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Exploring the Role of BIM in Construction Safety in Developing Countries: Toward Automated Hazard Analysis

Ramsha Akram [1], Muhammad Jamaluddin Thaheem [2,*], Shamraiza Khan [1], Abdur Rehman Nasir [1] and Ahsen Maqsoom [3]

1 Department of Construction Engineering & Management, School of Civil and Environmental Engineering, National University of Sciences and Technology (NUST), Islamabad 44000, Pakistan
2 School of Architecture and Built Environment, Deakin University, Geelong, VIC 3220, Australia
3 Department of Civil Engineering, COMSATS University Islamabad, Wah Campus, G.T Road, Wah Cantt 47040, Pakistan
* Correspondence: jamal.thaheem@deakin.edu.au

Abstract: Safety is a well-researched yet underperforming management aspect of the construction industry. Building information modeling (BIM) can help, and some frameworks have addressed safety management in limited phases of the project lifecycle. This study positions BIM centrally in the safety management process and develops a safety management framework that covers the entire lifecycle of a construction project in the context of developing countries. A systematic literature review is conducted to identify the safety factors and BIM features that are synthesized to devise BIM-based safety improvement strategies. The strategies are presented to construction management professionals from developed and developing countries through an online questionnaire survey, and their level of agreement is identified. Afterward, construction safety experts are engaged to integrate these strategies into appropriate lifecycle phases. Additionally, these experts are also engaged to develop an automated hazard recognition process to leverage BIM potential in safety management. The integration of strategies into project lifecycle phases resulted in a comprehensive safety implementation framework leveraging the BIM platform. This framework takes a lead from the experience of developed countries and considers the limitations of developing countries in terms of resources and technology. Furthermore, a BIM-based process map for hazard identification is developed. The process map takes the BIM model as input and provides a detailed safety report. The process map can be automated to enhance effective safety management. This study expands the body of knowledge through a BIM-driven lifecycle safety management framework for developing countries where BIM adoption is still in its early stages. It is a fresh take on safety automation to make the construction industry safer and more reliable. However, it is limited due to inadequate safety reporting and documentation in developing countries. Future research can improve upon this limitation by positioning in a safety-compliant culture.

Keywords: construction safety; safety management; BIM; automation; process map

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1. Introduction

The construction industry is vast and dynamic and engages millions of employees worldwide [1]. However, the frequency of accidents in this sector undermines its reputation, calling for attention to safety concerns and their implications [2]. Many statutory bodies—such as the Occupational Safety and Health Administration (OSHA) in the USA, the Health and Safety Executive in the UK, Safe Work Australia [3], and the Labor Department in Hong Kong—strive to develop safety policies and enforce regulations. Despite these efforts, the safety state of the construction industry is still alarming. According to the Bureau of Labor Statistics [4], the construction site accident rate has increased from 15% to 19% in the past five years in the UK. Similarly, worker fatalities in construction were

15% of all the work-related fatalities over the period of 2003 to 2005 in Australia [3]. The state of construction accidents in developing countries is even more alarming, and, making matters worse, the standard recording and notifications systems for construction accidents are either absent or dysfunctional [5,6].

Past research has revealed many factors behind this dismal state, such as the lack or poor enforcement of safety rules and regulations, the lack of proactive measures for accident prevention such as safety training, and improper hazard identification and control [1,2]. Due to the unique and dynamic nature of construction projects, the manual application of safety processes becomes overly taxing since it involves excessive planning, monitoring, and resource utilization. Therefore, it is desirable to have technological support which can assist in automatically analyzing safety issues and providing potentially viable solutions. Thus, such technological intervention automates safety management in construction projects.

From a handful of potential technological solutions supporting construction projects, building information modeling (BIM) is a promising advancement [7]. Eadie, Browne, Odeyinka, McKeown, and McNiff [8] perceived considerable positive impacts of BIM on project performance throughout its lifecycle. For instance, BIM can facilitate information management from concept to closure of a project for terrestrial data, building components, materials and their specifications, spatial relationships, costs, and temporal information [2,9]. It is also useful for facility management in addition to project development. Alongside many other features, BIM can manage safety during the project lifecycle, addressing several safety issues [10].

Rodrigues, Estrada, Antunes, and Swuste [11] realized that the ideal time to improve safety is during the conceptual and design phases of a project. This ultimately curtails the effort to influence safety later in the project. Therefore, it is necessary to address safety at the initial project stage by Prevention through Design (PtD) which emphasizes the safety measures in the design phase to eradicate hazards that may occur later. Akram, Thaheem, Nasir, Ali, and Khan [12] identified safety training and planning, PtD, job hazard analysis, site equipment layout planning, and accident analyses as major areas for BIM application in construction safety. Other than a few studies investigating the suitability and applicability of BIM for safety management [2,11,13,14], the body of knowledge lacks holistic and self-organizing research which may utilize BIM to allow component-level visualization and decision making regarding safety [12].

A major challenge for any BIM-driven solution is the lower diffusion of the enabling environment of BIM as a core decision support system. This challenge is much more pronounced in developing countries due to their poor economies, low interest margins, lack of collaboration between academic or industrial researchers and practitioners, and an overall lack of enthusiasm toward technology adoption. Under such a grim state of practice, if research on BIM-based safety management is to yield satisfactory solutions, the level of BIM adoption must be holistic in terms of technology, process, and people to achieve practical advantages [15]. Simply put, if the platform on which safety improvements will be implemented is missing, no solutions can be effective. Past studies report an incoherent trend of BIM adoption. Several organizations, especially in developing countries, have not adopted BIM as a technology, and very few have reached the level of integrated BIM [16]. This highlights the need for a holistic framework for organizations that are willing to comprehensively adopt BIM for safety management. Furthermore, organizations that have adopted BIM need a proactive approach to achieve safety through automation.

To fill this research gap, the current study proposes a BIM-driven conceptual safety management framework in the construction organizations of developing countries that encompasses the entire project lifecycle. In doing so, the strategies for BIM-based safety improvement are synthesized through a systematic literature review and expert opinion. To bridge the gap between developing and developed countries, expert opinion is gathered from all over the world. The involvement of global experts helps propose a technologically robust as well as realistically attainable solution to automating safety management. As a result, the organizations currently using BIM can benefit and enhance their safety practices with the development of an automated concept. For this purpose, taking a lead from [12], a process map is formulated to act as a blueprint for developing a BIM plugin for integrating safety data in an automated platform. The findings may help building professionals in appreciating the role of BIM in construction safety and helping them accomplish the basic requirement of BIM adoption. Moreover, this could facilitate application developers in automating the BIM-driven safety management process, paving the way for the development and integration of BIM tools for enhanced safety. This research can facilitate organizations in improving safety, but this solution is not proposed to replace all existing solutions for improving safety in the construction industry. Rather, the proposed solution complements the existing solutions in paving a way for safety improvement. Furthermore, the adoption of BIM will facilitate various aspects of construction practices.

2. Literature Review

To identify the prominent attributes across the BIM and safety management domains, a systematic literature review is carried out with a focus on the BIM implementation process, safety factors, and BIM features along with their associated strengths. Based on the most significant factor–feature relationship, automation strategies are synthesized to improve safety management through BIM. This factor–feature approach is sourced from a recent study on BIM [17].

2.1. BIM Implementation

The implementation of BIM can be theoretically explained in terms of the socio-technical approach which considers the application of technology along with socio-cultural aspects like people and the process of technology adoption [15]. In socio-technical terms, BIM implementation requires considerable changes in the associated organizational processes [18]. Eadie, Browne, Odeyinka, McKeown, and McNiff [8] highlighted substantial organizational impacts on BIM implementation for all stages of the construction process. They concluded that such an implementation may impact all the processes within the project organization and, therefore, cannot be treated in isolation as a software tool. Previous studies have considered different factors of BIM implementation, including people, processes, technology, policies, information management, and training [8,18]. Kouch, Illikainen, and Perälä [19] concluded that the most recurring and demanding factors to consider in BIM implementation are people, process, technology, and policy. Malik, Nasir, Muhammad, Thaheem, Ullah, Khan, and Hassan [7] have also identified the areas that need attention and proposed improvements for BIM implementation.

There are many barriers to BIM implementation, including legal and contractual limitations [20], team incompetency, the high cost of implementation, a reluctance to adopt new technology [7,21], and risk transformation [9]. Due to these inherent limitations, there is a region-wide variation in BIM adoption and maturity levels [16]. Therefore, the current study tried to address this region-wide variation with the help of a global survey that involves respondents from developed countries where the level of BIM adoption is higher than the respondents from developing countries that are still struggling with implementing BIM. Such a distribution of respondents was thoughtfully chosen to achieve a solution that can be implemented but is not over-simplistic. Thus, the trade-off between convenience and robustness is tilted toward robustness.

It may be questioned why a study on BIM-based safety management is concerned about the level of BIM adoption. It is because BIM is an enabler for the findings of the study to function. Therefore, while addressing construction safety, the BIM implementation roadmap [18] has been examined and viable strategies have been extracted to provide holistic as well as realistic support to improve the state of safety.

2.2. BIM Application in Safety Management

BIM can transform project performance in all stages of the project lifecycle, including planning, design, construction, and facility management [21]. BIM can enhance project delivery outcomes by reducing mistakes, conflicts, and omissions, and provide better business development. Safety management is considered an important issue in the construction industry, and research has established the advantages of BIM for safety management [22]. Chan, Leung, Fung, and Leung [23] highlighted that safety can be effectively improved by BIM-based automation in the form of safety information modeling. Akram, Thaheem, Nasir, Ali, and Khan [12] found some efficient BIM features for safety management, including 3D modeling and visualization, 4D simulation, tools for examining the risks and safety of proposed designs, and data exchange. Similarly, Enshassi, Ayyash, and Choudhry [2] found hazard identification and minimization as well as safety training and education as the two most significant safety-related BIM applications.

A thorough understanding of safety risks plays a significant role in project design by realizing automated BIM-based risk identification [9]. Zhang, Boukamp, and Teizer [24] proposed a construction safety ontology for safety management and analyzed its association with BIM. They performed an operative and dynamic inquiry of safety knowledge and took a major stride toward automated safety planning. Zhang, et al. [25] advanced it by developing a framework that includes automated safety rule-checking algorithms for BIM and tested the prototype on different case studies which showed that BIM-based modeling and 4D simulation improve the safety logistic procedures. Further, Rüppel and Schatz [26] presented the use of 3D modeling to generate game content that can analyze the behavior of workers in case of hazardous conditions. The idea was to create a realistic scenario effectively using BIM. This association of BIM and game content allows different stakeholders to simulate different situations and observe their reactions.

A recent review by Akram, Thaheem, Nasir, Ali, and Khan [12] of BIM applications in safety management has revealed that much of the previous work is focused on the design and planning stage of a project while relatively less work has been carried out in other project stages. To expand upon this, the existing frameworks have been analyzed, as given in Table 1. Observing their coverage of the project lifecycle, it is found that these frameworks focus on the design and planning, and execution phases. Moreover, save for Zulkifli, Takim, and Nawawi [27], all the frameworks focus on a single phase of the entire project lifecycle. Whereas it is effective to be a specialist and focus on a particular phase, this approach results in a lack of holistic coverage of critical lifecycle phases from a safety planning, management, and implementation point of view. Furthermore, the framework of Wetzel and Thabet [28] is the only one that supports safety maintenance and repair practices during the transitionary phases of project closure and operations and maintenance. It is important to note that no article could be found covering the project initiation phase. This is partly because the planning and initiation phases are interrelated, and the authors may have treated them collectively. Moreover, since the project initiation occurs on an organizational level and decisions are on a strategic level, its impact on safety may not have been realized from the perspective of BIM. However, project planning is an operational process. That BIM and safety are also operational explains why articles mostly cover the planning phase. Despite this reassurance, it points to a missing link between the integration of BIM implementation aspects and safety management throughout the project lifecycle. Therefore, the current study includes the entire project lifecycle by considering different socio-technical aspects like people, process, technology, and policy, as suggested by Kouch, Illikainen, and Perälä [19], in configuring strategies for BIM-based safety management.

Table 1. BIM application in safety management.

Reference	Project Lifecycle				Summary
	Initiation	Design and Planning	Execution	Closure/O&M	
Azhar and Behringer [29]			✔		A framework to explore the advantages of BIM in providing site safety plans and communicating them using 4D simulations and 3D rendering and walkthrough.
Park and Kim [13]			✔		A safety management framework to integrate BIM, AR, location tracking, and game technologies to improve the identification of field safety risks.
Hayne, Kumar, and Hare [30]		✔			An interactive digital teaching tool to educate and disseminate design for safety knowledge using BIM.
Zhang, Sulankivi, Kiviniemi, Romo, Eastman, and Teizer [25]; Zhang, Teizer, Lee, Eastman, and Venugopal [31]		✔			A safety rule-checking system to identify fall-related hazards during the design and planning stage.
Wetzel and Thabet [28]				✔	A framework to support safety maintenance and repair practices through hazard identification, processing the identified data, and rule-based decision-making.
Zulkifli, Takim, and Nawawi [27]		✔	✔		A basic theoretical framework for the Malaysian construction industry for automated rule-based checking during the planning and execution phases.
Getuli, Capone, and Bruttini [32]			✔		Standardized protocols using BIM and VR integration for providing safety training to workers on construction sites.

2.3. Synthesis of Safety Factors and BIM Features

To synthesize safety factors and BIM features into a matrix, an in-depth review of relevant peer-reviewed articles was carried out. As a result, 18 factors of safety along with 18 features of BIM that support safety practices were extracted. Their relationship in a factor–feature matrix was developed for the identified attributes of BIM and construction safety, as given in Table 2. The strength of the associations was calculated based on the frequency of occurrence in the literature on a 10-point Likert scale such that negligible = 0; low = (0, 3); medium = (3, 5); high = (5, 7); and very high $\geq$ 9.

The matrix demonstrates that owing to a very high frequency, hazard recognition has a strong link with visualization, which highlights the effectiveness of this feature in improving safety conditions and enhancing safety practices. Visualization is considered a valuable tool for encouraging safe practices [33]. Golparvar-Fard, Peña-Mora, Arboleda, and Lee [34] criticized traditional means for their ineffectiveness in forecasting the actual jobsite conditions, which makes it difficult to manually identify safety hazards and educate the workers accordingly. Particularly, the increasing foreign or illiterate local workforce needs a clear visual and pictorial demonstration of safety hazards to adequately assess jobsite conditions [13,14]. Likewise, Afzal and Shafiq [35] demonstrated that 4D-based BIM visualization improves knowledge exchange in a multilingual work environment where jobsite workers cannot understand safety instructions written in a common language. In developing countries, such a low-literacy workforce is quite common, increasing the need for innovative ways to provide health and safety education [2,32,33,36].

Table 2. Factor–feature matrix.

Factor–Feature Matrix	**Features of BIM**	**3D Imaging/Rendering**	**Real-time Monitoring**	**Clash Detection**	**3D Walkthroughs**	**4D Simulations**	**Visualization**	**Automated Rule-based Checking System**	**Constructability Review**	**Facility Management**	**Location-based Sensing**	**3D Animation**	**Databases**	**5D Simulation**	**Data Sharing/Coordination**	**Design Review**	**Structural Analysis**	**Risk Management**	**Cost Estimate/Quantity Takeoff**
Factors of Safety	Frequency of Occurrence																		
Hazard Recognition	Frequency of Occurrence	3	5	4	2	5	9	6	0	1	3	2	1	0	1	1	1	2	0
Coordination of Work Tasks		1	1	0	1	2	2	0	0	0	2	1	0	0	0	0	0	1	0
Conformance to Standards		1	0	0	0	0	1	2	0	0	0	0	0	0	0	1	0	0	0
Safety Training		2	1	0	1	0	4	0	0	0	0	2	0	0	0	0	0	0	0
Safety Planning		1	0	1	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0
Worksite Safety		0	2	1	0	2	3	1	0	0	3	0	0	0	1	1	0	1	0
Facility and Maintenance Phase Safety		1	0	0	0	0	2	1	0	3	0	0	0	0	1	0	0	0	0
Design for Safety		1	0	1	0	0	2	2	1	0	0	0	0	0	0	1	0	0	0
Accident Investigation		1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Job Hazard Analysis		0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0
Hazard Prevention		1	4	3	0	1	4	4	0	1	3	2	1	0	2	1	1	2	0
Safety Codes and Regulations		0	1	1	0	0	2	5	0	0	0	0	0	0	0	0	0	1	0
Safety Cost		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Structural Safety Analysis		1		0	0	1	1	0	1	0	0	0	0	0	0	1	3	0	0
Safety Risk Analysis		1	1	2	0	3	1	1	0	0	0	0	0	0	0	0	0	1	0
Activity Execution Workspace Management		0	1	1	0	1	1	2	0	0	1	0	0	1	0	0	0	0	0
Behavior-based Safety		0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Environmental Monitoring		0	1	0	0	1	1	3	0	1	1	0	1	0	0	0	0	0	0

Further, hazard detection is essential because construction tasks inherently involve risks, and their knowledge is as important as the need to prevent accidents. Hazard prevention also attained a significant position among safety factors with a high frequency of occurrence because once the hazards are identified it is necessary to develop prevention strategies by following safety codes and regulations and providing appropriate training to workers. This helps in reducing interruptions and compensations in projects [27,37,38]. Such practices can support safe work performance and execution of activities which consequently prevent hazards.

Safety training can also be carried out efficiently by visualization since it helps eradicate language and literacy barriers [2,32,33,36]. In another study, safety training was provided to a group of construction management students for testing the effectiveness of the visualization approaches and their applicability to industry practices. Students were encouraged to share their post-training observations and feedback on following traditional as well as visualization techniques. The results were significantly positive for the use of visualization techniques [39]. In addition, most recently, safety animations with voice-over in local languages have been tested to successfully sensitize construction workers to several hazards on construction sites and their remedies [2,32,33,36].

Conversely, automated rule-based checking is an essential feature that can affect many safety factors resulting in a safe work environment. A fall is the most occurring hazard on construction sites and for height-related risks, Benjaoran and Bhokha [40] developed a rule-based system. Factors such as element type, size, placement, activity, and accident type were used as inputs. The system was found useful in identifying hazards and recommending safety measures. Similarly, real-time monitoring is also considered effective for construction safety. Traditionally, construction sites are monitored manually by safety inspectors. However, this process is time- and resource-intensive, and error-prone [41,42]. Real-time location system monitoring is effective in identifying and tracking the position of resources such as personnel, materials, and equipment [43]. Another important and key application of real-time monitoring is jobsite monitoring for safety augmentation [41]. Hazard recognition can also be performed using real-time monitoring and location-based sensing. Thus, hazards can be prevented through observations.

Asadzadeh, et al. [44] studied the consistency of localizing and monitoring the construction resources by using an automated sensor-based safety management system. It was established that sensing and tracking assets on construction sites saves time for safety monitoring and can be proactively used to prevent accidents by notifying workers of an incoming hazard. Furthermore, the inappropriate use of personal protective equipment (PPE) causes many injuries and casualties. Therefore, Dong, Li, and Yin [45] developed a system for the automatic identification and assessment of PPE by integrating pressure sensors and localization technologies in BIM. The system can track a worker's location and dangerous situations, send warning signals, and assess the location where PPE is necessary. It also provides feedback for hazard prevention.

It is interesting to see that BIM is sufficiently capable to address all the major safety concerns experienced by construction practitioners. Technological development has positioned BIM centrally for effective safety management in the construction sector. However, how these features will be realized at the lifecycle scale in a construction project has not been fully explored. In the absence of such a framework, practitioners can only appreciate the technological and scientific advancements realized by the researchers but cannot apply these advancements in their projects to obtain the required improvement in safety management. To fill this gap, the current study provides an applied framework offering a configuration of strategies based on the safety-supporting features of BIM at the project lifecycle scale to help facilitate the uptake of BIM for safety management.

3. Methodology

The current study is performed in four phases as graphically shown in Figure 1 and explained below.

3.1. Research Motivation and Design

The primary step was to critically review recent publications that showed the relevance and importance of BIM. This helped to identify a research gap, bringing attention to safety management. It was hypothesized that safety management can benefit from BIM. Previous studies provide an impetus for more research by emphasizing BIM-based safety implementation. However, the lifecycle perspective and automation guidelines are missing. Considering this gap, objectives were formulated which involved determining the attributes of BIM and safety management and their relationships. To accomplish these objectives, a comprehensive literature review was performed, expert opinion was gathered, and strategies were synthesized to design the framework for BIM adoption in the project lifecycle for safety improvement. Although this was not a BIM implementation framework, it addressed the barriers to BIM adoption in the construction industry generally and to developing countries specifically, paving the way for BIM-based safety management. The motivation to address this extensively researched phenomenon came during the engagement with BIM experts spread across the world who reported differing levels of BIM adoption in their organizations.

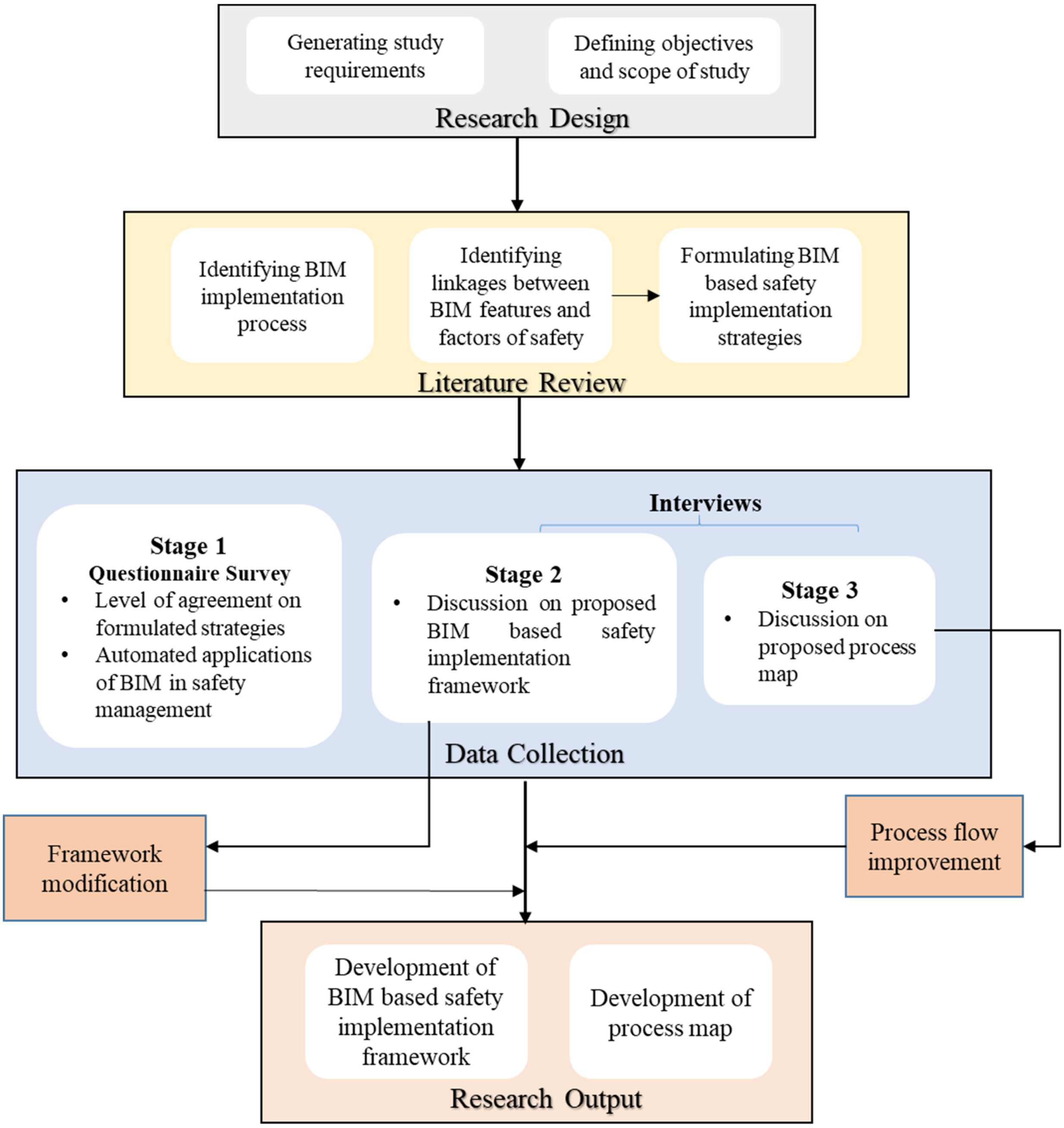

Figure 1. Research methodology.

3.2. Literature Review

Upon formulating research objectives, an extensive literature review was conducted. For this purpose, articles were searched for using the keywords "Building information modeling" OR "BIM" OR "Building information modelling" OR "Automation" AND "Safety management" OR "Construction Safety" OR "Safety" using different databases including Scopus, Web of Science, ScienceDirect, ASCE library, and Google Scholar. Initially, this resulted in 382 articles starting from the year 2010 to March 2021. All duplicate and irrelevant articles relating purely to health and safety were removed, resulting in

220 remaining articles. The articles in a language other than English were also removed. The abstracts of the remaining articles were carefully studied to understand the scope and purpose of the research. All those articles not dealing with the scope of the current study were removed based on their content. This provided 74 relevant articles for further study and for extracting factors of safety, features of BIM, and their relationships. Content analysis, which is a systematic process of reviewing literature and extracting required information to systematically examine a large amount of textual data [9,46], was performed to identify the significant attributes. Afterward, the strength of the relationship between safety factors and BIM features was assessed through a factor–feature matrix. Finally, the strategies to encourage BIM-based safety applications were extracted from the literature. For this purpose, research articles previously used for extracting BIM features provided a starting point, but some new articles were also used to source the strategies. Interestingly, none of the published frameworks provided any strategies incorporated into the current study. This is mainly because of the limited focus of the previous frameworks and basic-level BIM applications. The extracted strategies were refined through expert opinion. For this purpose, 4 safety experts were engaged who suggested improvements keeping in view the local conditions as well as BIM adoption levels. Since implementing BIM is essential to adopting safety improvements, protocols for BIM adoption and its implementation were also studied.

3.3. Data Collection and Analysis

Data collection was performed in three main stages as shown in Figure 1. A participatory approach was employed for data collection in the form of an online questionnaire survey and data validation through interviews. A survey form was developed using the synthesized strategies to collect the opinion of industry and academic professionals on BIM and its application in safety management. The survey contained two sections: section 1 inquired about a respondent's demographic and organizational information, and section 2 contained short questions to find the level of agreement upon identified strategies on a 5-point Likert scale (1 = very low and 5 = very high). Keeping in view the maturity level of various organizations, the strategies were divided into two parts: the first part contained basic-level strategies for organizations with a lower BIM adoption. Such organizations were hypothesized to mainly belong to developing countries. However, there could be organizations with lower BIM adoption from developed countries as well. The second part consisted of short and multiple-choice questions to improve the safety conditions using advanced BIM applications. This division of different levels of strategies helped in addressing safety problems for organizations as well as for countries that have varied BIM maturity levels. Respondents were encouraged to provide additional strategies through an open-ended question.

After data collection, the reliability, normality, and correlation of data were checked using Cronbach's alpha, Shapiro–Wilk, and Kruskal–Wallis tests, respectively. Further, to determine the extent of agreement of professionals, statistical analysis was performed. In doing so, arithmetic mean (m) was calculated, and ranges were developed such as agree = $5 \leq m \leq 4$; neutral = $4 < m \leq 3$; and disagree = $3 < m \leq 1$. This illustrated that the strategies with $5 \leq m \leq 4$ would be considered for further research [47].

To ensure representativeness, the minimum sample size was calculated. The number of respondents varies in survey-based studies; Farooq, Thaheem, and Arshad [48] gathered risk-related data from 57 construction project managers, but Chong, Fan, Sutrisna, Hsieh, and Tsai [47] engaged with only 36 BIM experts due to limited availability. Therefore, to calculate the sample size using a statistical approach, the Cochran [49] formula was used as shown in Equation (1), where n is the required sample size, m is the factor of confidence level obtained from the normal distribution table, p is the sample mean, q is 1-p, and y is the margin of error. Substituting m = 90%, ± 10% marginal error, and 50% sample mean, the sample size came out to be 41.

$$n = \frac{m^2 \times p \times q}{y^2} \quad (1)$$

3.4. Research Output

The safety management framework was generated by centrally positioning BIM as a vehicle for safety enhancement. For this purpose, significant strategies were grouped into project lifecycle phases, as per the expert opinions, leading to BIM implementation in the construction projects of those organizations that had not even adopted BIM. The framework was validated by interviewing field experts with over 15 years of experience. Initially, a framework was developed with the help of previous studies and respondents' input, which was further discussed in face-to-face and Skype interviews. A total of 19 interviews were conducted in which the experts suggested improvements and modifications in the structure as well as the content of the framework. As a result, major revisions were carried out to the structure, content, and mechanics of the framework. Afterward, to automate the process of safety improvement using BIM for high-maturity level organizations, a process map was formulated providing a blueprint of a BIM plugin. This plugin will treat BIM as a core decision support tool that can be used by practitioners in implementing safety practices. Similarly, the process map was validated by 5 experts with higher BIM skills. Lastly, conclusions were given followed by industrial and research implications.

4. Results and Discussion

4.1. Demographic Information

The questionnaire was distributed to over 250 construction professionals from different regions of the world and a total of 60 responses were received. A similar kind of study conducted in this knowledge area by Chong, Fan, Sutrisna, Hsieh, and Tsai [47] deployed a sample size of 36 for finding the level of intent on the identified strategies.

The demographic information in Figure 2 shows the broad regional background of the respondents. Respondents were targeted from both developed and developing countries to achieve uniformity and broader coverage of expert opinions. To overcome the diversity of BIM adoption levels in the construction industry, strategies were divided into basic and advanced levels based on the BIM maturity in organizations. In the first part, the strategies are of a basic level specifically formulated for organizations that are willing to adopt BIM practices but have not yet started applying them to projects. However, organizations that have already adopted BIM to a certain level can utilize advanced applications for safety management. The organizations that are currently using BIM have already adopted it to some maturity level. Similarly, the use of BIM cannot be wholly identified by the rationalization of developed and developing countries since some top-level organizations from developing countries have better BIM maturity than their counterparts from developed countries. Therefore, the following question was asked about the use of BIM in respondents' organizations: "Is your current organization using BIM in construction practices?" Interestingly, respondents from the same country reported different answers to the question. Two out of nine respondents from Pakistan reported that BIM is not used in their organizations. On the other hand, one out of two respondents from Australia, which is a developed country, reported that their organization is not using BIM for any construction practices. This indicates that when it comes to advanced technologies like BIM, any generalization based on the overall development of a country's construction industry cannot be made. Some tech-savvy organizations will adopt BIM regardless of the national trend and some will not despite the reputation of their country.

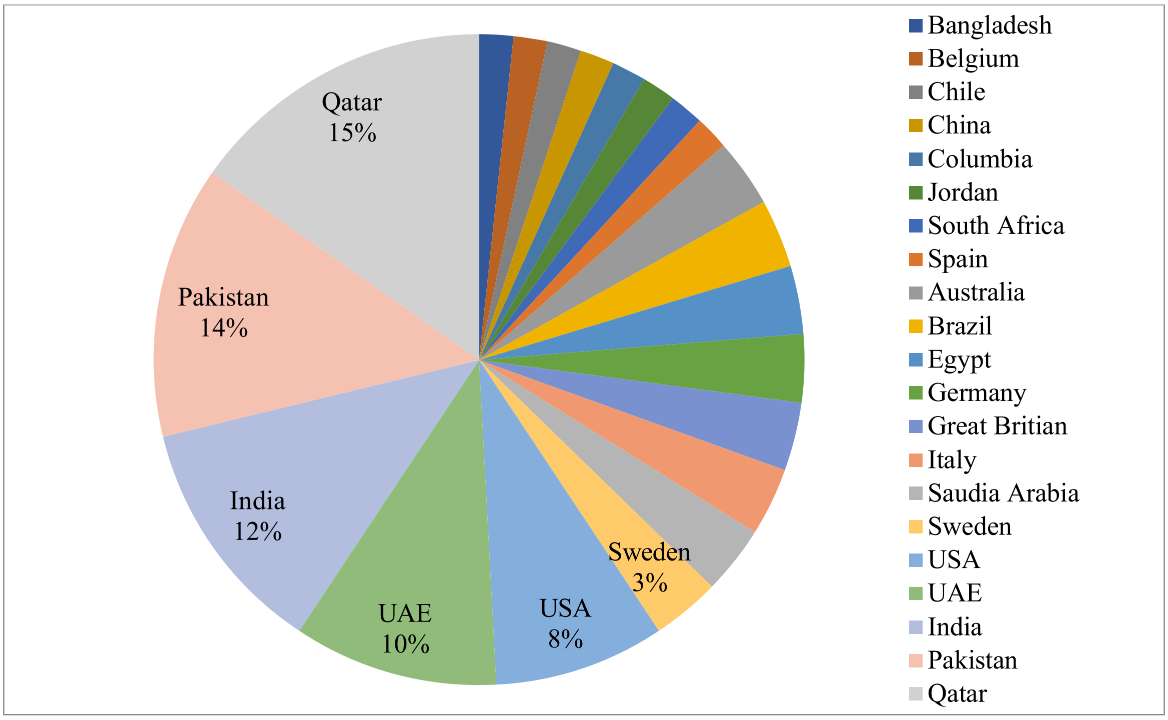

Figure 2. Regional distribution of respondents.

Most respondents were from Qatar (15%), and they all reported that their organizations use BIM for construction practices. This indicates a high level of adoption of BIM in Qatar despite its being a developing country. Moreover, they all marked their level of understanding of BIM as advanced. This corresponds with Hafeez, Vukovic, Chahrour, Kassem, and Dawood [50] who declared the Qatari construction industry a major regional hub of BIM adoption. Indeed, the major infrastructure of Doha, which includes the Qatar Railway Network, Doha Metro, New Doha Port Project, Doha International Airport, a total of 55,000 new hotel rooms in 140 new properties, and 12 stadiums with a capacity of 605,000 spectators, have been planned with BIM [51]. However, the respondents from Qatar highlighted that their organizations use BIM for project planning and visualization and occasionally for safety improvement with the help of its visualization feature. Following Qatar, the other large cohorts of respondents were from Pakistan (14%), India (12%), and UAE (10%), all of them developing countries. Although there is a sound regional representation, the level of BIM adoption in these countries is quite low. In Pakistan, the key stakeholders are not yet convinced to adopt BIM mainly due to the high cost of implementation and less trained staff. The construction industry is also faced with the barriers of insufficient government regulation, resistance to change, communication gaps, and complacent behavior [48]. Similarly, the full potential of BIM is not realized by the majority of the Indian construction sector due to several technological, organizational, and environmental factors [52].

Thus, the use of BIM for safety management is low. This lower usage is generally because of the unfamiliarity of using technology for management practices, and it also highlights that mere technological advancement, which comes at a significant cost of adoption, does not necessarily guarantee a technology's involvement in improving everything that it can. Therefore, concerted efforts are required to reap the benefits of BIM in safety along with its advantages in building design and execution.

Further, most respondents belonged to consulting and contractor organizations since they are the primary stakeholders in implementing and administering safety in a construction project. Therefore, it was necessary to obtain their opinion. Responses were received from professionals with a high level of qualification, as shown in Table 3.

Table 3. Demographic information of respondents.

Nature of Organization	Client	Architecture	Contractor	Consulting	Academia
Response	5%	15%	30%	42%	8%
Experience	1–5	6–10	11–15	16–20	21 and above
Response	23.30%	33.33%	21.66%	13.33%	8.33%
Qualification	BSc/BEng	MS/MSc	PhD	Others	
Response	53.33%	35%	11.67%	0%	
Level of Understanding of BIM	Advanced	Good	Basic	No understanding	
Response	65%	28.30%	6.70%	0%	

Furthermore, most respondents reported having 6–10 years of experience. This is because BIM has started gaining momentum recently [47]. Despite this, 35% of respondents reported having over 10 years of individual experience. The questionnaire was deliberately carried out to engage only those respondents who understood BIM to some extent. Therefore, 65% of respondents reported advanced understanding and no respondent reported a complete lack of understanding of BIM. This information can also be validated by checking the designation of respondents shown in Figure 3. A total of 59% of them worked as BIM managers. Other categories included civil engineers, BIM modelers, health and safety executives, senior architects, managing directors, and professors. Furthermore, the frequency with which their organizations used BIM for safety improvement was also inquired and the results were mixed due to varying levels of BIM adoption in each organization. The longer experience and more relevant positions of the respondents in their organizations helped build confidence in the findings as these experts possessed the knowledge and authority to effect change in the management practices in the construction industry.

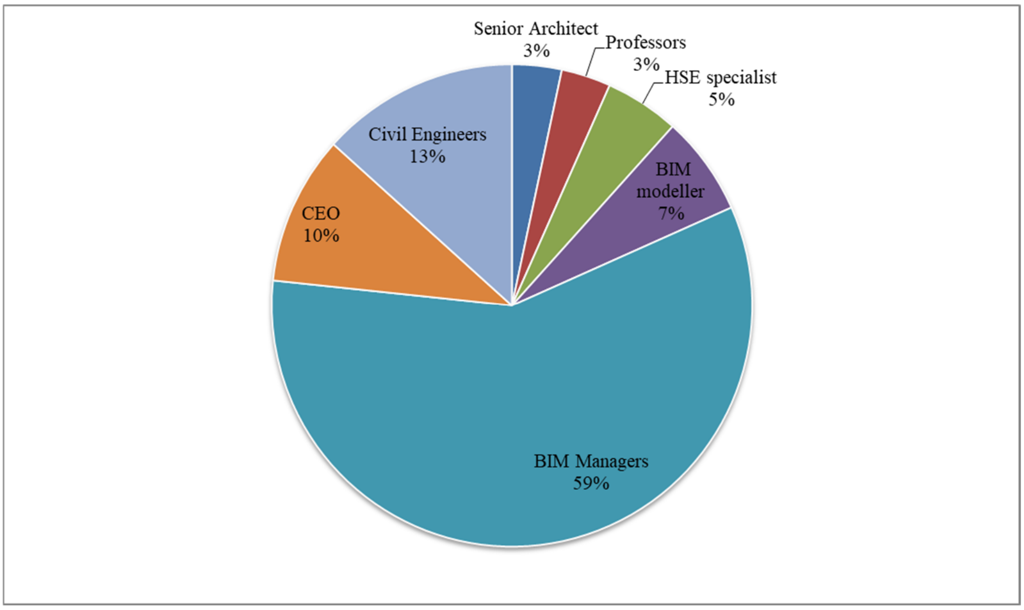

Figure 3. Designation of respondents.

4.2. Safety Management Strategies

To facilitate the uptake of BIM for effective safety management, strategies were synthesized from the literature and the factor–feature matrix as shown in Table 2. The concept of synthesizing strategies is explained with the help of Figure 4.

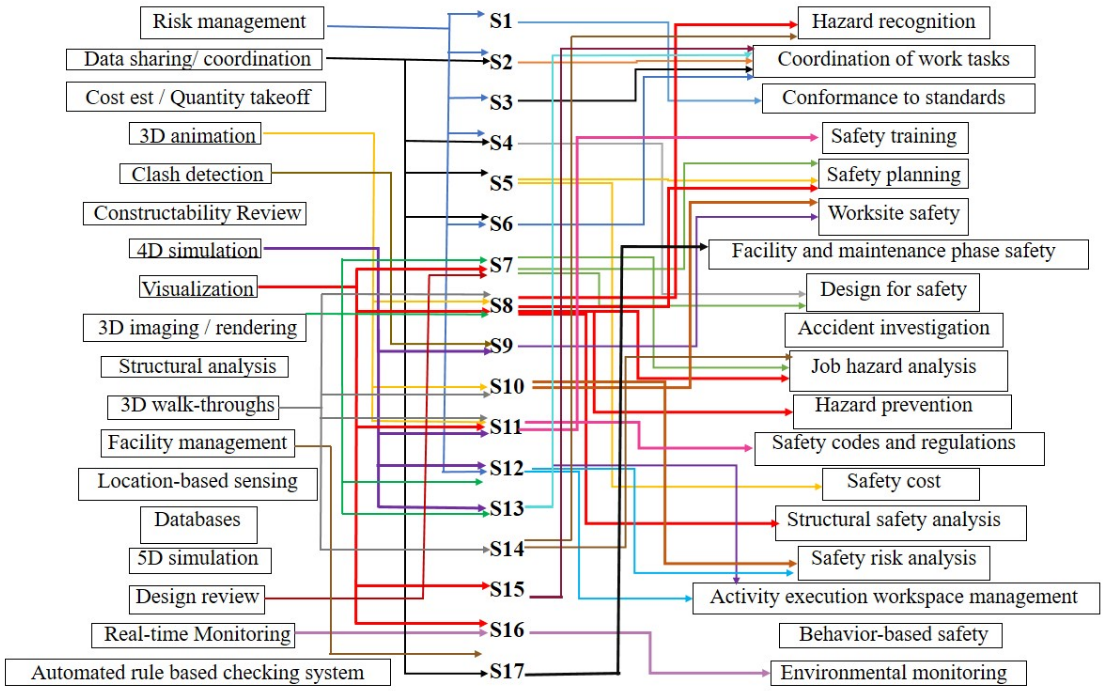

Figure 4. The synthesis of strategies.

It shows that, based on the synthesis given in Table 2, BIM has sufficient capability to address almost all the major safety factors. Furthermore, BIM features that could be used for safety improvement were extracted from the literature, and strategies were developed by taking into consideration the use of these BIM features and how they could positively affect an individual safety factor. In other words, it can be posited that the input of suggested improvement is the features of BIM which address one or more factors of safety as an output. For example, S1 addresses the coordination of work tasks, and S5 addresses safety planning and safety costs. Similarly, S7 addresses multiple factors of safety such as safety planning, job hazard analysis, and design for safety. All the strategies address different safety factors using different BIM features as input. S9 uses BIM features of clash detection and 4D simulations to improve the critical factor of worksite safety, and S14 uses 3D walkthroughs to recognize and analyze job hazards.

After synthesizing the strategies with this approach, these were arranged, adapted, and validated with the help of expert opinion, as shown in Table 4 with the associated BIM feature.

To improve construction management practices using BIM, the first step is its contractual and legal adoption in the projects. Therefore, the BIM-based contract provision (S1) has been highlighted as one of the most significant steps in the implementation framework, and over 90% of experts very highly agreed with it. To administer BIM-based contracts, sufficient protocols are established such as the AEC BIM protocol [57], and the construction industry council BIM protocol [58] in the UK. Practitioners can use them as a guideline to adopt BIM as discussed by Chong, Fan, Sutrisna, Hsieh, and Tsai [47] as well as Arshad, Thaheem, Nasir, and Malik [20].

BIM implementation should be well-defined in terms of scope. Therefore, the practitioners must explicate BIM goals based on project scope and information exchange procedures (S2) and enforce them to clarify the requirements for the adoption and flow of information between the stakeholders [53]. BIM facilitates many dimensions such as clash detection, design review, cost estimate, project planning, constructability review, structural analysis, and many other managerial practices [15,59]. Therefore, its implementation in a project must be explicitly based on its scope. The same is ratified through the survey results. Subsequently, the strategy for BIM implementation should be outlined to achieve the defined scope of the project (S4). However, in the present situation, the principal goal of adopting BIM is to improve construction safety.

Table 4. BIM-based safety improvement strategies.

Code	Associated BIM Features	Strategies	Selected References
S1	Risk Management	Provide BIM-based contracts in the project	[47]
S2	Risk Management, Data Sharing/Coordination	Define BIM goals based on project scope and information exchange procedures	[53]
S3	Risk Management	Set up a BIM team with well-defined tasks (BIM manager, coordinators, and modelers)	[10]
S4	Risk Management, Data Sharing/Coordination	Define strategy for BIM implementation to achieve the scope	[53]
S5	Data Sharing/Coordination	Clarify the cost for tools (BIM) and safety equipment in the early project stages	[10,21]
S6	Risk Management, Data Sharing/Coordination	Hire safety professionals well acquainted with the BIM process and workflow	[10]
S7	3D Imaging/Rendering, Visualization, Design Review	Generate a preliminary BIM model in the schematic design phase to visualize the project in the early stages	[17,54]
S8	Visualization, 3D Walkthroughs, 3D Animations, 3D Imaging/Rendering	Identify and prevent hazards through BIM-based visualization	[25]
S9	Clash Detection, 4D Simulations	Remove activity timeline conflicts by linking the 3D BIM model with the schedule to improve workspace management for executing activities	[17,55]
S10	3D Walkthroughs, 3D Animations	Prepare safety evacuation plans for the worksite through BIM	[26]
S11	Visualization, 3D Walkthroughs, 3D Animations, 4D simulations	Provide safety training demonstrating safety concerns using digital models, walkthroughs, and 4D simulations	[14]
S12	3D Imaging/Rendering, 4D Simulations, Risk Management	Perform appropriate execution planning for high-risk construction activities using 3D models and 4D simulation	[56]
S13	3D Imaging/Rendering, 4D Simulations, Data Sharing/Coordination	Explain, distribute, and communicate work tasks within the project team in 3D and 4D environments	[10,14]
S14	3D Walkthroughs	Prepare 3D walkthroughs for hazard identification in congested spaces on a worksite	[14]
S15	Visualization	Deliver BIM-based visual presentations for promoting effective communication throughout the project	[54]
S16	Visualization, Real-time monitoring	Perform safety monitoring through BIM-based visualization	[44]
S17	Data sharing/Coordination	Prepare and disseminate BIM-based safety completion reports to observe and record safety performance	[14]

Despite BIM's value addition, its implementation cost cannot be ignored. Therefore, its execution mandates the hardware and software requirements, acquisition of dedicated human resources, and frequent training, which burdens many construction organizations with huge costs. This high upfront cost required for software tools and the training of staff has proven to be the most significant barrier to BIM implementation [59]. This necessitates the clarification of the cost required for BIM and safety in the early project stages (S5). Addressing this can help in resolving many legal and relational ambiguities and issues during a project's life.

Further, to improve safety management practices in the construction stage of a project, it is important to develop BIM models early since generating the preliminary model in the schematic design phase (S7) can help in visualizing the project and foreseeing the possible risks [54]. The visual demonstration of a model can help in identifying possible hazards. In turn, this can help formulate prevention strategies earlier on. Expert opinion suggests that there is a lack of efficient delivery of safety training to the workforce. Most immigrant and illiterate workers cannot understand the training material provided to them. Therefore, strategy S11 has been articulated to provide visual training [2,32,33,36]. Even the safety toolbox talks can be expanded into toolbox screenings. Likewise, safety planning can be performed effectively by utilizing strategies S9, S10, and S12. After planning safety, it is vital to monitor safety conditions on the construction site and generate safety reports which can assist in decision-making and taking appropriate measures in safety management.

4.3. Statistical Analysis

To check the reliability of the collected data, Cronbach's alpha test was performed, giving a result of 0.958, which shows that the data is highly reliable and consistent [60]. Normality was also checked using both Shapiro–Wilk, and Kolmogorov–Smirnov tests. The results reveal a significance value of zero, indicating that the data were not normally distributed and were non-parametric. This suggested the need for non-parametric tests for further analyses [61]. Therefore, the Kruskal–Wallis H test was performed to articulate any differences in the number of independent samples against different groups [62,63]. The groups were the respondents' organizational type and their regional classification. Primarily, the test fields were assessed against their organizations in which most respondents showed the same perception of the identified strategies except for two strategies. The distribution of BIM-based contract provision (S1) is different according to the organization's nature as adopting contractual obligations is critical. The results reveal that the null hypothesis is rejected for this variable, showing that different companies have different legal and contractual requirements. Contract documents are mostly formulated on special conditions agreed upon by all parties involved in the contract and help in overcoming project issues through regulatory instruments. However, adopting BIM in the contractual process is still dubious for stakeholders. The difference of opinion in explaining, distributing, and communicating work tasks within the project team in the 3D and 4D environments (S13) might be due to the lack of a collaborative working environment in the construction industry. In most organizations, collaboration is based on two-dimensional drawings, and stakeholders are reluctant to adopt a 3D approach for this purpose [29]. This always leads to serious issues during project execution. The test fields were checked for any difference in opinion based on regional distribution, as safety and BIM adoption levels are different everywhere. However, no difference was observed in the solutions proposed for BIM-based safety implementation. This validates one of the initial assumptions that, despite the difference in technological development, the role of BIM in safety management is comparable across developed and developing countries. After analyzing the collected data, strategies were arranged in a systematic framework leading to safety improvement during the project lifecycle.

4.4. Safety Implementation Framework for Project Lifecycle

The strategies were synthesized into a framework that provides an enabling environment to improve safety management throughout the project lifecycle, as shown in Figure 5 and explained below.

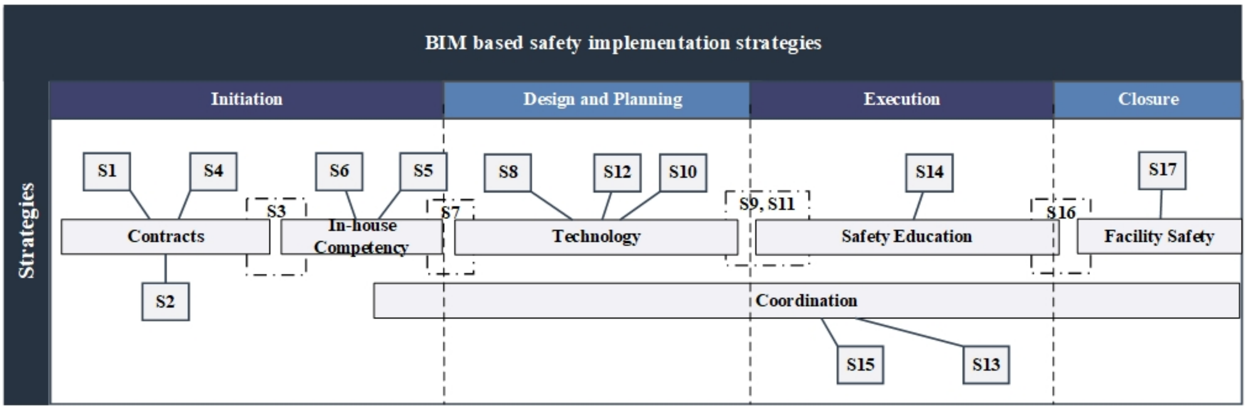

Figure 5. Safety implementation framework.

4.4.1. Project Initiation

BIM adoption is different at the country, organizational, and even stakeholder levels. Therefore, to apply the technological advancements of BIM, it must be adopted by organizations willing to embrace technological innovation. However, it was concluded from the in-depth discussion with experts that in the initiation phase of a project *'contracts'* and *'in-house competency'* are two considerable factors and sometimes barriers to the adoption of BIM. Likewise, Aibinu and Venkatesh [64] as well as Eadie, Odeyinka, Browne, McKeown, and Yohanis [59] concluded that the adoption cost and contractual and legal issues are the most prominent hindrances to BIM adoption. Therefore, strategies S1 to S7 which address these barriers are incorporated into the framework. Interestingly, these strategies support projects across the divide between developed and developing countries. Additionally, the shared strategies S3 and S7 can support both factors and are also suggested by industry experts. Furthermore, since the initial cost has been acknowledged as the top barrier to BIM adoption, the proposed framework makes a necessary provision for it. For example, one of the practitioners highlighted that the cost of BIM adoption and the cost of acquiring and training new staff fall under the *'in-house competency'*. Therefore, S5 and S6 are coupled in the initial stage of a project and their implementation can address the issues that are likely to occur in the later stages.

4.4.2. Project Design and Planning

Safety planning is a part of construction production planning but is usually conducted separately from project planning and control works. This divisive approach is unhelpful and is not considered productive [65]. Hence, strategies related to safety planning are integrated into the project design and planning stage. Since this phase is highly influential in a project's lifecycle, more resources invested in planning will ensure safer practices in the execution stage. Despite this potential, safety planning usually relies on manual interpretations, gut feelings, and the experience of safety planners [14]. This feeble link between safety planning and activity execution is due to the utilization of 2D drawings for hazard identification. Since their approach is manual and experiential, perceived results can be subjective and fallible. This warrants the inclusion of technology in planning, as validated through expert opinion. Therefore, most of the strategies that can be better implemented using technology are included in this phase.

Furthermore, safety design and planning include hazard identification and prevention techniques. By using different features of BIM, such as 3D modeling, visualization, clash detection, walkthroughs, and 4D simulations, strategies have been synthesized for safety planning. After developing a BIM model, hazards can be visually identified and their control mechanisms can be devised accordingly. Additionally, 4D simulations can be generated focusing on safety procedures to show the transition of temporary elements and high-risk areas. This can be further enhanced to remove conflicts in the activity execution timeline since most workspace conflicts, leading to injuries and accidents, occur due to confined execution space. Likewise, Zhang, Teizer, Pradhananga, and Eastman [42] identified potential workspace conflicts in confined spaces using BIM-based visualization, since the construction site safety hazards are mostly related to the proximity of construction resources. After effective safety planning, the workforce must be trained to overcome these hazards.

4.4.3. Project Execution

The most hazardous stage of a project from the safety point of view is execution because most construction accidents occur on-site during this time [56]. What prevents workers from safe practices is the lack of safety training and demonstration in accordance with their understanding. Along with expert observation, many authors have emphasized the safety training of workers through graphical and pictorial demonstrations [2,33,39]. It is important to note that all the prevention techniques for identified hazards in the design phase must be communicated to workers and especially for the hazards in a confined workspace. Therefore, safety education must be provided using different features of BIM, and the strategies S11 and S14 serve in this regard. One of the experts from Qatar highlighted the practice of daily safety demonstrations to the workforce using visualization and 3D walkthrough before the start of work on their project. Reportedly, workers appreciated this mode of delivering safety education, resulting in zero accidents. Furthermore, with all these potential endeavors, it is essential to monitor ongoing safety conditions on the site.

Moreover, the experts indicated that there is a deficit of coordination among the entire project team which influences construction safety. Therefore, coordination needs sufficient commitment from the beginning of the project until finishing, as shown in Figure 5. Coordination can be reinforced by strategies S13 and S15. Although these two strategies do not cover every aspect of addressing the barriers to coordination, the inclusion of BIM can efficiently play its part.

4.4.4. Project Closure

In the initial development of the framework, strategies were distributed in three lifecycle phases, but experts suggested adding the closure phase. They emphasized the safety of operations and facility management phase due to a large number of accidents, as also reported by the Bureau of Labor Statistics [4]. It is recommended to develop safety handbooks for the facility management staff to aid in the provision of relevant information. The use of BIM is also appreciated in this phase as it can act as a central database for the storage and retrieval of safety information. Furthermore, Wetzel and Thabet [28] developed a BIM-based framework for facility safety which can aid in obtaining safety protocol information specific to the requisite tasks, resulting in improved safety.

Previous studies have shown that BIM-based safety focuses on specific phases of the project [11,25,28,30,31,42,56]. Thus, the novelty of this framework lies in the proposition and integration of all BIM-based safety implementation strategies in a single framework, which not only improves safety management but also provides the opportunity to exploit all other BIM advantages. However, the cultural aspects of safety that have long slowed down the proper implementation of safety management regimes in several developing countries might not be directly impacted by the use of technology and as such are beyond the sphere of influence of this framework. Furthermore, the framework, which offers a fresh take on BIM-based safety automation throughout the project lifecycle, could help organizations with low levels of BIM maturity or even those that have not adopted BIM. They can exploit this applied framework, fulfilling its adoption protocols, and use it for safety improvement. However, organizations that have reached the level of integrated BIM should adopt the developed process map under total automation.

5. Realization of Hazard Identification Process

Construction organizations with a high level of management and technology maturity must have already adopted BIM in different phases of their projects, as described in the developed framework. Therefore, it merits having an advanced approach to fulfill the requirement of BIM-based safety improvement. To determine the most demanding and efficient aspects of safety integration with BIM, the questionnaire asked: "Hazard identification and prevention can best be performed by which of the following BIM features". The maximum number of responses were received for "Automated rule-based checking". Experts highlighted the fact that even though many advanced BIM applications have been developed, a detailed safety management framework has yet to be integrated into mainstream BIM tools. This provided an impetus to exploit the opportunity of developing the BIM-driven process map for hazard identification. For this purpose, experts in construction management and automation were engaged to obtain their opinion on the information flow and structure of the map shown in Figure 6. Several rounds of revision and improvement were carried out according to the advice given by experts. For example, the developed process map was only addressing "Element selection" by selecting elements on the screen, but experts suggested adding more filters like category, family, level, etc., in selecting building elements. The database schema was also improved through expert opinion. Lastly, IT experts were also engaged to assess the practicality of the process map in the BIM platform. This rigorous exercise resulted in a comprehensive and applicable theoretical process map shown in Figure 6 and explained below.

Automated Hazard Identification Process Map

The process map utilizes relevant data from BIM and the *Hazard Information Database* to generate safety reports and propose appropriate safety controls for project execution.

The main objective of the proposed process map is to encourage an integrated application of BIM for safety management. Inputs, outputs, and functional requirements were established after discussing and validating the entire process with BIM experts. This development mainly targets the Autodesk Revit platform due to its popularity and wider use. However, open-source BIM tools may also benefit from the proposed framework after minor modifications. In this proposed framework, Safety Management Plugin is an independent icon in the main toolbars of Autodesk Revit. By clicking on the added icon, a pop-up will appear with the command Element Selection. Afterward, Elements will be selected from the building and relevant hazards will be assigned.

The workflow requires a model with a high level of detail for all architectural, structural, and MEP components along with flexible schedule data. Since the central focus is safety, stand-alone Revit families can be generated for highly hazardous construction equipment and elements such as tower cranes, scaffolding, formwork, etc. Moreover, the *Centralized Hazard Information Database* along with BIM data are used as an input to mine safety data for all BIM elements to generate safety reports. To generate the hazard database, explicit as well as tacit knowledge of safety is essential [30,66]. Explicit information is obtained from the published literature, previous project safety records, accident reports, and clauses of OSHA or any other safety protocol for all hazards. However, tacit information is obtained from the experience of safety managers. The database pools together standard safety information such as a unique *ID* for hazards and safety codes along with their description, appropriate mitigation strategies, and possible associated elements for the listed hazard.

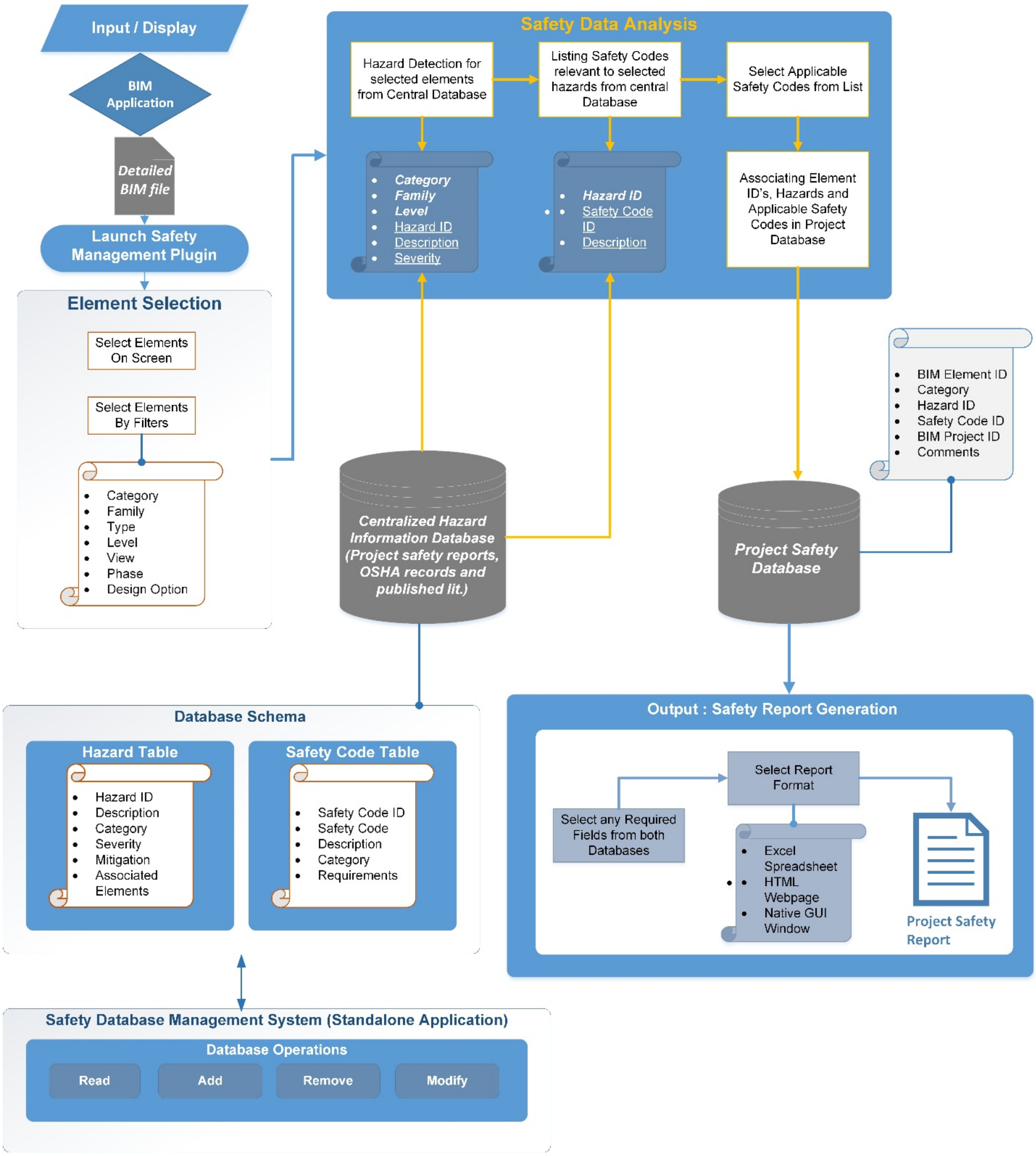

Figure 6. Process map.

The proposed plugin functions by associating selected elements from the BIM model with applicable data from the *Centralized Hazard Identification Database* and proposing safety control mechanisms for the identified hazards. Elements can be selected based on their *Category*, *Family*, or *Level*. However, the possible applicable data from the database can be the *Hazard ID*, *Severity*, and *Description*. Afterward, information such as the *Safety Code ID* and *Description* can be mined from the *Safety Code Table*. This association of data will result in the *Project Safety Database* which contains all the safety-related information for a particular project. For example, shuttering is a hazardous activity during the construction process of structural members, which requires safety codes to be followed strictly. During project construction, the safety manager can explicitly draw safety information related to that activity and propose safety measures accordingly. The system is not adept at providing strict and close decisions. Therefore, decision-making and providing controls are mainly the responsibility of the user. Since BIM can analyze job hazards [67], this capability can be augmented through the safety manager's expert opinion or real-time input from automatic safety detection systems [41,44]. A detailed project safety report can be obtained in any specified format as an output. Furthermore, the *Project Schedule Information* is also helpful in automatically removing schedule-related conflicts in activities with the help of 4D simulations [55]. Overall, the generated report puts into perspective the physical and temporal hazards of a digital building component which acts as a basis for effective safety management.

6. Conclusions

BIM has the potential to cause a paradigm shift in the way construction projects are managed through its advanced features. However, the construction industry lacks awareness of adopting innovative managerial practices. Therefore, this study aimed to motivate practitioners to adopt BIM in a holistic way for safety improvement, especially in developing countries. In doing so, features of BIM and factors of safety along with their association strengths were identified from the literature to synthesize the significant strategies. Strategies usually define and drive decisions in an organizational design. Therefore, this study initially focused on defining the need for organization-level improvement. To achieve a more refined outcome, strategies were modified using the expert opinion of BIM managers and arranged in a systematic framework over the lifecycle of a typical construction project. The developed framework could help in adopting proposed strategies by addressing the significant factors that can hinder BIM-based safety implementation. Furthermore, this study has contributed to providing a step-by-step guide to achieving safe practices throughout the project life. The developed framework can help construction organizations and authorities in facilitating the uptake of BIM-based safety which will ultimately bring down the injury and fatality rate. Owing to its focus and the set unit of analysis, which is not the individual project but rather the construction organizations, project-related technical data are neither collected nor analyzed. On the contrary, construction organizations are treated as singular entities affecting and being affected by BIM adoption.

Since BIM adoption is still in its infancy in most organizations, the developed framework could considerably help them. However, some organizations, most probably in developed countries, have achieved a higher level of BIM adoption and can exploit it for safety management. For them, a process map providing a blueprint of the plugin is proposed using integrated advancements in BIM. This advanced approach is also focused on more improvement in BIM-based safety management. The plugin fuses safety-related data into BIM and suggests control mechanisms after performing safety data analysis. Project-related safety information can be gained as an output, which is used to produce a safety report. The safety report can aid in the execution phase. This holistic development positions BIM centrally, which practitioners can exploit to improve safety management. However, the proposed solution does not replace the existing safety management strategies and their framework. Rather, it complements them, integrates them, and provides a centrally implementable and manageable solution that leverages the existing safety management strategies.

This study is a progressive synthesis of BIM features that address safety factors with strategies of safety management in the project lifecycle phases, eventually giving rise to the BIM-based safety implementation framework. Construction organizations willing to opt for BIM for their managerial practices can benefit from its findings. In this study, parts of the findings have higher applicability for construction organizations in developing countries due to their less mature BIM adoption. However, those construction organizations in developed countries that have similar BIM portfolios may also benefit from these recommendations. The automated hazard identification map, on the other hand, is not country-specific and can be generalized all over the construction world. Organizations with high BIM adoption levels can take advantage of this conceptualized framework.

Despite its promise, the study has a few limitations. We could not gather details of the types and sizes of construction projects the respondents were involved in. This missing information could provide insight into the work experience and background of the respondents. By knowing the types and sizes of their projects, the readers could have a better understanding of the body of knowledge and its application. It can also allow for determining the approach of BIM-based projects in relation to the topic of this study. Future research may improve upon this limitation. Moreover, the proposed framework has some limitations, such as the plugin design requiring the manual selection of model elements to associate the safety hazards and codes. However, future research can eradicate this manual selection in the proposed automated framework. Finally, the proposed framework operates with the bottleneck of limited safety reporting and documentation in developing countries. This inherent limitation is built into the core of limited safety management systems in these countries and exacerbated by a weak safety culture and legislation. Future research can better contextualize this study in a more supporting study environment where safety practices and culture are better evolved. Additionally, further effort can be put into integrating sensing technology like a drone for providing real-time input to BIM for improving construction site conditions. This could help in automating the whole lifecycle safety management system.

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