database and that only English journal papers in the final publication phase were included. Any recent research conducted in other languages or other forms of papers, such as conference proceedings may theoretically be removed.

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