Role of BIM in Construction Safety Management: A Step in the Direction of Automatic Hazard Analysis

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THESIS ACCEPTANCE CERTIFICATE

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I dedicate this thesis to my family and teachers who have supported me in this challenging journey.

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Abstract

Deplorable safety management practices are damaging reputation of the construction sector. Though legislation has specified rules and regulations for safety improvement, the state of safety violation is still alarming. Its root causes are information unavailability and integration of present data with other project activities. The technology that can help in overcoming these issues is the need of hour. Building Information Modeling (BIM) has the potential to address poor safety performance and therefore has inspired many researchers to focus towards BIM and its application for safety improvement throughout project lifecycle. This study performed a comprehensive literature synthesis to explore the factors of safety and features of BIM with their association strengths. This has led to the identification of BIM based safety improvement strategies from previous studies. Expert opinions upon the identified strategies are collected using questionnaire survey and semi structured interviews. With the aim of developing a lifecycle implementation approach, strategies are distributed into different project phases and an application framework is developed. The developed framework addresses almost every important aspect of BIM adoption for safety improvement. To validate the usefulness of this framework, interviews of highly experienced professionals, who have good understanding of BIM, were conducted. Lastly, another framework integrating safety into the BIM platform is proposed for further improvement. This might motivate the industry professionals in adopting BIM which will consequently improve safety.

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Chapter 1

Introduction

1.1 Background

Construction industry is deliberated to be one of the most substantial industries due to its contribution to gross domestic product (GDP) and also in terms of its social and economic importance (R. U. Farooqui et al., 2008). The economy of any country and its level of development are largely dependent upon the presence of buildings and infrastructure (Demirkesen et al., 2015). However, it is also the most hazardous industry as compared to other industries due to its dynamic nature (Tam et al., 2004) and involvement of activities which require effort and dedication at all levels. This industry faces higher accident statistics which not only damaging its reputation but also posing a challenge to future innovation (Y. Zou et al., 2017). Despite a significant improvement in safety enforcement due to appropriate legislation such as Occupational Safety and Health Act (OSHA) in the USA, National Institute for Occupational Health (NIOH) in India, Health and Safety Executive (HSE) in UK and Labor Department of Hong Kong, the socio-economic influence of injury and fatality rates is still alarming (Li et al., 2015; Tixier et al., 2017). In the workplace comparison of European statistics over the period 2008 – 2016, AECO industry represents the highest number of fatalities (Eurostat, 2016). Globally, the fatality rate in construction industry has increased from 15% to 19% during the last five years (Bureau of labor statistics, 2016). To reinforce it further, some authors reported accident rates between 24% to 30% (Ganah et al., 2015; Li et al., 2015; Sunindijo et al., 2011). The contributing factors behind these alarming figures are dynamic workplace, worker's behavior, lack of coordination, inadequacy with risk management and many others (Enshassi et al., 2016; Gibb et al., 2006). These excessive figures demand to deploy technology, resources and finances for bringing down the casualty rates rather than just pointing out the reasons. It can be done by changing the mindset of construction workforce and engraving safety in every task (Li et al., 2015) as safety is the essential key for successful outcome of any project (S. Zhang et al., 2011). And it is not unstoppable; Han et al. (2009) found that construction accidents can be prevented by providing effective safety management.

Safety management includes many factors such as planning (Biagini et al., 2016; K. Kim et al., 2016; Kim et al., 2014), training (Clevenger et al., 2015; C.-S. Park et al., 2013), codes and regulations (J. Park et al., 2016), cost (Li et al., 2015) and others. Among all, safety planning is a fundamental step and includes identification of potential hazards along with their preventive measures (Chantawit et al., 2005). However, current practices do not consider safety planning as part of overall planning for project execution (Getuli et al., 2017; S. Zhang et al., 2011). Due to the fragile link between safety planning and work task execution, safety personnel face difficulties like availability of information and integration of available data with project work activities, ultimately resulting into hazardous worksite conditions (S. Zhang et al., 2013). A majority of construction accidents are neither reported nor documented except for those which gain public or media attention. Thus without appropriate information, it is difficult to perform operative safety planning (Raheem et al., 2016). Likewise, Zahoor et al. (2016) stated that most of the contractors do not pay sufficient consideration to safety manuals and some of them even do not prepare such manuals. In contrast to this, Masood et al. (2012) found that according to managers, accidents are reported and recorded thoroughly but workers do not agree with this opinion. Also, a poor exchange of communication between workers and administration is reported in the literature (Emmitt et al., 2009) and in that, the increasing number of migrant and illiterate workers cause more communication problems (Han et al., 2009). Similarly, S. Zhang, Sulankivi, et al. (2015) concluded that safety communication is a challenging task under the dynamic and rigorous jobsite conditions. In view of all the existing problems, the AECO industry needs to improve inadequacies of existing manual practices so that safety improvements can be attained with the help of innovative technology (S. Zhang et al., 2013).

In this regard, the technology to assist in analyzing and communicating safety issues would be desirable for improving overall performance (Han et al., 2009). Consequently, visualization technique is the most appropriate tool for effective safety management because of the advantages such as information exchange between different stakeholders and generating walk-throughs for ideas transmission (Bouchlaghem et al., 2005). Motiboi et al. (2017) concluded that animation is the most effective method for safety understanding which is also an application of visualization. A person's ability to hypothesize and understand construction concepts can be enhanced with the help of visualization. Clevenger et al. (2015) found that Building Information Modelling (BIM), a visual demonstration of physical and functional properties of a facility, helps in explaining the concepts using 3D visualizations. BIM not only manage visuals, but also have information that can help in generating drawings, design analysis reports, energy analysis, facility management and others that can help in better decision making (L. Ding et al., 2014; Ganah & John, 2015; S. Zhang, Sulankivi, et al., 2015). BIM can be used during the lifecycle of a project as a shared source of information about any facility (Antwi-Afari et al., 2018). It can provide enhanced collaboration and coordination between all stakeholders of project (Abbasnejad et al., 2013; Ahmad et al., 2018; Enshassi et al., 2016). Azhar (2017) found that BIM can be utilized for better construction safety by developing close link of safety issues with construction planning and can provide comprehensive site layout and safety plans to facilitate safety communication. Ahmad et al. (2018) found that BIM has a positive trade off in project risk and thus can be considered as an active risk management system. Despite a handful of papers investigating the suitability and applicability of BIM for safety management, the body of knowledge lacks a holistic and self-organizing research which may utilize BIM to allow component-level visualization and decision-making regarding safety.

And even if research yields such solutions, the level of BIM adoption must be holistic in terms of technology, process and people to achieve any practical advantages. However, studies report an incoherent trend of BIM adoption such that some organizations have not adopted BIM as a technology; some have reached to the level of integrated BIM (iBIM). Therefore, a proactive approach is necessary to achieve safety through automation.

To achieve this particular aim, there is a need to identify safety related issues and possible solutions must be addressed using features of BIM. The current study develops a framework for BIM adoption in construction organizations that can improve safety condition. In doing so, strategies are selected from systematic literature review and expert opinions. Furthermore, another framework is proposed for BIM plugin to integrate safety data in an automated platform. The developed frameworks will help practitioners during the project lifecycle by accomplishing three basic requirements for BIM adoption, and the application developers in automating the BIM driven safety management process. This provides way for development and integration of BIM tools for improved safety management on construction sites.

1.2 Selection of topic

Due to increasing concern towards safety improvement and technological advancement, it is essential to provide suitable framework for the implementation of safety using BIM. Everyone talks about innovative technologies but no one show enough courage to overcome their fear of change about adopting those technologies. Thus, a proper mechanism is needed for safety using modern tools. Knowing the relationships between factors of safety and BIM, we would better be able to devise a strategy for its execution. The possible solutions to safety issues need to be addressed using features of BIM.

1.3 Research objectives

- To identify the factors of safety and features of BIM.
- To synthesize strategies for significant safety factors through BIM.
- To develop a framework for safety implementation based on integration with BIM.

1.4 Significance

Construction industry of Pakistan is highly labor intensive and lacks advance technology that creates communication gap, huge monetary and human loss. Lack of coordination, commitment towards safety, in-house competency and familiarity with advance tools to apply safety culture are the factors hindering better implementation of safety on construction sites in Pakistan (R. Farooqui et al., 2007). To improve safety performance of construction projects, BIM technology must acquaint with developing countries like Pakistan. This technology helps to integrate the phases of construction project lifecycle and resolve conflicts.

Identification of safety issues and features of BIM would give a clear understanding of relationship between them and their possible application. The importance of this framework is to lessen the safety hazards for workers by using advanced technological approach. This study can serve as a model for other construction industries to further develop and improve their construction safety environment. This study will help construction industry to adopt technology-based solution to pertinent issue of construction project site related to construction safety.

1.5 Scope

The scope of this research covers the present safety conditions and their improvement using advance visualization technology. All of the lifecycle phases of the project would be covered and addressed in developing framework. Present research utilizes BIM for improving safety management, which would ultimately lower down the accident and fatality rate.

Chapter 2

Literature Review

2.1 Review Methodology

To ascertain the current research on the state of BIM and construction safety management, a comprehensive literature review has been carried out in four phases with flowchart shown in Figure 1 and description given below.

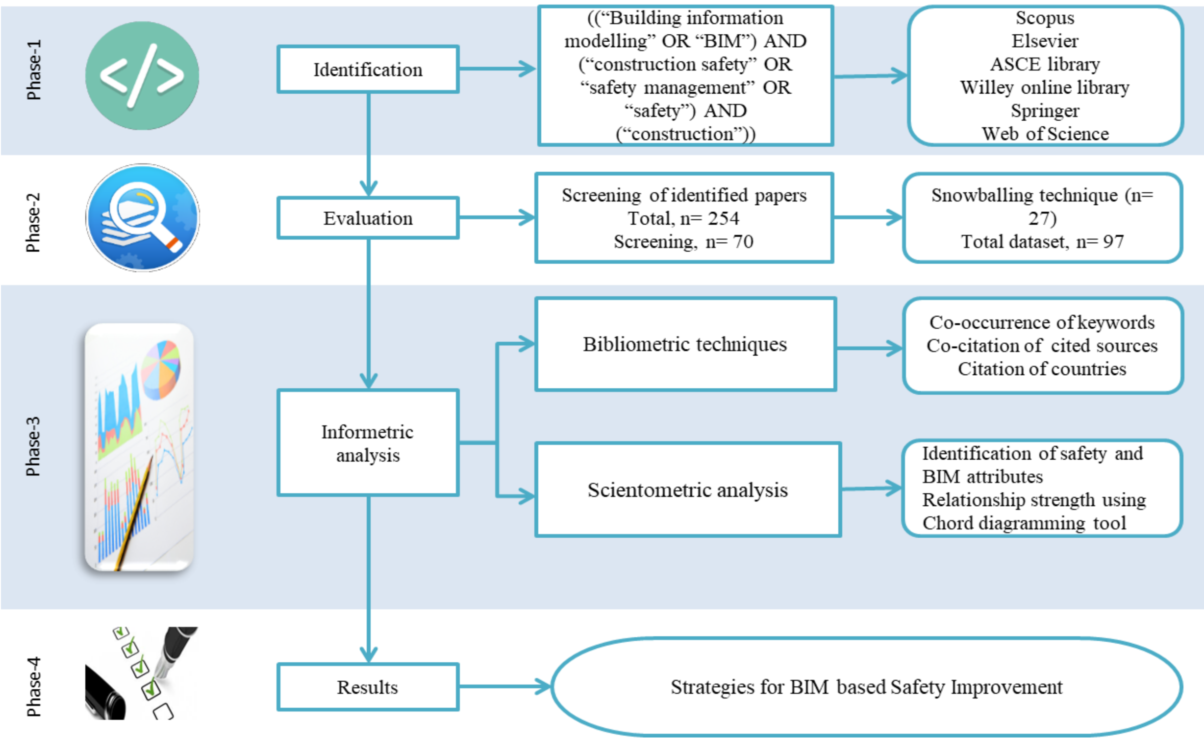


Figure 2.1 Flowchart

The phase-1 included the identification of relevant academic journals and associated databases. This was done using different search engines such as Elsevier, Scopus, ASCE library, Google Scholar, Web of Science (WoS) and others. The search period was fixed between the years 2000-2018. Boolean operators AND and OR were used to formalize keyword search. The search string used was ((“Building information modelling” OR “BIM”) AND (“construction safety” OR “safety management” OR “safety”) AND (“construction”)). The search explored the title, abstract and keywords which were sufficient to identify and extract the relevant articles. The selection criterion of journals was based on previous studies of similar nature to encompass only those journals which have at least two published articles for the relevant period of study (Antwi-Afari et al., 2018; Darko & Chan, 2016; Martínez-Aires, López-Alonso, & Martínez-Rojas, 2018). A total of 254 documents including journal and conference papers, and books were extracted as a result of this exercise.

The phase-2 of this study involved the evaluation of identified articles. To enhance the quality of review, only peer-reviewed articles were selected for further analysis, and conference papers and books were omitted. This is due to the reason that journal articles provide more accurate and valued information due to their rigorous review process, and most of the similar studies in the field of construction and project management have included only the journal articles (Zhao, 2017; Zheng, Le, Chan, Hu, & Li, 2016). Keeping in mind above criterion and removing duplicates, another round of screening of documents resulted into 70 journal articles for further analysis. These articles represented the major journals which report research in this particular area. However, to cover all the relevant publications outside these journals, snowballing technique was applied as suggested by Tixier et al. (2017) and Oraee et al. (2017). The objective of this step was to add pertinent literature outside the principal construction engineering and management journals. With the help of snowballing technique, citations were checked for the identified articles on the similar criteria to include only the relevant articles. This resulted into addition of 27 papers from different journals, making the total number of papers 97 which were used for the final analysis.

The phase-3 mainly included informetric analysis which is defined as the study related to quantitative aspects of information and it contains bibliometric and scientometric techniques (Hood & Wilson, 2001). Bibliometrics incorporate the analysis of publications and their respective properties, called subdivision of scientometric (de Rezende, Blackwell, & Gonçalves, 2018). Generally, bibliometric methods, tools and techniques for literature evaluation are covered by scientometric analysis (Hosseini et al., 2018). In this research, science mapping is used for visualizing the physical aspects of scientific research. It also helps in bibliometric analysis that describes how scientific domains and their respective disciplines are structured. Numerous tools are available for visualization of scientific research which include CiteSpace, VOSviewer, BibExcel, Science of Science tool (Cobo et al., 2011), Gephi and others (Bastian, Heymann, & Jacomy, 2009). Special features and shortcomings of various software were studied which led to selection of VOSviewer and Gephi whose features are shown in Table 1.

Table 2.1 Features of selected science mapping tools

Tools	Network Mapping	Networks Analysis	User Friendly	Availability	Normalization
VOSviewer	✓	×	✓	Open source	Association strength
Gephi	✓	✓	✓	Open source	Centrality

VOSviewer is a freely available visualization tool for configuring and observing bibliometric maps (Van Eck & Waltman, 2010). Alternatively, Gephi is used for network analysis and graphical representation, and can give more precise networks and graphs (Bastian et al., 2009). It is important to note that data for bibliometric analyses was retrieved from WoS and Scopus for the identified articles because the selected science mapping tools analyze the articles only in the text format (.txt) files. Due to this, the science mapping and scientometric analyses are performed using different databases. Further, three types of bibliometric analyses were performed in this research: 1) co-occurrence of keywords, 2) co-citation of cited sources and 3) citation of countries. Such analyses have been applied in previous studies (Hosseini et al., 2018; Oraee et al., 2017; Zhao, 2017).

Further, scientometric analysis, which deals with the quantitative aspects of science (Zhao, 2017), was performed to find the BIM features and safety management factors through an inclusive content analysis. Using these attributes, a relationship matrix was developed in the form of D3 chord diagram with hover which is a graphical representation of correlation between data in a matrix and is coded in JavaScript. The attributes are arranged symmetrically around a circle by means of a relationship between the data points (Jalali, 2016). The circular layout of this diagram simply illustrates information with large number of attributes, making demonstration of relationship relatively easy (Gu, Gu, Eils, Schlesner, & Brors, 2014). Further, to give a clear understanding of highly focused phases, articles were distributed into the lifecycle phases under the scientometric analysis. The observation of these analyses resulted into research findings based on which appropriate recommendations are given to help expand future research endeavors.

2.2 Bibliometric Analysis

The phases 1 and 2 of the study, as illustrated in Figure 1, include the identification and screening of articles. The retrieved articles were further reviewed and analyzed. To avoid any bias and limitation of the manual review, quantified systematic techniques using software platforms were used to explore the body of literature (He et al., 2017; Yalcinkaya & Singh, 2015). Literature reviews are based on various techniques, bibliometric technique is one such which encompasses the scientific mapping and visualization of dataset in an information domain (Van Eck & Waltman, 2010). VOSviewer and Gephi have been used for bibliometric analyses in the current review. Information for VOSviewer was imported directly from WoS in the required format. The results of various analyses are explained in the next sections.

2.2.1 Co-occurrence of Keywords

Keywords depict the fundamental content of articles and clearly demonstrate the range of knowledge areas within a particular domain (Su & Lee, 2010). Following the adopted methodology, the extracted papers were imported to VOSviewer to generate a network of author keywords. The related keywords convey precise picture of the knowledge domain with its relationship and pattern (van Eck & Waltman, 2014). Thus, a network was formed for co-occurrence of keywords as suggested by Lee and Su (2010). Normalization using fractional counting was performed for analysis of publications as recommended by van Eck and Waltman (2014). As a result, VOSviewer created a co-occurrence map based on the bibliographic data obtained from WoS. The distance between the nodes depicts the level of proximity between them while the font size shows the level of concentration on that particular aspect (Oraee et al., 2017; van Eck & Waltman, 2014). While creating this map, 29 keywords met the minimum level of co-occurrence; this was set as a criterion for source 2.

In order to simplify the results and harmonize various linguistic regimes, similar terms such as 'building information modelling', 'building information model', 'BIM', 'building information modelling (BIM)' were merged into a single keyword 'building information modeling'. Thus, a network shown in Figure 2 was developed, highlighting the main research areas in the field of construction safety and BIM.

In the visualization of network, weights were based on the strength of links while scores were calculated on average normalized citations. The font size shows the number of occurrences for a specific keyword; the larger font size represents the most influential terms. Thus, it can be seen that the most recurring keyword was 'building information modeling' followed by 'cloud computing', 'prevention through design', 'scheduling' and 'rule checking'.

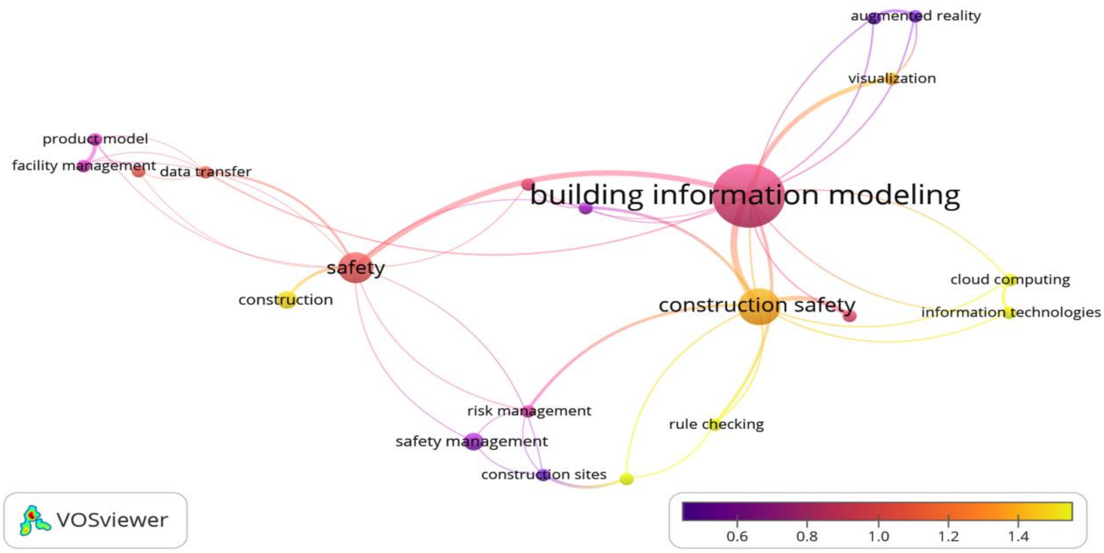


Figure 2.2 Co-occurrence network of author keywords

It is sufficiently established that most of the accidents in AECO industry are due to schedule overlapping (Moon, Dawood, & Kang, 2014) since the traditional approaches of scheduling lack in utilizing 3D tools and do not take into account the uniform resource distribution (Chau, Anson, & Zhang, 2004; Dawood, 2010; Dawood & Mallasi, 2006). Lack of proper scheduling create ineffective workspace management and conflicts between different activities and constructability issues which result into chaotic site conditions (Moon, Kim, Kim, & Kang, 2014; J. P. Zhang & Hu, 2011). Existing planning techniques like Gantt chart, critical path method (CPM) and network diagrams are considered ineffective for detecting schedule conflicts, and it requires new tools to analyze, detect, monitor and control conflicts in workspace (Dawood & Mallasi, 2006). Therefore, scheduling and planning with the help of BIM is an attentive area of research (Moon, Kim, et al., 2014). Based on this motivation, Y. Zhou, Ding, and Chen (2013) developed a prototype in which safety is integrated with the detailed information model and scheduling of construction site activities. They concluded that visualization of real-time safety status helps in recognition and elimination of risks during the whole project lifecycle which ultimately leads to an improved safety management. Similarly, rule checking, which is an application of BIM, helps in monitoring the performance of building without modification in its design (S. Zhang et al., 2013; Y. Zhou et al., 2013). The strong linkage of BIM and safety is showing its importance while safety has no weighted link with emerging areas like cloud computing. It shows that less research has been conducted in these knowledge areas.

2.2.2 Co-citation of cited sources

Co-citation analysis of sources categorizes the most prominent journals in this research area. The identification of key journals may add value to the researchers for working in the field of construction safety and BIM, and it can also help authors in publication matters (Hosseini et al., 2018). Therefore, a network was created using VOSviewer for co-citation analysis which gives the weighted degree of cited documents. Again, fractional counting was deployed in creating a bibliographic map. The minimum threshold for citation of sources was set to 6, thus 28 out of 1055 sources met the requirements. The generated map was imported into Gephi for improved visualization and better quality in line with suggestion of Cobo et al. (2011) who highlighted the effectiveness of collaborative working.

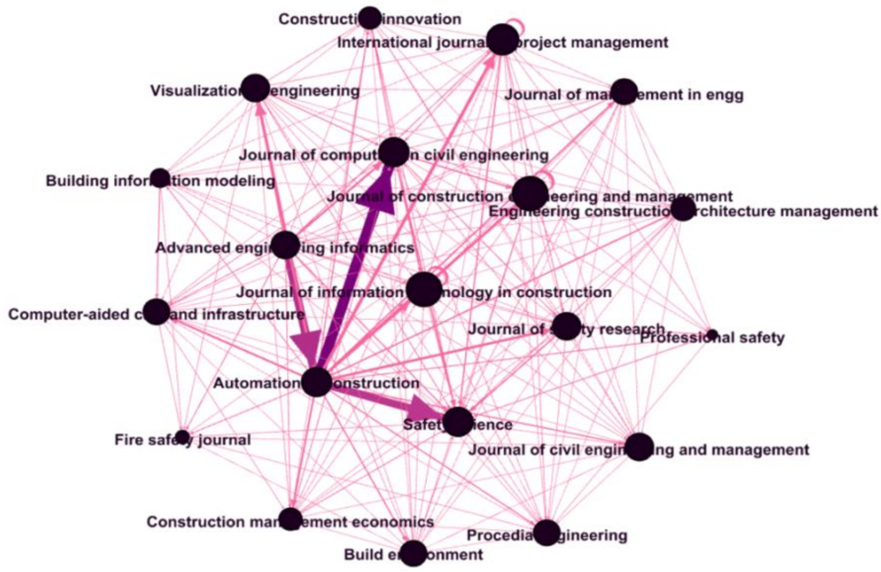


Figure 2.3 Co-citation of cited sources

Fruchterman and Reingold algorithm was applied for generating a high quality and comprehensive network as shown in Figure 3. This algorithm has the ability to centralize the highly rated sources by the virtue of gravity feature (Cherven, 2015). Similar terms were merged together and generic terms such as ‘thesis’ and ‘lecture notes’ were excluded. Thus, a network consisting of 20 nodes and 169 edges or connections was formed, highlighting the main journals in the field of safety and technological applications in construction sector. The size of nodes demonstrates the highly cited sources while the thickness of links highlights the strength of association between them. The varying colour intensity demonstrates the strength of links according to the number of citations. The sources with thick edges and dark coloured links represent a high level of collaboration such as Automation in Construction has a strong link with Journal of Computing in Civil Engineering, Safety Science and Advanced Engineering Informatics.

It can be seen that the emphasis of highly weighted journals is on technologies. The focused research areas for Automation in Construction are computer-aided design and engineering, facility management, graphics and robotics (Automation in Construction, 2018) while Journal of Computing in Civil Engineering is dealing with database-management systems, computer-aided design systems, remote sensing and bar coding (Computing in Civil Engineering, 2018). The scope of these journals is greatly dependent upon the use of information technologies in construction. However, Advanced Engineering Informatics and Safety Science are not only discussing technological applications but also focus on engineering informatics and techniques of control and management of safety respectively (Advanced Engineering Informatics, 2018; Safety Science, 2018). While Fire Safety Journal has a low citation because the scope of this journal is limited to fire safety design, its management and investigation (Fire Safety Journal, 2018). Professional Safety has relatively a less influenced node as it mainly deals with the hazards identification and protection strategies, and safety investment education. However the role of technological application in this journal is limited (Professional Safety, 2018).

Table 2 shows the degree and weighted degree centrality of sources showing the same results. Degree centrality of a node helps in finding the influence of edges present on a particular node (Kapoor, Sharma, & Srivastava, 2013). Weighted degree centrality, also known as strength of nodes, is the sum of all links present on a node in a network (Antoniou & Tsompa, 2008). The relative importance of the sources can be calculated based on weighted degree rankings. Weighted degree centrality of Automation in Construction is the highest, illustrating its higher contribution in the publications and co-citations of this knowledge area. While journal of Building Information Modeling has the lowest value, which depicts its impact and relative influence.

Table 2.2 Degree centrality and weighted degree of sources

Sr. #	Sources	Weighted Degree	Degree
1	Automation in Construction	154.7359	19
2	Journal of Computing in Civil Engineering	59.3578	19
3	Safety Science	46.7284	19
4	Advanced Engineering Informatics	44.6746	18
5	International Journal of Project Management	19.9094	20
6	Journal of Construction Engineering and Management	17.7699	22
7	Visualization in Engineering	16.7519	18
8	Journal of Safety Research	16.7345	18
9	Journal of Information Technology in Construction	15.7426	22
10	Computer-Aided Civil and Infrastructure	11.4124	17
11	Construction Management Economics	9.7888	15

12	Journal of Management in Engineering	7.3748	17
13	Construction Innovation	6.1385	15
14	Engineering, Architecture and Construction	5.9688	16
15	Professional Safety	5.6757	8
16	Building and Environment	5.4036	17
17	Procedia Engineering	5.3023	17
18	Journal of Civil Engineering and Management	5.1391	18
19	Fire Safety Journal	4.8961	10
20	Building Information Modeling	4.5343	13

2.2.3 Citation of countries

After analyzing the journals, the network of countries was developed using VOSviewer to explore the countries contributing in the field of construction safety and BIM. The same configuration was adopted as recommended by van Eck and Waltman (2014). A network was developed with 19 sources, showing the link strength of citations. This network was then imported to Gephi for a better output and to modify source names where required, such as 'people of china' was modified to 'China'. Gephi incorporates only those nodes in which link strength is present, therefore some of the sources like Canada, France, Italy and Qatar were not accommodated.

The PageRank algorithm was used to rank the nodes of network based on their significance level (Khokhar, 2015). This algorithm was utilized to visually identify the most significant nodes by re-sizing and re-coloring them as illustrated in Figure 4. The large size of a node and font depicts the highly focused source for this knowledge area. Therefore, USA is found to be the most influential node indicating its role in the advancement of research in the body of literature (Martínez-Aires et al., 2018). It is since this technology was originated in the USA and many companies have developed BIM software packages there. Strong links of USA with other countries like South Korea, Germany, Australia, England and Spain show a high level of collaborative research effort. While countries like Pakistan, Hungary and Egypt have deficient research in this body of literature. Therefore, researchers present in these countries are encouraged to realign their research focus by addressing and studying technology based research problems which may directly help their AECO sectors.

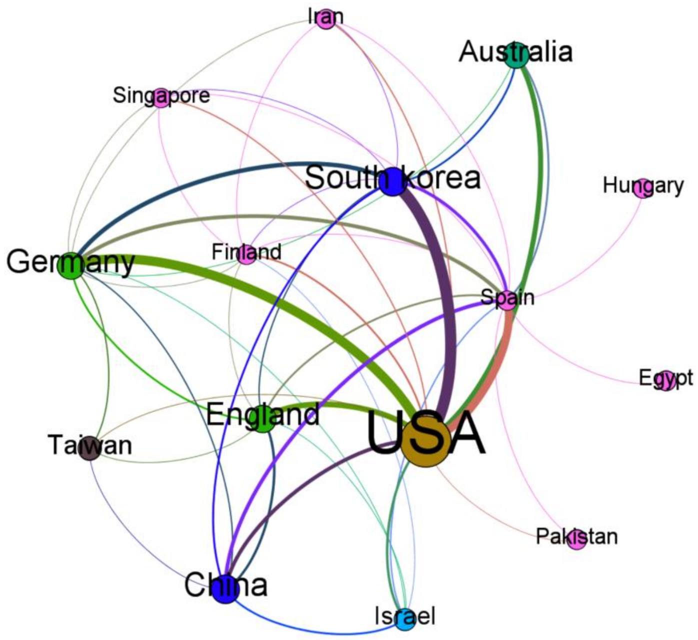


Figure 2.4 Citation of countries

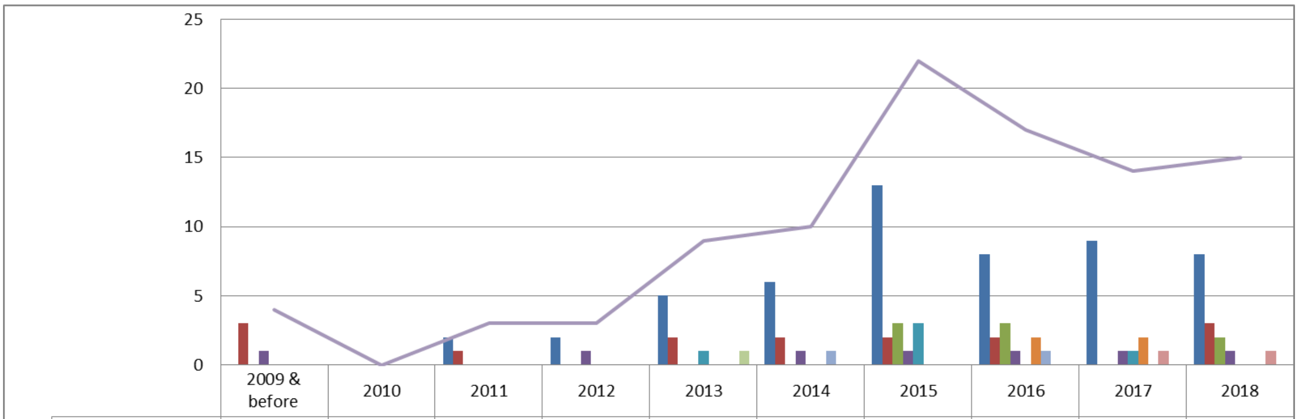
2.3 Snowball sampling

Furthermore, in order to cover all of the related publications outside the selected journals, snowballing technique was applied by checking the pertinent citations of present dataset (Badampudi, Wohlin, & Petersen, 2015). This technique has already been applied in previous review articles (Oraee et al., 2017; Schanes, Dobernig, & Gözet, 2018; Stingl & Geraldi, 2017; Zahoor et al., 2016). Stingl and Geraldi (2017) employed snowballing sampling technique as their review was focused on key journals of project management, thus adding 10 more articles in their study. Similarly, the applied technique in this research resulted in the addition of 27 articles as illustrated in Table 3.

Table 2.3 Number of documents regarding construction safety and BIM

Source	**Documents**
Automation in Construction	32
Safety Science	9
Journal of Construction Engineering and Management	9
Journal of Information Technology in Construction	5
Journal of Computing in Civil Engineering	5
Visualization in Engineering	4
Advanced Engineering Informatics	4
Computer-Aided Civil and Infrastructure Engineering	2
Others (Snowballing)	27
Total	**97**

The final dataset includes 97 relevant papers from different databases and their yearly distribution is shown in Figure 5. It can be seen that the number of articles summarily become prominent in the year 2015 representing that the trend has been shifted towards BIM research. Among the databases, Elsevier is publishing large number of content on the technological applications while rest of the databases are still in their maturity phase.



	2009 & before	2010	2011	2012	2013	2014	2015	2016	2017	2018
Elsevier	0	0	2	2	5	6	13	8	9	8
ASCE library	3	0	1	0	2	2	2	2	0	3
Google scholar	0	0	0	0	0	0	3	3	0	2
Scopus	1	0	0	1	0	1	1	1	1	1
Springer	0	0	0	0	1	0	3	0	1	0
Emerald	0	0	0	0	0	0	0	2	2	0
Wiley library	0	0	0	0	0	1	0	1	0	0
MDPI	0	0	0	0	0	0	0	0	1	1
Taylor & francis	0	0	0	0	1	0	0	0	0	0
Total	4	0	3	3	9	10	22	17	14	15

Figure 2.5 Trend of published articles for construction safety and BIM

2.4 BIM application domains in safety management

One of the main objectives of this review is to identify the attributes of BIM and construction safety, which was only possible by a detailed scrutiny of all the selected articles. Therefore, final dataset was reviewed fully. The data was scruitinized for all the attributes of BIM and safety, and focus was not particularly on the relevance between them. The study revealed significant attributes in the relevant body of literature, which came out to be 21 for construction safety and 24 for BIM. A quantitative score was calculated for the identified safety attributes and their relative importance based on their frequency of occurrence which can be seen in Figure 6.

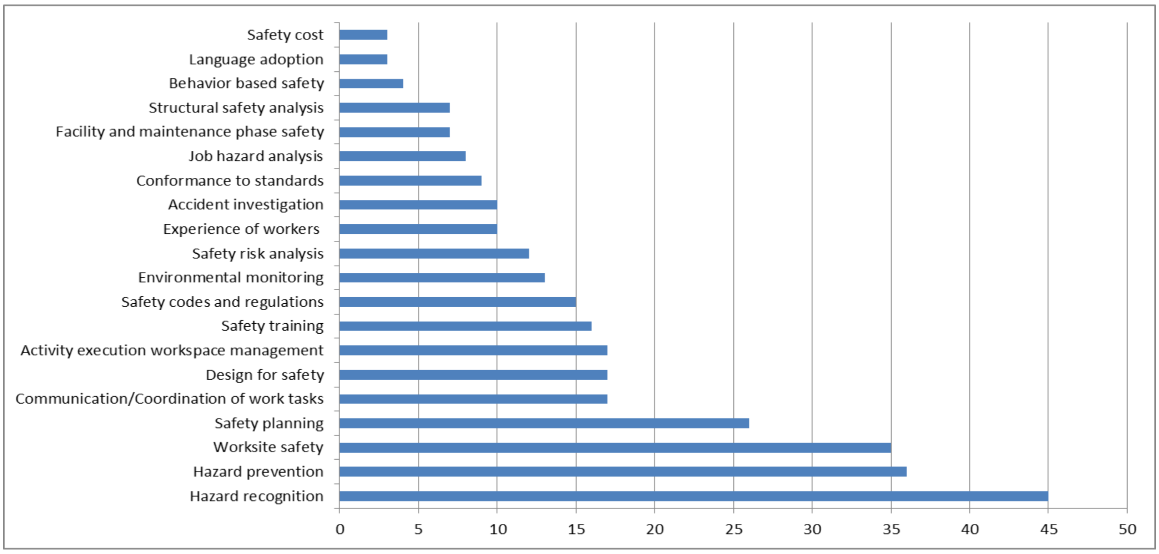


Figure 2.6 Frequency of safety factors

Hazard recognition and hazard prevention are the most frequently used factors of safety in the application domain of BIM. Carter and Smith (2006) concluded that unidentified hazards pose the most problematic conditions and prevention techniques can not be applied without proper hazard identification. Therefore, safety planning, which includes identification and prevention of hazards, is considerd as a fundamental step towards safety improvement and is the frequent research area in body of literature (Azhar, 2017; Sulankivi et al., 2012). Further, worksite safety is also a recurring factor since most construction accidents occurr directly on construction sites (H. Kim, Lee, Park, Chung, & Hwang, 2016; Li, Chan, & Skitmore, 2012). This motivates the researchers to focus on planning for jobsite safety (Akula et al., 2013). While factors like safety cost and language adoption are least significant in the literature of BIM and safety because of no direct link with technology. However, they are discretely significant and have an indirect relationship with technology such as safety cost incurs due to accidents on construction site (Ikpe, Hammon, & Oloke, 2012; Yilmaz & Çelebi, 2015). This implies that appropriate safety planning would lower down the safety cost. Futher, language adoption adds into the effectiveness of communication which otherwise remains low due to immigrant workforce on construction sites. But it can be resolved with the help of safety training (Jaselskis, Strong, Aveiga, Canales, & Jahren, 2008; Trajkovski & Loosemore, 2006).

2.5 BIM technology characteristics

Similarly, attributes of BIM were identified from the body of identified literature and only those attributes are displayed in Figure 7 whose minimum frequency was 5. On top of the list is visualization which is portrayed as the most promising feature in the literature, since it can improve safety management by allowing the stakeholders to visually observe worksite conditions and get familiar with hazards beforehand (Azhar, 2017; Bouchlaghem et al., 2005; Hadikusumo & Rowlinson, 2004; K. Kim & Teizer, 2014). Further, automated rule based checking has got sufficient consideration in recent years and has been focused by many authors in their study (Luo & Gong, 2015; Malsane, Matthews, Lockley, Love, & Greenwood, 2015; Melzner, Zhang, Teizer, & Bargstädt, 2013; S. Zhang, Teizer, Pradhananga, & Eastman, 2015). Hongling, Yantao, Weisheng, and Yan (2016) performed the integration of design safety codes and OSHA regulations with BIM to automatically identify safety issues. They concluded that automated checking saves time and labor cost which is otherwise employed in improving safety management.

Finally, though MEP and structural analyses are undoubtedly the important features of BIM, they provide no significant role in this research area, justifying considerably low frequencies.

2.6 Project lifecycle analysis of articles

While distributing the identified articles into the project lifecycle phases, it was found that much of the work has been focused on design and planning phases of project while relatively less amount of work has been conducted for construction and operations phases as shown in Figure 8.

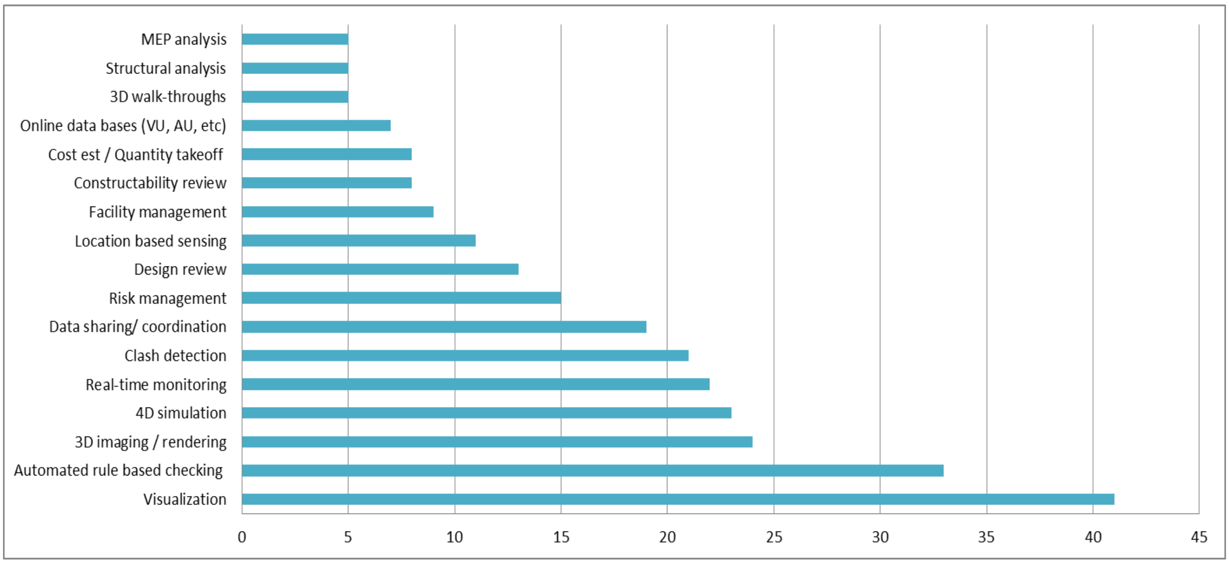


Figure 2.7 Frequency of BIM attributes

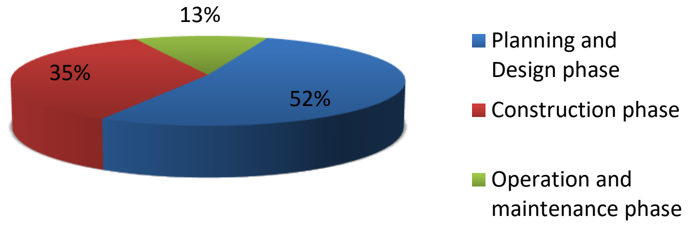


Figure 2.8 Percentages of related publications in project lifecycle phases

Construction safety entails a special concern throughout the project lifecycle, from design phase to facility management of a project (S. Zhang et al., 2013). But the major contribution in worksite accidents are due to lack of efficient design and planning aspects (Gambatese, Behm, & Hinze, 2005). Waly and Thabet (2003) concluded that safety planning in the earlier phases of a project is a crucial step for best safety management practices. Most of the accidents occur during construction phase (P. X. Zou, Zhang, & Wang, 2007) and improper safety planning is the major contributing factor behind these high rates of fatalities (Azhar, 2017;

Lappalainen, Mäkelä, Piispanen, Rantanen, & Sauni, 2007). Therefore many researchers have focused on design and planning segment of projects (L. Y. Ding, Zhong, Wu, & Luo, 2016; K. Kim & Teizer, 2014; Li et al., 2015; Malekitabar, Ardeshir, Sebt, & Stouffs, 2016; S. Zhang, Teizer, et al., 2015) which depicts the efficacy of BIM in preventing accidents through design (Qi, Issa, Olbina, & Hinze, 2013; Rüppel & Schatz, 2011; S. Zhang, Sulankivi, et al., 2015). Though Wetzel and Thabet (2015) highlighted the severe rate of injuries in the facility management phase of project while providing repair and maintenance services, relatively less amount of work has been done for providing safe practices in this phase. Most of the study practices involve identifying construction hazards with the help of visualization to control safety (Cheng & Teizer, 2010). The utilization of 4D models can be made both in the design and construction phases to detect workspace conflicts (Koo & Fischer, 2000). W. Zhou, Whyte, and Sacks (2012) showed that a 4D model generated during design phase can be employed in safety planning for construction sites. Thus, Y. Zhou et al. (2013) collected the information about construction components and their respective schedule in the design phase to generate 4D model, so that potential conflicts can be identified by automatic rule based checking, before construction starts. Some authors also focused on providing safety during emergency situations such as testing the building occupants response with fire emergency cases by developing a game using 3D BIM modeling (Rüppel & Schatz, 2011).

2.7 Relationship of BIM and safety domains in literature

A relationship matrix was developed for the identified attributes of BIM and construction safety, and their linkages were established based on their frequency of occurrence in the literature. The matrix is represented in the form of a Chord diagram which was coded using JavaScript, as shown in Figure 9. The thickness of links shows the strength of correlation and width of an attribute shows its individual significance in comparison to others.

Of the identified factors, hazard recognition is the most influential factor of safety because of its maximum width and high number of links with features of BIM. In order to provide safe working environment and enhancing the chances of project success, it is important to identify hazards in the earlier phase of a project (Li et al., 2012). Hazard detection is essential because the construction tasks inherently involve risks and their knowledge is as important as the need for diminishing accidents (Mohammad & Hadikusumo, 2017). Hazard prevention also attained a significant position among safety factors and clearly depicts the high degree of correlation with features of BIM. Because once the hazards are identified, it is necessary to develop prevention strategies which can be done by ensuring safety codes and regulations, and appropriate training of workers, reducing interruptions and compensations of the project (Ikpe et al., 2012; H. Kim et al., 2016). Similarly, visualization is the most dominant feature of BIM with a much wider span and large number of correlation links. Visualization is the elementary part of digital technologies; most of the workforce lacks technical expertise to better comprehend the outcome without picturing it (Nasir, 2017). Thus, visual representation helps in understanding the product and needed information (H.-T. Chen, Wu, & Hsieh, 2013; Rohrer, 2000). Therefore, visualization has a noteworthy prominence amongst all aspects of BIM. Automated rule based checking also has a significant correlation linkages revealing a significant amount of work that has been conducted for safety management by the virtue of this feature. S. Zhang et al. (2013) developed a framework for automated checking of safety rules and validated it with the help of a case study. Melzner et al. (2013) utilized the developed framework for identifying hazards in planning phase of a project and suggested protective measures and equipment required to eliminate safety hazards. Similar kind of effort was deployed by different researchers to enhance safety practices (Eastman, Lee, Jeong, & Lee, 2009; Sulankivi et al., 2012).

The strong relationship between hazard recognition and visualization illustrates the usefulness of this approach for enhancing construction safety. Sadeghia, Mohandesb, and Abdul (2016) concluded that visualization is the most valuable tool for positive safety practices. The traditional use of safety information on construction sites does not predict the factors involved in real jobsite environment, and makes it difficult to identify possible safety issues and communicate the right information to workers (Golparvar-Fard, Peña-Mora, Arboleda, & Lee, 2009). The growing overseas workforce also requires a clear visual representation of safety hazards to sufficiently asses jobsite conditions (Azhar, 2017; C.-S. Park & Kim, 2013). Hazard recognition has a strong correlation with automated rule based checking which helps to identify hazards without exploiting effort of safety experts in focusing visualization. Regional health and safety regulations are merged with 3D visualization tools and translated from human language into computerized parameters with the help of accident related components, thereby automatically highlighting the safety hazards (Hongling et al., 2016; H. Kim et al., 2016; S. Zhang, Boukamp, & Teizer, 2015). Benjaoran and Bhokha (2010) developed a rule based system for height related risks because fall has high statistics in construction fatalities. The attributes such as element type, size, placement, activity and accident type were used for providing input. This helped in recognizing hazards and suggesting safety measures which can be approved by a safety professional.

Hazard recognition can also be done with the help of clash detection and 4D simulation, and these features also show a significant association. Construction safety clashes are the inconsistencies among the crucial attributes of jobsite conditions, which can cause problems (Tixier et al., 2017). There are many activities on construction sites that run adjacent to one another. Thus, to minimize workspace conflict, a system was developed by Moon, Dawood, et al. (2014) for automatic checking of workspace clashes using 4D simulations so that schedule of conflicting activities can be changed. Similarly, Marzouk and Abubakr (2016) developed a framework for selecting type and location of a tower crane at jobsites. The framework performed clash detection for crane operations using 4D simulation, which was used to identify and resolve the issue of parallel working cranes.

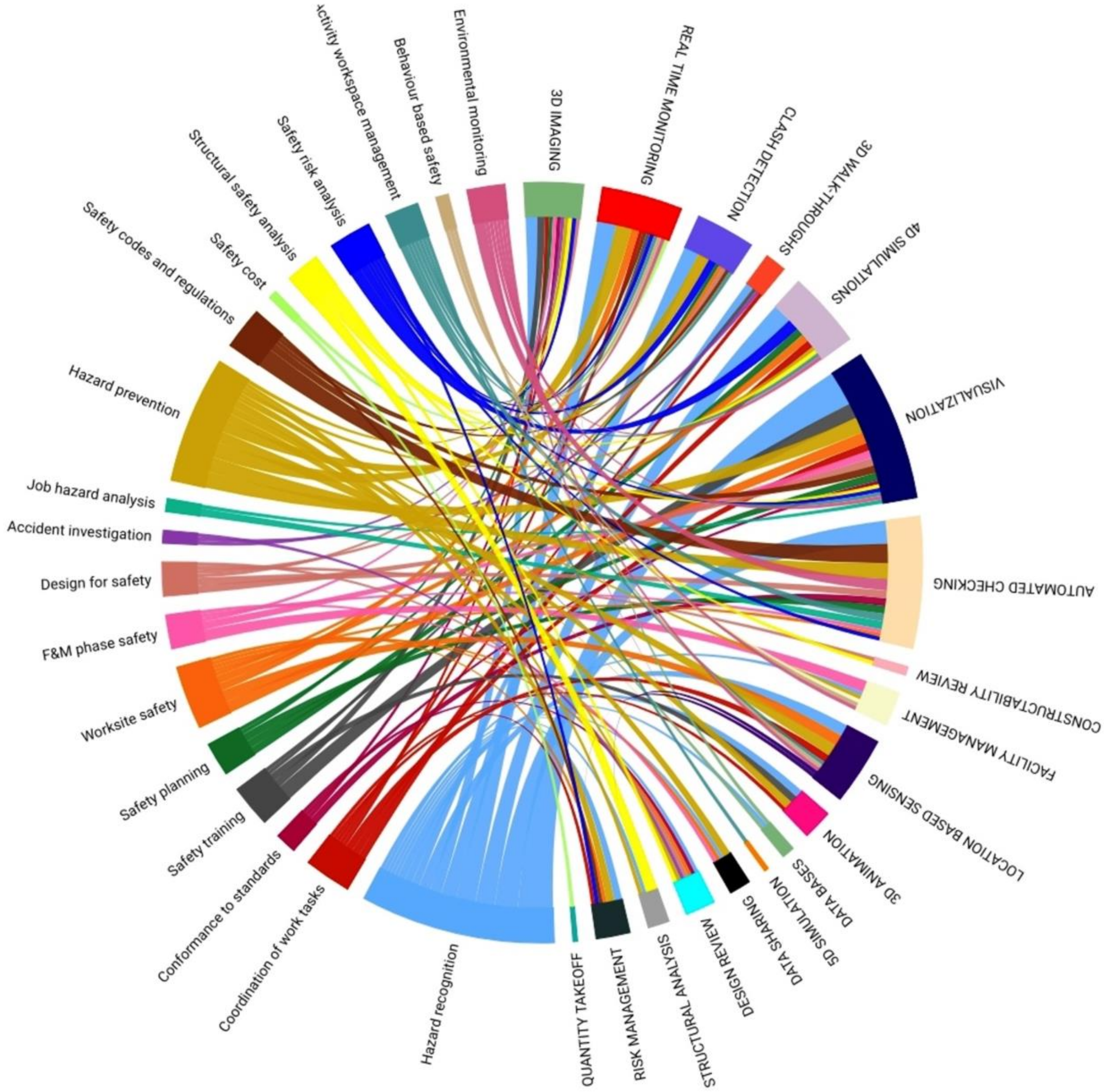


Figure 2.9 Chord diagram showing BIM and safety association

Location of resources on construction sites is usually manually monitored which requires experienced professionals but this approach is time consuming and error-prone (Cheng & Teizer, 2013; S. Zhang, Teizer, et al., 2015). Real time location system monitoring is considered an effective approach to identify and trace the location of resources such as personnel, materials and equipment (Li, Chan, Wong, & Skitmore, 2016). One of the fundamental areas for application of real-time monitoring is jobsite monitoring for safety augmentation (Cheng & Teizer, 2013). Therefore, hazard recognition has been performed by many researchers using real-time monitoring and location-based sensing. Thus, hazard prevention can be implemented based on observations. Teizer (2015) demonstrated the reliability of localizing and monitoring the construction resources with the help of active visualization system. It was concluded that sensing and tracking of assets on construction sites help the professionals by saving time spent on safety monitoring, and can focus attentively on cost and schedule control. The inappropriate usage of personal protective equipment (PPE) causes many injuries and causalities, therefore a system was developed by Dong, Li, and Yin (2018) for automatic identification and assessment of PPE by merging pressure sensors and localization technologies in BIM. The system has the ability to track workers location and dangerous situations, sending warning signals and assessing the location where PPE is necessary. It also provides feedback for hazard prevention.

It is found that visualization addresses the maximum number of safety aspects as compared to other features of BIM which exhibits its prominence as illustrated in Figure 10. However, it has a relatively weak link with environmental monitoring and activity execution workspace management which shows the amount of deficient research in these areas. Still, Riaz, Arslan, Kiani, and Azhar (2014) illustrated that BIM has a strong potential for improved visualization for effective monitoring of workspace environment. There can be numerous hidden hazards on execution sites such as disturbed temperature and humidity levels mostly in confined spaces. Thus, utilizing the visualization feature of BIM and integrating it with wireless sensing technologies, environmental monitoring can be performed which would help in reducing possible fatalities (Arslan, Riaz, Kiani, & Azhar, 2014; Cheung, Lin, & Lin, 2018; Sousa, Almeida, & Dias, 2014). Researchers must focus on activity workspace management as it is one of the significant resources as well as constraints at a jobsite, and ineffective workspace management results in safety hazards and low quality (Choi, Lee, Park, Cho, & Kim, 2014; C. Zhang, Hammad, Zayed, Wainer, & Pang, 2007). As a conflict in schedule of activities creates difficulties for professionals to safely manage the workspace, therefore with the help of visualization and simulation, algorithms were developed to actively manage activity workspace and minimize conflicts (Moon, Kim, et al., 2014).

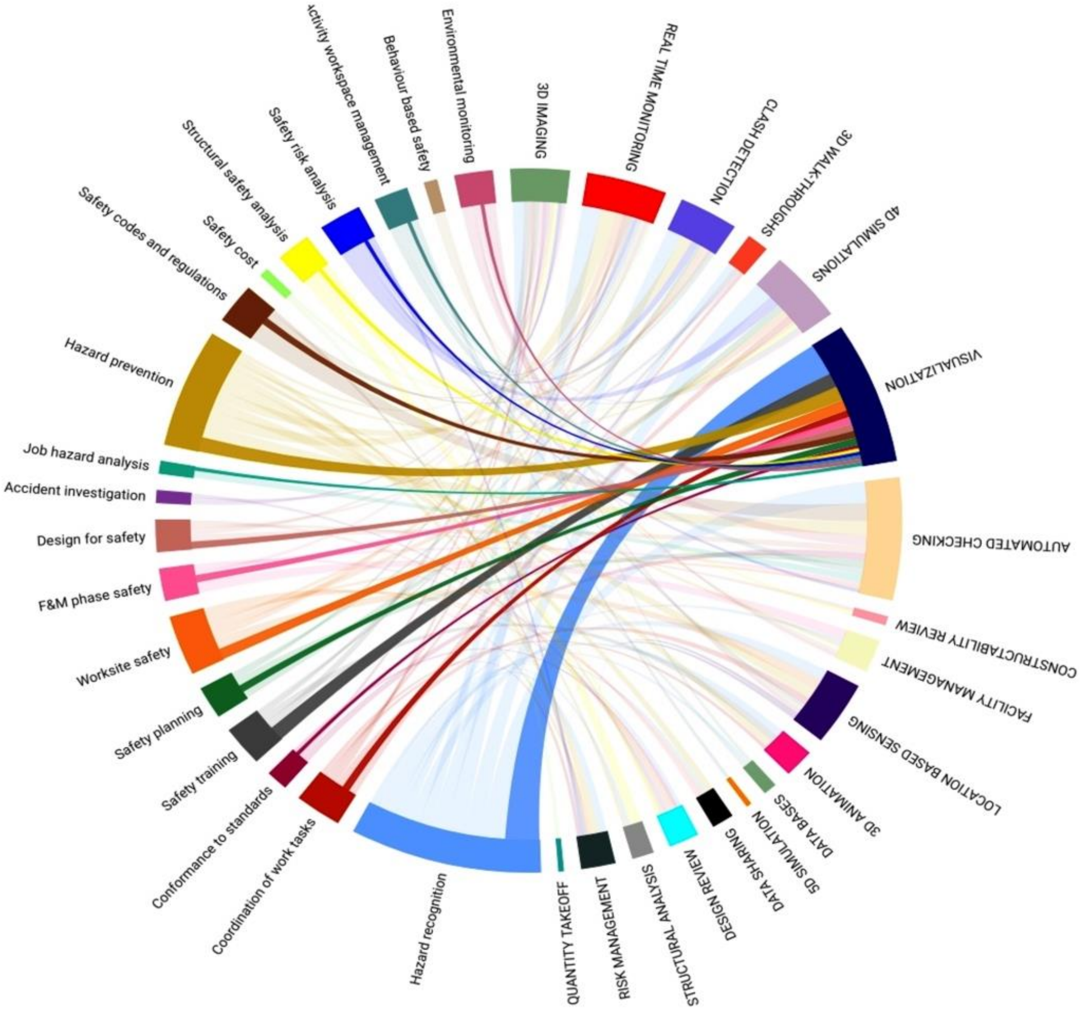


Figure 2.10 Correlation of visualization

Further, visualization has proven to be substantial in safety training as it helps in overcoming language barrier which workers face during training session. Most of the immigrant workforce faces difficulty in understanding the training material. Therefore, BLR (2007) suggested using visual representation for providing training to workers. A survey conducted by Demirkesen and Arditi (2015) demonstrated that majority of the US companies consider effective safety training as a fundamental step for improving safety management. Training for safety was conducted on a group of construction management students to test the effectiveness of visualization approach, and applicability for industry practices. The students were asked to share observations after the training session which was conducted in two ways; first test was following traditional training techniques, while the second utilized visual-aids. The results came out to be positive and appreciable for visualization (Clevenger et al., 2015).

Safety planning, the first and foremost aspect for providing any safety practice, includes hazard recognition and hazard prevention as the main components of safety management. While performing safety planning, all the hazards as well as near misses must be observed and reported to construction site personnel so that mitigation strategies can be developed (Cambraia, Saurin, & Formoso, 2010; Marks, Teizer, & Hinze, 2014). Near miss reporting information, like hazard recognition and jobsite safety planning, can be greatly improved by visualization (Elbeltagi, Hegazy, & Eldosouky, 2004; Hallowell, Hinze, Baud, & Wehle, 2013). Thus, Shen and Marks (2015) developed a database for near miss information in BIM, so that reporting and visualization can be performed. This should be considered while planning for safety, so that safety professionals can visualize near misses throughout the construction phase. Similarly, S. Zhang, Sulankivi, et al. (2015) developed automatic checking of safety hazards and the understandable visualization of those identified along with a protective system for their mitigation.

The large number of casualties and injuries results in an excessive cost and worktime loss which ultimately affect the safety cost of project (Huang, Leamon, Courtney, Chen, &

DeArmond, 2011). BIM might not directly address the aspect of safety cost but it helps in lowering down the cost spent on accidents due to its effectiveness in improving construction safety (Zuppa, Issa, & Suermann, 2009). However, the body of literature lacks such a framework for enhancing safety through BIM features. To bring down the statistical figures, experts have been focusing towards identifying the root cause of many injuries, out of which unsafe human behavior came out to be the most significant with a large number of injuries from lifting or carrying, trapped between objects and slip, trip or fall (Labor department HongKong, 2016). To mitigate unsafe behavior from human nature, D. Chen and Tian (2012) suggested behavior based safety as the most effective approach. However, less amount of work has been conducted in different dimensions of this knowledge area, such as analyzing the impact of safety culture on workers behavior and relationship between workers and safety superintendents (P. Zhang, Li, Fang, & Wu, 2017). The detail scrutiny of literature resulted in the solutions for the adoption in the project lifecycle as shown in Table 4.

Table 2.4 BIM based Safety Improvement Strategies

Code	**Strategies**	**Selected References**
S1	BIM based contract provision in project	(Chong et al., 2017)
S2	Define BIM goals based on project scope and information exchange procedures	(Eastman et al., 2011)
S3	Set up a BIM team with well-defined tasks (BIM Manager, Coordinators and modelers)	(Singh et al., 2011)
S4	Define strategy for BIM implementation to achieve the sc ope	(Eastman et al., 2011)
S5	Clarify the cost for tools(BIM) and safety equipment in early project stages	(Zhou et al., 2012)
S6	Hiring of safety professionals well acquainted with BIM process and workflow	(Akula et al., 2013)
S7	Generating preliminary BIM model in schematic design phase to visualize the project early	(Azhar et al., 2012;Ding et al., 2014)
S8	Hazard identification and prevention using BIM based visualization	(Zhang et al., 2015)
S9	Removal of activity timeline conflict by linking 3D BIM model with schedule to improve activity execution workspace management	(Hu and Zhang, 2011;Moon et al., 2014)

S10	Safety evacuation plans to be made for worksite using BIM	(Rüppel and Schatz, 2011)
S11	Safety trainings demonstrating safety concerns using models, walkthroughs and 4D simulations.	(Azhar, 2017)
S12	Appropriate execution planning for **high risk** construction activities using 3D model and 4D simulation	(Akula et al., 2013)
S13	Explanation, Distribution and Communication of work task within the project team in the 3D & 4D Environment	(Azhar, 2017)
S14	3D walkthroughs for identification of hazards in congested spaces on worksite	(Azhar, 2017)
S15	BIM based visual presentations for promoting level of communication at all stages of project	(Ding et al., 2014)
S16	Safety monitoring through BIM-based visualization	(Arslan et al., 2014)
S17	BIM based safety completion reports for observing and recording safety performance	(Azhar, 2017)

Chapter 3

Research Methodology

This study has been carried out in four different stages with flowchart shown in Figure 11 and description given below.

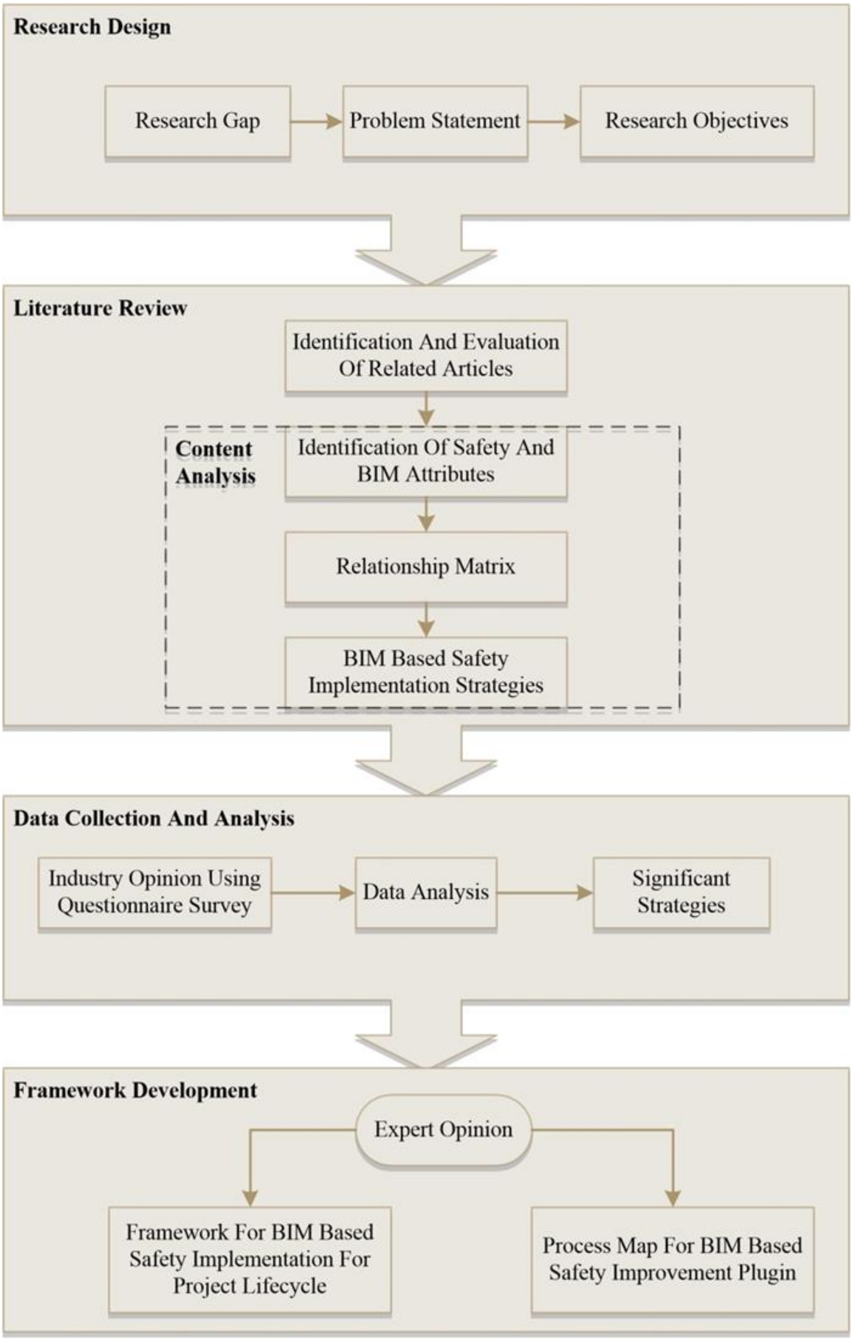


Figure 3.1 Research Methodology Flowchart

3.1 Research Design

The primary step was to analyze the latest published articles in the field of construction management. The trend of articles displayed the relevance and importance of BIM in this field. Afterwards, literature on BIM was critically explored to find the research gap, bringing attention towards safety management. Despite extensive work in this knowledge area, safety condition of construction industry is still miserable. Therefore, safety management was found to be a potential area which can be addressed using advanced features of BIM. Previous studies present the work of these knowledge areas with little emphasis on BIM based safety implementation. Considering this knowledge gap, objectives were formulated which involve finding attributes of BIM and safety management and their relationship. Based on their relations, possible strategies were identified to design the framework for BIM adoption in project lifecycle leading to safety improvement.

3.2 Literature review

After formulating research objectives, an extensive review of literature was conducted whose methodology has already been explained in the literature review section. Content analysis, which is systematic process of reviewing literature and extracting required information (Li et al., 2018) and used by many researchers to examine large amount of textual data in a systematic manner (Ahmad et al., 2018;Mok et al., 2015), was performed to identify the significant attributes. Afterwards, strength of relationships between BIM features and safety factors was assessed through a feature-factor matrix. The strategies were then identified based on this relationship strength to encourage BIM based safety application.

3.3 Data Collection and Analysis

A participatory approach was employed for data collection in the form of online questionnaire survey and data validation through interviews. Similar technique has been adopted by different researchers (Aarons et al., 2011;Landsverk et al., 2012). An online survey form was developed based on the identified strategies to attain the opinion of industry and academic professionals, literate of BIM and its application. It contained two sections; section 1 inquired respondent's demographic and organizational information and section 2 comprised of short questions to find the level of agreement upon identified strategies on a 5-point Likert scale (1= very low and 5= very high). These strategies have two parts; first part contains basic level strategies for organizations having low level of maturity of BIM adoption. The second part consisted of short and multiple-choice questions to improve the safety conditions using advance applications of BIM. Respondents were encouraged to provide additional strategies through an open-ended question.

After collecting, 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 = $4 < m \leq 3$; Disagree = $3 < m \leq 1$. This illustrates that the strategies with $5 \leq m \leq 4$ would be considered for further research (Chong et al., 2017).

To ensure representativeness, minimum required sample size was calculated because the number of respondents can vary in different quantitative studies. To calculate the sample size using statistical approach, Cochran (2007) formula was used as shown in Equation 1, where n is the required sample size, m is the factor of confidence level obtained from normal distribution table, p is the sample mean, q is 1-p and y is the margin of error.

$$n = \frac{m^2 * p * q}{y^2} \qquad Equation\ 1$$

Substituting m = 90%, ±10% marginal error and 50% sample mean, sample size came out to be 41.

3.4 Framework Development

The frameworks were generated using BIM as a tool for safety enhancement. For this, significant strategies were grouped into project lifecycle phases leading to BIM adoption in construction projects. Afterwards, to automate the process of safety improvement using BIM, a process map was formulated giving blueprint of a BIM plugin. This plugin will position BIM centrally as a decision support tool which can be used by practitioners in implementing safety practices. The frameworks were then validated by interviewing industrial experts having experience greater than 15 years. A total of 14 interviews were conducted and frameworks were modified as per their opinions. Lastly, conclusions are given followed by industrial and research implications.

Chapter 4

Results and Discussion

4.1 Data Analysis and Results

The questionnaire survey 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 et al. (2017) deployed a sample size of 36 for finding the level of intent on identified strategies.

The demographic information in Figure 12 shows the dispersed regional background of the respondents. Most respondents are from Qatar (15%) which indicates that the level of adoption of BIM is particularly high in this region, and all the respondents from Qatar marked their level of understanding of BIM as advanced. They highlighted that their organizations use BIM for building projects but not for construction safety improvement. This is generally because unfamiliarity of technological use for management practices.

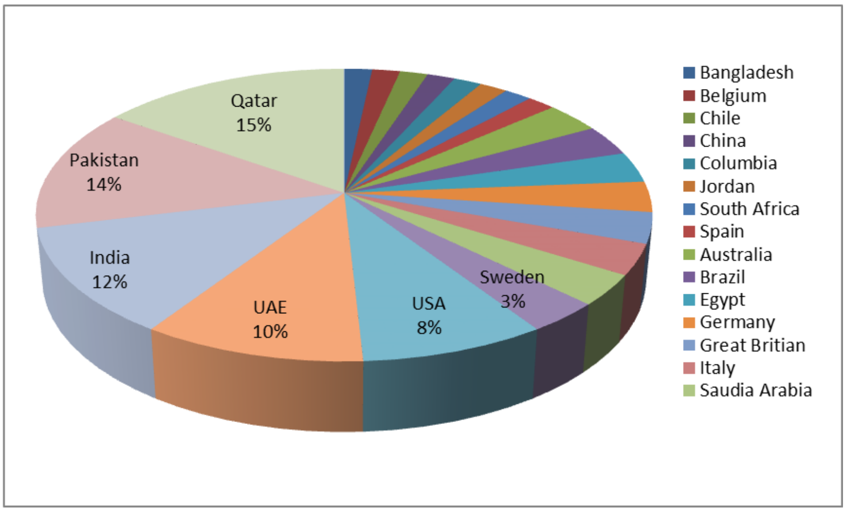


Figure 4.1 Regional Distribution of Respondents

Most respondents belong to consultant and contractor organization since they are the primary stakeholders and can implement safety practices in any construction project. Therefore, it was necessary to take their opinions. Similarly, a good number of respondents report over 5 years' experience as given in Table 5. It was deliberately done to engage only those respondents who understand BIM to some extent; therefore 65% of the respondents report advanced understanding and there is no respondent with zero understanding of BIM.

Table 4.1 Respondents Information

Total Respondents = 60	
Profile	**Percentage**
Nature of Organization	
Client	5%
Architect	15%
Contractors	30%
Consultants	42%
Academia	8%
Years of Experience	
1 to 5 years	23.30%
6 to 10 years	33.33%
11 to 15 years	21.66%
16 to 20 years	13.33%
21 and above	8.33%
Qualification	
B.tech	13.33%
BSc/B Engg	40%
MS/MSc/M.A	35%
PhD	11.67%
Others	0%
Level of Understanding of BIM	
Advanced	65%
Good	28.30%
Basic	6.70%
No understanding	0%

Similarly, in current job position, 59% respondents work as BIM Managers. Other categories include Managing directors, Health and Safety Executives, Professors, Senior Architects and Civil Engineers with sufficient knowledge of BIM applications.

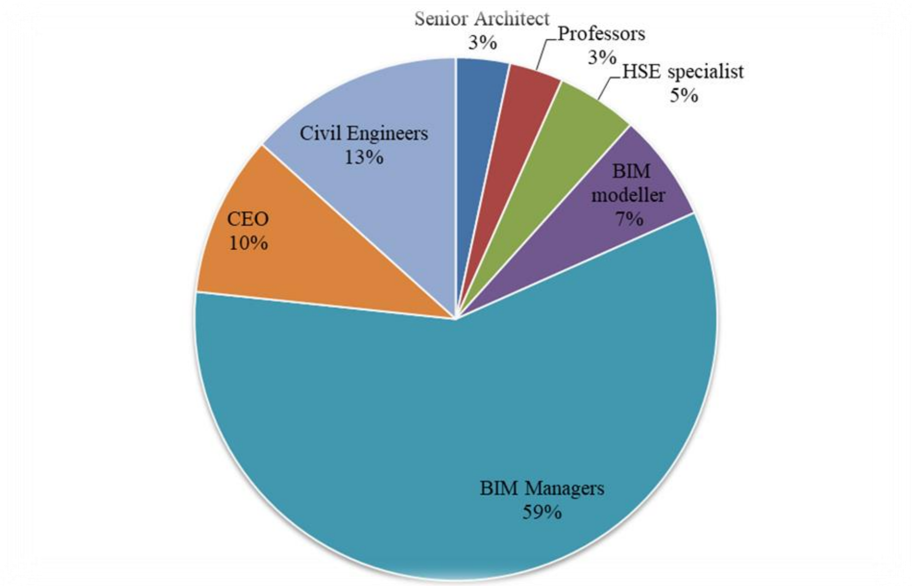


Figure 4.2 Designation of Respondents

More than 90% of respondent's organizations were using BIM and other less than 10% respondents having basic to good understanding of BIM and their organizations are not using BIM in their projects. Respondents were asked about the project delivery method which their organization used during projects and mostly used method is public-private-partnership (PPP) which is 37% and second mostly used method is design-bid-build which is 23% rest of organizations were using construction method, design build and integrated project delivery method.

Respondents were also asked to provide about the safety issues they face during projects. Out of 60 only 13 respondents said that they always face safety issues and hazards while 12 respondents said they rarely face any safety hazards which shows that respondents have mixed response for safety issues. More than 50% respondents said using BIM has proven to be beneficial for their organization.

To check the reliability of collected data, Cronbach's alpha test was performed, giving a result of 0.958, showing that data is highly reliable as well as consistent (Bautista and Bayang, 2015). Normality check was also carried out using both Shapiro-Wilk and Kolmogorov-Smirnov tests.

The results reveal significance value of zero indicating that data is not normally distributed and is non-parametric. This indicates the prerequisite for non-parametric tests in further analyses. Therefore, Kruskul Wallis H test was performed to articulate any differences on number of independent samples against different groups. The groups are respondent's organizational type and their regional classification. Primarily, the test fields were tested against their organizations in which majority of respondents shows same perception on identified strategies expect for two. The distribution on BIM based contract provision (S1) is different according to organization's nature as adopting contractual obligations is critical. The results revealed that null hypothesis is rejected for this variable showing that different companies have different legal and contractual binding requirements. Contract documents are mostly formulated on special conditions agreed by all parties involved in the contract and help in overcoming project issues in the light of laws and regulations. However, adopting BIM in contractual process is still dubious in view of stakeholders. While, the different opinions for explaining, distributing and communicating work task within the project team in the 3D & 4D environment (S13) might be due to lack of collaborative working environment in construction industry. Because in most organizations, collaboration is based on two dimensional drawings and stakeholders are reluctant to adopt 3D approach for this purpose. This situation always leads to serious issues in execution of project.

The test fields were checked for any difference in opinion on the basis of regional distribution, as safety and BIM adoption level is different everywhere. However, no difference was observed in the solutions proposed for BIM based safety implementation. Furthermore, explored the status of BIM implementation in different countries, and revealed that developing part is lagging behind and needs due consideration and an explicit course of action is required for the adoption and execution of BIM based practices.

4.2 Framework for BIM based Safety Implementation

To implement safety in construction sector, a self-regulatory approach which includes formulation and operation of safety management systems should be adopted by organizations (Ng et al., 2005). As the organizational commitment to safety has a strong positive influence in promoting safety culture, it would encourage teamwork between the administration and workforce (Gibb et al., 2001). Agile participation from top management is vital for successful accomplishment of project and should be replicated by lower staff. While in present situation, information exchange is usually prone to error due to involvement of different parties. Therefore, a system is needed which aids in providing exact information and to make inroads into better coordination. This brings towards the digital approach in implementing safety on organizational level. Eadie et al. (2013) highlighted the substantial organizational impacts through BIM implementation for all stages of the construction process. They concluded that BIM implementation may impact all the processes within the project organization and hence cannot be treated in isolation as a software tool. Therefore, a framework is developed based on the findings and analysis of this study, as shown in Figure 14. The framework encompasses BIM in construction project lifecycle to enhance safety application. As the BIM practice is still in its infancy (Enshassi et al., 2016), the framework provides initial adoption steps which will act as a breeding ground for improving safety by accomplishing basic requirements in the conceptual stages of project.

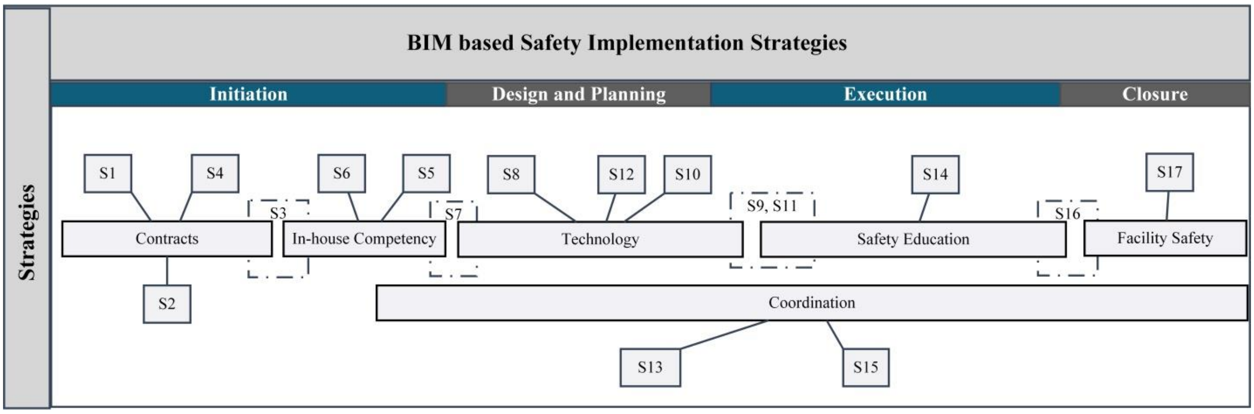


Figure 4.3 Framework for BIM based Safety Implementation

Contracts are the preliminary step to carry out any construction work, so the first and foremost phase in adopting BIM is its inclusion in contracts (S1) as it helps in dealing the legal and contractual issues associated with its implementation. All of the experts suggested adding BIM in the contractual part of project. Furthermore, almost 80% of the experts recommended adding stringent safety clauses in the contract. Chong et al. (2017) encouraged and developed the BIM based contractual framework in the project lifecycle. However, to facilitate the uptake of BIM, legal risks have been identified and addressed by Arshad et al. (2019) along with allocating risk ownership to the concerned stakeholders.

Afterwards, define BIM goals based on the project scope (S2). Mature organizations develop BIM execution plan (BEP) for successful implementation in the initial phases of project. Although BIM covers many dimensions, BEP helps focusing its scope within a project. Besides the value addition this facility provides, cost of implementation cannot be ignored. Executing BIM demands the hardware and software requirement for the organization and its projects (S5). With this, experts highlighted that training of acquired software must be provided to augment in-house competency which ultimately brings considerable financial effects. This high front end cost required in software tools and training of staff has proven to be most significant barrier in the implementation of BIM (Azhar, 2011;Eadie et al., 2014). However, one suitable way to reduce this cost is the selection of appropriate application areas. Therefore, it is necessary to list out the BIM goals depending upon the project scope (S2) in initial phases of project. Additionally competent team (S3), having advanced understanding of BIM, should be engaged for the realization of project objectives. Afterwards, the team should prepare strategy for BIM implementation to achieve the scope (S4). This will include the level of detail for BIM modeling and flow of information exchange between different stakeholders. Once the BIM process is fully merged with organization's structure, hiring of safety professionals well acquainted with BIM process and workflow (S6) is necessary to monitor project situation and develop policies as per the project requirements.

Generally, it is observed that safety planning is done separately from project design and planning (Azhar, 2017). However, safety personnel should utilize the construction drawings to foresee the project conditions and plan for safety accordingly. For this, it is needed to develop BIM model in the schematic design phase to visualize the project early (S7). This visualization of the project would help observing the safety issues more closely and accurately; thereby encourage developing prevention strategies for the identified hazards. With the help of BIM, 4D construction sequencing can facilitate in interpretation of construction site safety clashes prior to start of project. Therefore, activity timeline conflict can be removed by linking 3D BIM model with schedule to improve activity execution workspace management (S9). Temporary structures used for onsite construction activities such as tower crane, formwork and scaffolding operations yields high risks. Regardless of knowing high injury statistics for these risky structures, safety planning procedures fails to concentrate on safety issues caused by temporary structures (Kim and Teizer, 2014). However, BIM can facilitate in this regard by appropriate execution planning for high risk construction activities using 4D simulations (S12). To discover the nature of accidents that happen mostly on construction sites, Malekitabar et al. (2016) deployed a model check on some cases which revealed that majority of the fatalities occur due to improper design for safety. They highlighted that emergency evacuation plans are one of those many things that needs due consideration in safety planning. Therefore, safety evacuation plans must be prepared for worksite using BIM (S10).

Similarly, lack of safety education is one of the highlighted barriers in effective safety management (Park and Kim, 2013;Enshassi et al., 2016). A formalized system for providing safety knowledge to workers should be present in every construction organization. Azhar and Behringer (2013) underlined that an additional use of BIM is the provision of safety training with the help of features like visualization, 3D walk through and simulations. Because in the execution stage of project, every day comes up with new challenges therefore workforce should be prepared in advance to deal with risky situations. However, such kinds of trainings are recommended throughout the construction stage. In addition to this, monitoring of all the safety procedures should be carried out during execution; which ultimately curtails the causalities and ensure effective safety.

In construction industry, lack of coordination is also reported as the prominent cause of delays, clashes and accidents. However BIM can provide collaborative working environment; as Shenyun (2016) conducted a collaborative analysis of safety level during the execution process. Safety should not be ignored even in the closing phase of project, therefore this study made an attempt to address all the safety issues using BIM in the complete project lifecycle. Initial development of framework did not included the closure phase of project, but upon discussion with industry and academia experts it was recommended to add this phase so that safety issues incurring in the facility and maintenance can be minimized. This framework has been developed after the validation from highly experienced experts who had good understanding of BIM and its applications in construction management.

4.3 Hazard Identification Process Chart

BIM encourages construction management practices in many ways. In discussion with experts, integrated aspects of BIM were focused which resulted in the most demanding application for safety management. They added that although multiple advanced applications have been devised and executed for this technology platform, but detailed safety information have yet to be integrated in the visualization and communication protocols of BIM. Considering this, a theoretical process map of fully automated safety management plugin shown in Figure 15 has been generated for integrating safety practices and associated codes in to the BIM model. This plugin will illustrate possible safety hazards and their controlling mechanisms. The detailed architecture of the process map is represented in Figure 16 which gives a clear picture of plugin inputs, functions and outputs. In an attempt to automate the safety management process, BIM acts as a central platform in the anticipated plugin framework. Different BIM modeling tools can be employed due to the flexible and candid nature of proposed plugin design. Model development should incorporate all the technical information including architectural, structural and MEP design of the project along with probable schedule data.

As BIM acts as the decision support tool therefore contribution of stakeholders and technical experts in the functioning of plugin will noticeably bring constructive outcomes. As an input, plugin incorporates component level details (n-D) and proceeds further by involving relevant stakeholders exclusively those who can influence in decision making regarding safety control measures. To mine the hazard database, information will be extracted from published literature, previous project safety reports, site implementation knowledge of safety managers and OSHA clauses for these hazards. It is suggested to frequently keep on updating the database, as per devised standalone application in Figure 16, because every project is unique and can have varied linked risks.

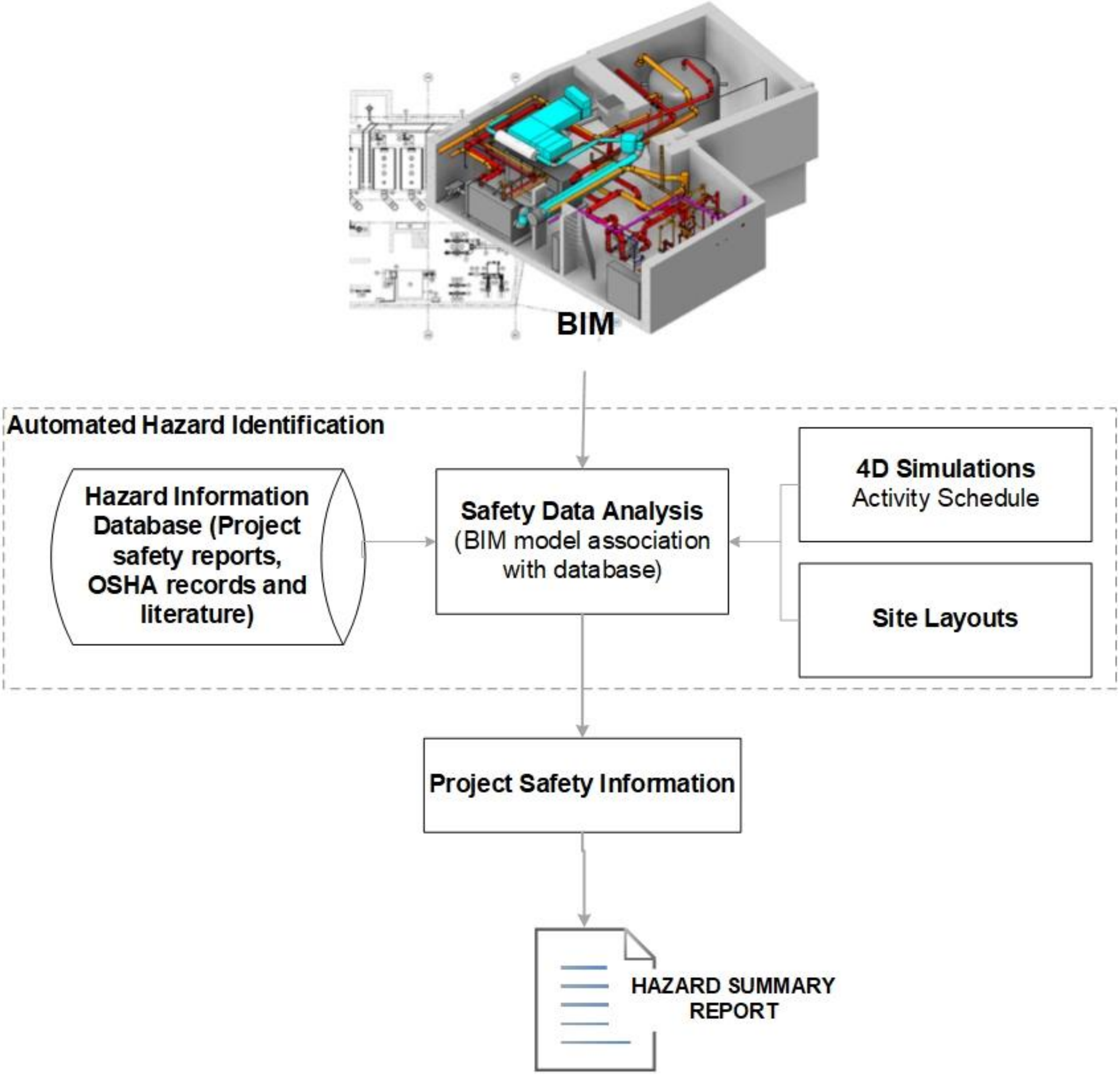


Figure 4.4 Automated Hazard Identification Process Chart

After going through the process of BIM model development, database is associated with the model elements by appropriate selection. This plugin functions as the automatic hazard identification tool by associating safety data with the model elements in the conceptual stages of project, which will ultimately generate project safety database. Safety personnel can use this database in any stage of the project to visualize the possible hazards and make preventions. To prevent activity execution timeline conflicts, information received from 4D simulations will facilitate. As an output, plugin will produce safety reports which can be used by safety managers to imply safer practices and record observations.

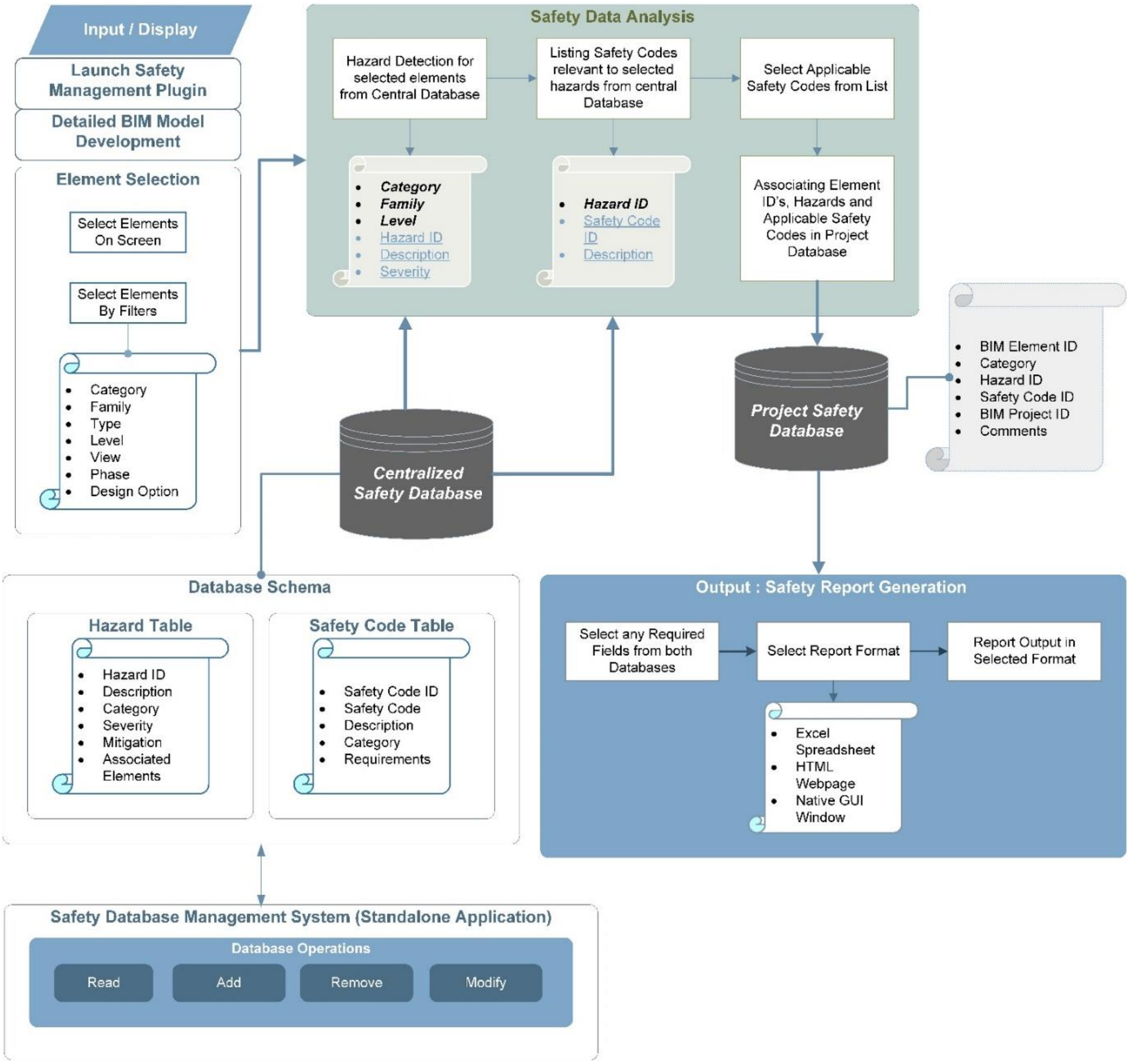


Figure 4.5 Functional Architecture

This safety enhancement tool can be created using application programming interface on BIM platform. This functional plugin is created to facilitate the developer in understanding the information flows and report output.

Chapter 5

Conclusions and Recommendations

Construction industry is slow in adopting advanced managerial practices therefore comparatively less amount of work has been focused towards practically improving safety management using BIM. Many construction organizations have not even adopted BIM in their projects thus a systematic guideline, for the project lifecycle, is the need for hour for BIM based safety implementation. This study has contributed towards providing step by step guide in achieving best applied approach throughout the project life.

For this purpose, factors of safety and features of BIM were studied and association strengths were identified from previous literature. This leads to the development and identification of possible solutions for BIM based safety improvement. Significant strategies were discussed with academia and industry experts and framework was generated subsequently. The framework addressed the significant barriers in adoption of technological safety practices and presents possible solutions to them at every stage of the project. On the recommendation of experts and critical scrutiny of literature, an automated plugin has been developed to integrate safety aspects with BIM platform. The proposed plugin addresses the major aspects related to internal project information as well as the site related detail. The database in BIM includes all the safety standards present in regulations and literature. This effort would help in automating the identification and prevention of construction site hazards related to logistics as well. It is recommended to adopt proposed solutions for the improvement of safety conditions in construction industry. Furthermore, future work can be performed by integrating sensing technology like drone for providing real-time input to BIM for improving construction site conditions.

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