IMPROVING PREVENTION THROUGH DESIGN IMPLEMENTATION BY GLOBAL SAFETY RISK REPOSITORY USING BUILDING INFORMATION MODELING

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THESIS ACCEPTANCE CERTIFICATE

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DEDICATED

TO

MY FAMILY & FRIENDS

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LIST OF ABBREVIATIONS

Building Information Technology	BIM
Architecture, Engineering, Construction	AEC
Prevention through Design	PtD
Designing for construction safety	DfCS
Critical Success Factors	CSF
BIM-Safety Risk Scoring System	BIM-SRSS
Personal Protective Equipment	PPEs
Occupational Health and Safety	OHS
Global Safety Risk Repository	GSRR
Occupational Safety and Health Administration	OSHA
National Institute for Occupational Health	NIOH
National Examination Board in Occupational Safety and Health	NEBOSH
Information and communication technology	ICT
Three-Dimensional	3D
Augmented reality	AR
Safety-Management and Visualization-System	SMVS
Valtion Teknillinen Tutkimuskeskus	VTT
Artificial Intelligence	AI

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ABSTRACT

Most of the construction site injuries and accidents occur due to a lack of proactive involvement of higher management and adaptation of “Prevention Through Design (PtD)” in work-site safety. Prevention Through Design most often leads to safer work-site conditions and has a positive impact on overall project planning, design, and execution. Critical Success Factors (CSFs) related to the PtD implementation are identified through literature review and further shortlisted using two-phased content analysis. This research study uses Building information modeling (BIM) and Django framework to develop a web-based BIM Safety Risk Scoring System (SRSS) that allows managing safety risks during the design phase. The developed BIM-SRSS tool keeps a repository of historical OHS data and updates the risk score systematically as frequent data is incorporated into the GSRR database. To establish the repository, the risk assessment data from the industry is obtained and respective risk scores are rated by three industry experts. To test the BIM-SRSS tool, the design elements are tested on a real-time case study using visual programming. Finally, the working of the BIM-SRSS tool is validated by conducting semi-structured interviews with seventeen (17) industry Designers and OHS professionals. Barriers to implementation of the BIM-SRSS tool and recommendations for its improvements were also discussed with the experts.

Key Words: Building Information Modeling (BIM), Prevention through Design (PtD), Construction Safety, Risk Assessment.

Chapter-1

1. INTRODUCTION

1.1. STUDY BACKGROUND

In every country, Gross Domestic Product (GDP) is important because it provides statistical information of Economy size and working. The growth rate of GDP is also used as a gauge of the economy's overall performance. The architecture, engineering, and construction (AEC) industry is a major contributor to economic growth and GDP. The AEC industry is an investment-driven economy with good funding from public sector (Farooqui et al., 2008). The economy and pace of development of every nation are heavily reliant on the presence of utilities and buildings (Demirkesen & Arditi, 2015). Nonetheless, the construction industry has a long history of being one of the most violent, with the construction site being an especially unsafe workplace. Although it is competitive, as opposed to other sectors (Imriyas et al., 2007) And the participation require frequent effort and devotion at all stages The construction sector is dealing with higher accident rates, which not only adversely affects its reputation but also negatively impacts its future creativity (Zou et al., 2017). Given a significant increase in health regulation because of applicable legislation, such as the UK Health and Safety Executive in the USA Occupational Safety and Health Administration (OSHA), In Hong Kong, the NIOH (National Institute of Health) is in charge of the Labor Department (National Institute for Occupational Health). In the occupational health and safety review of European figures for the period 2010–2019, the AEC industry has the largest fatalities (Eurostat, 2019). The mortality rate in the AEC sector has risen globally. In 2018, 5250 fatality injuries were registered in the United States, up 2% from 5147 in 2017 (Bureau of labor statistics, 2019). Since all workers deserve to work in a protected and clean environment, construction workplace health and safety are extremely critical for each on-site employee (Toole et al., 2017). The regularity agency must provide a safe environment. The majority of building accidents are not reported or documented, but those that catch the public's eye or make the news are. As a result, planning for operational health and safety is difficult without adequate information (Raheem & Issa, 2016).

The causes that have contributed to these alarming statistics are Lack of teamwork, employee conduct, inadequacy with risk control in a competitive workplace, and other factors all contribute to troubling statistics (Enshassi et al., 2016) The construction sector is beginning to realize that, by necessity, builders' protection measures during construction are restrictive and inadequate to protect the workers' wellbeing. Construction management in AEC sector aims to place a high emphasis on improving employee health and safety (J. A. Gambatese et al., 2002). Recent scientific studies have placed a greater emphasis on proactive health management strategies and their efficacy in preventing possible hazards (Rajendran & Gambatese, 2013; Toole & Erger, 2019). This is one of them. Many recent research projects and construction safety studies have concentrated on reducing construction site risks. Several previous building safety review papers and articles focusing on the management of construction-related risks (J. Gambatese & Hinze, 2002). Under the conditions of dynamic and competitive workplaces, safety coordination can be a difficult task. Despite the existing problems, the AEC industry needs to address the shortcomings in conventional manual processes such that advances in health can be made using advanced and new technologies (Sijie Zhang et al., 2013a). However, not everyone agreed that the mitigation methods implemented during execution were the most effective. Designing for construction safety (DfCS), also known as Prevention by Design (PtD) by those in the AEC industry, is the latest research aimed at "designing" hazards, adding less

Workplace through implementing a pragmatic security a management method that can be used during the planning stages of a project (Schulte et al., 2008; Sun et al., 2019; Toole et al., 2017; Sijie Zhang et al., 2013b), When architects use the design-for-safety term, it has an impact on construction site safety (Tymvios & Gambatese, 2016a). Proactive detection and avoidance of possible site threats are more efficient and less expensive than reactive management (J. A. Gambatese et al., 2017). The effectiveness of PtD understanding of threats to life and health during the designing phase. Hazards may be eliminated or tracked more easily with early detection, resulting in cleaner building practices and job sites. (Goh & Chua, 2016).

Building Information Modelling (BIM) is a digital representation of a facility's spatial and mechanical characteristics that uses 3-D or 4-D animation to illustrate the concepts (Sijie Zhang et al., 2015). The project is visualized using the BIM model in the design profile. BIM may be used to increase construction safety by establishing a strong relation between safety concerns and construction planning. The use of BIM in architecture and building design is increasingly expanding in the AEC industry, as it improves project efficiencies through simple visualization that integrates multiple techniques into the construction process (Sijie Zhang et al., 2015). BIM has quickly been known as a game-changer in the way construction projects are delivered. BIM may also be used to facilitate safety prevention and integrate safety with other construction preparation procedures, as has been discovered (Qi et al., 2014; Sijie Zhang et al., 2015). Most accidents arise with alarming frequency during the building's operation, resulting in many fatalities or serious injuries that exceed the technical architecture's requirements. Now it's time to assess the building's configuration in light of the initial security process.

The construction industry's high level of risk was explained by the industry's inherent characteristics. One of the unique features of the building is the varied sophistication of the work environment. In contrast to other industries that work in static and enclosed conditions (Tycho K. Fredericks1; Osama Abudayyeh, P.E., 2005) According to past studies, construction sites differ considerably in terms of scheduling, facilities, weather patterns, and land ecosystems. The involvement of multi-role work teams in a single place increases the risk level's safety complexity (Choe & Leite, 2017). Preventing accidents before they occur is the most important way to improve patient outcomes (Choe & Leite, 2017)

To accomplish this goal, It is essential to consider the implementation of safety measures. challenges and their remedies, as well as how to mitigate these concerns or strengthen safety management. This research aims to assess the most crucial success factor in the adoption of Prevention through Design in the AEC industry. Then developed a structure for how BIM or the latest technology tools would be cover PtD CSF considerations by designing a BIM-based tool that calculates the design element and their associated activities safety risk score. Finally, OHS professionals and designer's judgments are used to verify this BIM-SRSS system. This BIM-SRSS tool has the potential to enhance ability of the designers to conform with regulatory standards for OHS in AEC and incorporate design choices for workplace health and safety through mitigation into the structural design automatically to keep the building safe.

1.2. PROBLEM STATEMENT

Over the last few decades, there has been a dramatic rise in global attention to safety in the AEC industry. Any employee on construction site needs to be healthy and wants a safe working environment (Esmaeili et al., 2015). Workplace accidents still happen all too often, particularly in the construction industry. Via design reviews, modeling, and other BIM-based extensions, Designers may simply "design out" or minimize hazards and their associated risks using design reviews, modelling, and other BIM-based extensions. According to the findings of a survey conducted by Mohammad Kasirossafar 1 & 1, (2013), 75% of the participants were either research scientists or professional designers and engineers, agreed that BIM application in the design process could anticipate and deter construction accidents. According to Behm, (2005) PtD will remove almost one-third of possible safety risks, with 50% of those being specifically linked to unsafe design. Because of the growing concern about safety and technical innovation, it is critical to have a suitable way or system for implementing safety using BIM in the early stages of projects. Everyone speaks regarding emerging technologies, but no one has the confidence to overcome their fear of change when it comes to applying them and their consequences. Only a few experiments have been done to incorporate building health and safety issues into the planning and design processes (Gangolells et al., 2010). A major hindrance to the implementation of PtD is the lack of designers' knowledge of OHS procedures (Gangolells et al., 2010; Goh & Chua, 2016). Most construction risk assessment is done "manually" with little or no information sharing, and designers have low hazard recognition skills (Hallowell & Hansen 2016). BIM is one such approach that can be utilized to create a hazard database that can be used to augment designer hazard identification skills (Mohammad Kasirossafar 1 & 1, 2013). According to recent research studies, BIM-based tools in construction safety management result in better implementation of PtD, thereby improving construction site safety. However, most studies addressing construction safety at the design stage using BIM have only focused on a specific hazard (e.g., falls)((Hongling et al., 2016; Qi et al., 2014). Moreover, historical data of past experiences of similar projects or OHS professional opinion are not considered for risk assessment (Perlman et al., 2014).

1.3. RESEARCH QUESTION

Hence the question arises "How Can PtD be made a success using BIM and web-based technologies"?

1.4. RESEARCH OBJECTIVE

- To identify critical success factors for successful implementation of PtD to improve occupational health and safety in building construction.
- To develop a BIM-based Safety Risk scoring framework and tool to determine the Safety Risk score.
- To validate the developed framework or BIM-SRSS web-based Tool.

1.5. SIGNIFICANCE OF THIS STUDY

The construction industry in Pakistan is extremely labor-intensive and lacks modern technologies, resulting in a connectivity void, major financial loss, and human loss. The reasons preventing a deeper understanding of safety on construction sites in Pakistan include a lack of teamwork, attention to safety, in-house competency, and experience with specialized resources to apply safety culture. Pakistan's construction industry is technologically outdated and labor-intensive, resulting in communication gaps, human losses, and significant financial losses. Improved safety implementation at construction sites in Pakistan is hindered by a lack of experience with advanced resources, a lack of coordination, in-house experience, and a commitment to safety for enforcing a safety culture (Farooqui et al., 2008). In order to increase the safety of construction projects in developing countries, like Pakistan, BIM technology must become more familiar. This method assists in the alignment of the construction process' lifecycle processes as well as the settlement of conflicts. This study aids the designer or customer in the planning process by allowing them to visualize and monitor occupational health and safety risks using the most effective method proactive management. This research would assist the Construction industry in implementing a technology-based approach to the pressing problem of Occupational health and safety of AEC industry.

1.6. STUDY SCOPE

The risks of occupational health and safety in the AEC industry were the focus of this research. During the design process, the engineer or architect, as well as the client, may assess and envision the workplace safety risks. By reducing safety risks, this study benefits all project stakeholders. Using a safety risk scoring system, automatically assess workplace health and safety Risk. Construction safety monitoring that is both time and cost-efficient saves time and money by quickly detecting and eliminating safety risks. By using the BIM-Based Safety Risk Repository tool, To mitigate site hazards, proactive steps could be done throughout the design and planning phase. This study will ensure that safety is implemented during the building's development or operational stages.

1.7. THESIS LAYOUT

In this thesis, Chapter 1 includes the background in detail, previous work on this area of research with the problem statement, the objectives of this research, and the significance of this thesis in the construction and architect industry. Chapter 2 consists of a detailed literature review of the PtD practices implementation critical success factors and in past studies how they incorporate in the construction industry or how can improve the PtD practice by using the latest technologies. Chapter 3 involves the methodology adopted to acquire the safety Risk data involving the experimental paradigm and workflow and the development of the framework with the complete working of the framework. Chapter 4 describes the developed system or its, the complete working, evaluation, feedback from the industry and the analysis of results obtained, and a discussion in detail. Chapter 5 discuss the study conclusion and explains the future recommendation.

Chapter 2

2. LITERATURE REVIEW

An extensive literature review was undertaken to ascertain current work on construction safety management by using the proactive activity with help of the latest technologies like Building information modeling or Artificial Intelligence. In the first step identify the relevant journals or conferences by using the different search engines ASCE library, Research Gate, Elsevier, Google Scholar, Scopus, and others. The evaluation criteria for journals were based on earlier research of a similar nature and included only those journals that had at least two publications published for the applicable study period (Martínez-Aires et al., 2018).

2.1. CONSTRUCTION SAFETY

Since all workers deserve to work in a protected and clean environment, construction workplace health and safety are extremely critical for each on-site employee (Riaz et al., 2014). Responsibility of regularity authority must ensure that the environment is safe. The construction industry has a long history of being one of the most hazardous, with the construction site being one of the most dangerous places to work. (Benjaoran & Bhokha, 2010; Gambastese2, 2012; Ganah & John, 2015; Gangolells et al., 2010). Statistics indicate construction site fatality, illness, and injury in building construction is a worldwide problem of OHS (Martínez-Aires et al., 2018; Sijie Zhang et al., 2015; Zhou et al., 2012) Although it is competitive, as opposed to other sectors, (Imriyas et al., 2007). The AEC industry accounts for more than a third (36%) of all occupational deaths in the United States. Similarly, one out of every four fatal workplace deaths in Finland is caused by the AEC industry (Sijie Zhang et al., 2015). Construction safety problem causes the loss of many lives, or serious injuries, disrupting the production and personnel skills. Besides causing human tragedy, it is also the failure of the construction management & accidents that damage the reputation of the firm, disturb the project budget, and delay project progress (Gangolells et al., 2010; Sun et al., 2019). Reason's Injury Trajectory Model According to James Reason, injuries can be avoided by the successful application of three filtrations: facility design, influencing factors, and work environments. However, mistakes and factual errors in any of the three methods can consequence in a near-miss or injury (Hallowell, 2008).

2.2. PREVENTION THROUGH DESIGN (PtD)

Construction site worker safety planning has a key position in project planning. Mostly the construction site worker Safety planning is performed independently from project design and planning in the building construction industry (Benjaoran & Bhokha, 2010; Sijie Zhang et al., 2015). Occupational health and safety should be the prime consideration of the project life cycle in the preliminary design phase (Zhou et al., 2012).

When performing design tasks, PtD means being aware of and appreciating the safety of construction workers, making Including worker safety considerations in the constructability assessment process, and making design decisions in part based on how construction workers are affected by the project's inherent risk. To summarize, in the design of a project, PtD specifically considers the safety of construction workers. (Fonseca et al., 2014)

Many previous construction safety study reports and publications have concentrated on reducing construction site risks during construction (Jin et al., 2019). The 42%of the construction fatalities are related to the design features of the construction safety (Behm, 2005; Gangolells et al., 2010; Hossain et al., 2018). The safety accident has occurred during the project execution phase that is why the contractor becomes the sole responsible. To make construction worker safety management successful the identification of the hazard is the main consideration (Carter & Smith, 2006; Gangolells et al., 2010). Nowadays The awareness is rising that many hazard or safety problems during the maintenance, repair, operation, or project execution could be removed with or at least mitigated by close thought during the design phase (Hossain et al., 2018). Designers will play an important role during the design process in early influencing the safety of construction. Its designs direct the choice of construction techniques (Jin et al., 2019). Designers must know their superiority and the subsequent building techniques must be capable of identifying dangers and hazards. They then utilizing safer designs avoided or reduced any hazards or risks (Benjaoran & Bhokha, 2010). Proper safety precautions or design modifications may have avoided the accident or reduced the building danger. Some reviews of building deaths or surveys found that 50 percent -60 percent of them could have been decreased the risk of injuries or avoided with further consideration during the Design phase (Hossain et al., 2018). Several construction experts conclude that substantial decreases in construction accident rates on construction sites could be accomplished by addressing workplace safety during the planning of a building, not just during the construction process (Atkinson & Westall, 2010; Mohammad Kasirossafar 1 & 1, 2013). However, not everyone agreed that the mitigation methods implemented were the most effective. The latest research has been directed at "designing" risks, introducing fewer dangerous elements, or reducing the number of harmful exposures on the construction site by adopting PtD, as health on construction projects is influenced by builders integrating the idea of PtD (Jin et al., 2019). Recent scientific studies have placed a greater emphasis on proactive health management strategies and their efficacy in preventing possible hazards (Rajendran & Gambatese, 2013). Usually, designers specify the materials and their arrangement for a facility that forms the basis for the approaches and methodologies used during execution. Nevertheless, designers are still unaware of the health effects that they face while carrying out their projects (Gambastese2, 2012). However, only a few research reports on integrating construction OHS issues into design and planning processes have been performed (Gangolells et al., 2010; Jin et al., 2019). That’s Why needed to identify the critical success Factors (CSF’s) to implement PtD successfully in the AEC industry.

2.2.1. Critical Success Factor To Implementation Of The PtD.

Correct design choices decide construction approaches and plans, which is one of the major flaws of the current safety preparation mechanism. Designers often underestimate the effect of their work on construction techniques, timelines, and, most critically, protection. During the design stage, there is no awareness and clarity about the possible risks that could arise after a project mission is completed, and what mitigation plans may be used to address the safety problem (Hadikusumo & Rowlinson, 2002). Many contractors examine danger control approaches using two-dimensional drawings (2D); the relationship between safety preparation and job task implementation is always shaky (Qi et al., 2014). In construction worker safety management, existing procedures cause impossible to use and evaluate possible solutions. Also, with complete cooperation from all parties, current safety preparation and implementation is still highly dependent on manual assessment and expertise. Standard manual observing is time-consuming, labor-intensive, and therefore unreliable, and the observed outcome may be vulnerable to error due to subjective decisions (Sijie Zhang et al., 2011). Safety performance can be properly measured and controlled by PtD practices. That's why needed to implement the PtD Practices in the AEC industry to improve OHS management.

To successfully implementation the PtD influenced by many factors with the help of a detailed literature review identify the CSF's. A total of 100+ articles of the different journals was read which are related to construction worker safety. In the 32 articles, the PtD factors are discussed.

The PtD-CSF were identified from published articles in recent literature as summarized in the table list of the journals or their details.

Table 1 Details of CSF's related articles Journals

S No	Journal Name	Total Citation
1	ASCE Journal of Construction engineering and management	14
2	Journal of Automation in construction	6

3	Journal of Safety Science	8
6	Journal of Accident Analysis and Prevention	1
7	Journal of Construction management	1
8	Journal of Engineering Construction & Architectural	1
10	Journal of Advanced Engineering Informatics	1
	Total Paper	**32**

In determining the resultant project safety results, all participants involved a standard construction project play an essential role (Tymvios & Gambatese, 2016a). When the project is formulated and goals are identified, the effect on project OHS begins with the owner (J. A. Gambatese et al., 2017; Tam et al., 2004). Designers then play an important role as the project moves from inception to execution, and some structural risks can be eliminated with proper design monitoring. Finally, during the construction process, builders and subcontractors are responsible for preventing risks (Hallowell et al., 2013; Karakhan & Gambatese, 2017; Tymvios, 2017).

Owners will play a critical role in project occupational health and safety during the project lifecycle, despite the absence of legal standards. The owners have the authority to set project goals, direct project funds, shape the plan as it evolves, and oversee OHS management activities during execution (Huang & Hinze, 2006; Toole & Erger, 2019). J. A. Gambatese et al., (2017) said the influential effect of the owner on the success of the construction-project team involves impacting project safety. Owners are also allowed to include requirements for safety and prequalification of contracts. During the construction phase, representatives of the owner can actively engage in safety meetings, audits of occupational safety, and accident reports (Hallowell et al., 2013; Toole et al., 2017). This clear contribution and dedication to protection send a positive message to the staff that it is a top priority (Sun et al., 2019). It's also essential for project owners to think about the benefits of PtD not just during construction, but also throughout the project's life cycle (Hecker & Gambatese, 2004; Toole & Erger, 2019). The author assumes that when that is done, owners will ask designers for PtD in their projects (Tymvios, 2017; Young-Corbett, 2014). T. Michael Toole found that after a detailed survey the proactive owner leadership and involvement is required to ensure the health and safety of the worker in the design process with the help of contractor participation (Toole et al., 2017)

J. A. Gambatese et al., (2017) give suggestions by promoting some improvement in public companies or selling the importance of PtD to AEC companies or upper management of companies and making them change their normal ways of business.

When top management is invested & involved in safety, safety performance is extraordinarily high (Hallowell et al., 2013; Tam et al., 2004; Toole et al., 2017). Upper management time spent with representatives of field protection or Project Designer correlates favorably with safety performance(Tymvios, 2017). Rajendran & Gambatese, (2009) found the results in a Delphi report in which researchers concluded that the single most significant consideration for decreasing accident incidence is strong upper management support and dedication. To enhance the awareness and application of the principle of PtD, an enormous effort is required by Management (López-Arquillos et al., 2015). Many research suggests that now need to incorporate the PtD in the process of project management to construction safety (J. A. Gambatese et al., 2017; Young-Corbett, 2014). Several studies have established several major obstacles to enhancing hazards identification: issues with procedures and processes (i.e., Lack of a standardized strategy and unclear activity and hazard systems) information and knowledge issues (i.e., identification and risk management of qualitative risks, Lack of resources, dependency on tacit awareness and

Communication gap) (Frijters & Swuste, 2008; Gangolells et al., 2010; Karakhan & Gambatese, 2017; Riaz et al., 2014).

The designer of the project played a significant role initially and then the constructor in the project development (Hallowell & Hansen, 2016; Jin et al., 2019). But have a lack of knowledge or limited involvement in safety management (Karakhan & Gambatese, 2017; Kim & Teizer, 2014; Toole & Erger, 2019; Tymvios & Gambatese, 2016a). The sole obligation of the construction contractor is often considered to be the safety of construction workers (By Jimmie Hinze, 1 Member, ASCE, 1993; J. A. Gambatese et al., 2002, 2017; Karakhan & Gambatese, 2017; Sun et al., 2019; Toole & Carpenter, 2013; Toole & Erger, 2019). Hallowell found from the past studies that 42% of the deaths and fatalities in the building where 22% of accidents are related to decisions taken during the design process (Hallowell et al., 2013). Haslam et al said that 27% of accidents are connected with permanent works design (Haslam et al., 2005; Hossain et al., 2018), whereas Behm analysis that 42% of accidents that occurred are connected with design decisions (Tymvios, 2017; Tymvios & Gambatese, 2016a). Many studies confirmed that During the construction design facility's influence on the safety hazards (Dharmapalan et al., 2015; Hallowell, 2008). According to Gangolells, a lack of designer understanding of protection and building procedures makes it impossible to incorporate PtD (Gangolells et al., 2010). Toole & Carpenter, (2013)found that after a detailed survey (n=103) the liability fear, industry standards, more lack of knowledge, designer-builder partnership correlated with traditional contracting systems, and The biggest obstacles to implementing the PtD in the Social Sustainability are higher costs. Many researchers agreed that the designer has a lack of knowledge about construction safety because many hazards remain in the design (Gangolells et al., 2010; Hossain et al., 2018; Qi et al., 2014). The architect and design engineer could not be prepared to modify traditional understandings of on-site health and safety obligation and introduce PtD (J. A. Gambatese et al., 2017; Tymvios & Gambatese, 2016b)

The AEC industry wants a data-visualization approach for near-miss reports to complement near-miss reporting. Near-miss monitoring information can be significantly improved by visualization, analogous to hazard recognition and site-layout safety preparation (Cheng et al., 2011; Elbeltagi et al., 2004; Shen & Marks, 2016; Toole et al., 2017). Sadeghi et al., (2016) argued that the most valuable method for positive security activities is visualization. The conventional use of construction site safety information does not anticipate the conditions present in the actual working environment which makes it impossible to recognize potential safety hazards and relay the necessary information to employees (Ganah & John, 2015; Golparvar-Fard et al., 2009).

Weinstein states that the design engineers & Architects will complement site protection by considering safety in their projects, they are making an effort (Weinstein et al., 2005). Danger avoidance during construction has been hampered by a lack of design-for-safety software, procedures, and guidelines, as well as the inadequate availability of design for safety tools (Dharmapalan et al., 2015; Jin et al., 2019). The design tool and training help a designer to enhance construction site worker safety (Hale et al., 2007). Hallowell et al., (2013) states that the construction firms need to spend resources on the identification of the Hazards or Training programs and instructions to communicate the safety compliance for Correct and timely response T. Michael Toole et al., (2017) found that after a detailed survey the different support tools, like 4D CAD system and risk assessment documents help to implement the PtD in the AEC industry. Jia(Qi et al., (2014) makes a PtD Web-based tool to improve the current construction safety by automatically conduct compliance checking for fall hazards in the model

Designers and architects are required to include construction worker safety, However, in university engineering and architecture programs, mitigation by design is either neglected or not taught (López-Arquillos et al., 2015; Toole & Erger, 2019). As a result, Toole & Gambatese, (2008) noted that OHS safety issues should also be considered in examinations for professional engineers conducted by the various state review boards. Education authorities involved in PtD need to make several continuing education courses for engineers and architects.

The lack of standardized experience in safety standards and best practices makes it impossible to adopt PtD or DfS (Goh & Chua, 2016; Hossain et al., 2018).

Hossain et al., (2018)said that firstly sometimes safety knowledge deficiency discourages addressing the issues related to safety in the design. Secondly, the designer need helps from the safety experts related to safety to tell them what not to do and what to do. Through training, the risk recognition ability of designers can be increased in architecture designing (Hallowell & Hansen, 2016). A study undertaken by Demirkesen & Arditi, (2015) found that most US firms view successful safety training as a crucial step in enhancing safety performance. Through their plans, architects and design engineers are expected to incorporate construction protection (ILO, 1985), however sadly in university engineering and architecture, mitigation by design is either overlooked or not specifically integrated. The risk in building environments is also raised because construction site workers work mainly outside and must cope with unfavorable conditions. Staff turnover is also a source of worry, as is a lack of vocational training and a lack of a safety culture (Patrucco et al., 2010; Sun et al., 2019)

Karakhan & Gambatese, (2017)found that the designer's fear of liability, lack of knowledge of safety, and contractual methods are the most prevailing barriers to PtD implementation. Researchers recommend that now need to further move toward a collaborative project delivery method to ensure the PtD implementation.

In the safety literature, safety recognition and reward incentives are contentious issues. Recognition and Reward Incentives should be considered while designing a safety incentive program (C. S. Park & Kim, 2013) However, observational findings have all found that positive motivation for healthy job conduct can take the form of verbal support or public attention rather than safety results (J. A. Gambatese et al., 2017; J. Gambatese & Hinze, 2002; Toole & Carpenter, 2013). A constructive (safety) incentive program acknowledges, honors, and thereby promotes worker participation in the safety and health management system by encouraging or rewarding employees for disclosing accidents, diseases, near-misses, or dangers. Positive reinforces may be as basic as public acknowledgment, but they usually enable the project planner and management to learn how to recognize healthy worker actions (Hallowell et al., 2013; Toole et al., 2017).

When designer firms perform to PtD demand more designer fees. because firms need to add PtD expertise staff overhead or may take a longer time (Toole & Erger, 2019) Direct costs are expected to escalate as designers need to coordinate with field workers, review files, or use checklists for PtD, which are activities not usually done. In two cases, overhead costs would rise. To begin, designers would need to obtain safety training as part of their professional development. Second, if designers deliberately try to contribute to workplace protection, insurance companies offering general liability and mistake and omission insurance to designers can raise their premiums to cover higher costs associated with designer defense litigation (Toole & Carpenter, 2013)

Tymvios & Gambatese, (2016a) states that the PtD is implemented through industry and legislation standards. Past researches tell us that the designer identified the contractual obligations, liability, legal and economic obstacles in the PtD implementation. In the European Union (EU), legislation has been the tool of choice for demanding the use of PtD in building and other sectors. Major problems to not implement the PtD are lack of knowledge of the design solutions (Tymvios, 2017). Tymvios & Gambatese, (2016a) believe that PtD implementation problems are covered by education. The standards of the industry are established Professional organizations use policies that are vital to the professions they represent to guide its members (Toole & Carpenter, 2013). Several U.S. professional associations have established certain regulations that advise their members to practice PtD in acceptable ways, but none of them directly mention the building industry. To be adopted by designers in order to address the safety of construction workers, there is a need for formal standards to be established.

PtD checklists and guidance materials provided by international health and safety organizations, NIOSH, and OSHA can communicate an awareness of safety constructability, but their breadth is limited (Toole et al., 2017; Toole & Erger, 2019).

The majority of the claims put forward in court cases are related to the depth of designer role in ensuring workplace safety during building and the connection of the designer, contractual or presumed, to the injured worker (J. A. Gambatese et al., 2017; Toole & Carpenter, 2013). Standards of practice and professional obligation, or failure to use the latest safety information in legal cases can lead to increased liability of designer obligation (J. A. Gambatese, 1998; J. A. Gambatese et al., 2017; Martínez Aires et al., 2010; Young-Corbett, 2014).

In practice, safety data used on projects does not reflect the conditions found in real building work settings, During construction, it will be more difficult to detect hidden potential risks and communicate the essential information to the relevant work forces (Golparvar-Fard et al., 2009; C. S. Park & Kim, 2013). The selection of materials is a critical factor in evaluating the likelihood of safe activities of the project.(Frijters & Swuste, 2008; Hallowell & Hansen, 2016; Young-Corbett, 2014)

2.3. BIM and ICT

2.3.1. BIM And Construction Safety

The application of newer technologies like automation and BIM in the construction industry yields various benefits. BIM stands for Building Information Modeling, and it is a digital representation of a facility's physical and functional properties. A BIM is a shared knowledge resource for information about a facility that serves as a solid foundation for decisions made throughout its life cycle, which is defined as the period from conception through demolition. A core principle of BIM is that different stakeholders collaborate at different stages of a facility's life cycle to insert, remove, update, or alter information in the BIM to support and reflect their roles (NIBS, 2012).

In the AEC industry, BIM is one of the most recent and encouraging developments. Using the building information modeling, it is possible to create a detailed virtual model of a building. (Azhar, 2011). BIM can be used for visualization of the model, creation of drawings, construction code reviews, forensic analysis, facility management, estimation of cost, sequencing of construction, clash detection, etc (Azhar, 2011). BIM has quickly been accepted as a game-changer in the way construction designs are distributed. BIM has emerged as an information platform and a central evidence provider to assist decision making with rapid developments in information and communication technology (ICT) (Ahmad et al., 2018; Y. Wang et al., 2013; Zou et al., 2017) BIM's applications in the construction industry are increasingly evolving, as they boost the efficiencies of numerous projects that integrate various techniques into the construction project process. BIM should be used to facilitate safety prevention and integrate safety with other construction planning processes, according to previous publications.

The most commonly used construction safety management aspects in the BIM application area are hazard recognition and hazard prevention. (Akram et al., 2019). Carter & Smith, (2006) indicate that identification of hazards 66.5% for the construction and railway industry reason is that lack of information technology for safety management. They work to improve the identification of hazards based on their activities. Safety planning, which encompasses hazard identification and prevention, is a common research topic in the literature and is viewed as a critical step in enhancing safety management ((Azhar, 2017). Furthermore, because most construction accidents occur on sites, that’s why worksite safety is a recurring problem. This encourages the researchers to concentrate on workplace safety planning (Akula et al., 2013).

2.3.2. BIM approaches Identify Hazards

Hu & Zhang, (2011) introduces a new approach to safety management and conflict during construction by combining 4D construction management construction simulation, and safety management through the application of construction simulation by using BIM. Zhang et al., (2013b) established an automated safety-rule checking algorithm that detects the hazard and suggests action required for the fall hazards. Their BIM experts created a Solibri Model Checker-based rule collection kit (SMC) (Solibri, 2013). The construction, service, and repair processes, often simulate the permanent installation of protective equipment in a structure. Chan-Sik Park proposes a framework by using different technologies integration augmented reality (AR), game technologies, BIM, and location tracking for safety management and visualization-system (SMVS). This approach is tested using a hypothetical accident event (C. S. Park & Kim, 2013). BIM is capable of collaborating with emerging techniques, such as reaching high design efficiency through the integrated use of interoperable development resources (Scherer & Katranuschkov, 2018; Xu et al., 2018). In BIM Kim & Teizer, (2014) built a rule-based system that automatically plans scaffolding systems for proactive maintenance. This system scope was limited to the board scaffolding and traditional pipes. The system worked on the geometric or nongeometric conditions of the model. A comprehensive framework for modelling and 4D visualization of fall protection has been developed by Finland's Valtion Teknillinen Tutkimuskeskus (VTT) Technical Research Center (Sulankivi & Kiviniemi, 2014). Modeling of temporary protective systems and equipment used for secure construction work is part of the project. BIM may also be used to facilitate safety prevention and integrate safety with other construction preparation procedures, as has been discovered (Sijie Zhang et al., 2015). It has also been attempted to disseminate best practices to enhance joint preparation processes between the contractors, designers. J. Park et al., (2017) states that one of the most effective approaches to alleviate the inadequacies of manual efforts is to use automated safety monitoring., allowing consistent and continuous security monitoring by using BIM. BIM research has become diverse in the last decade as more innovations have been introduced into BIM. For example, BIM is able to promote the introduction of 3D printing (Arayici et al., 2012; Zhao, 2017) Wang suggested a computational framework of The spatial sense of each construction project or mission can be visualized in real time using BIM and Augmented Reality (AR) (X. Wang et al., 2013; Zhao, 2017). These previous studies established the road for using BIM to improve safety preparation and hazard identification, but more intelligent methods are needed to enable automated and time-efficient safety rule testing as opposed to the manual procedure (Hossain et al., 2018). It's tough to fully comprehend the risky situations that arise and then vanish on building sites because of a rapidly shifting climate.

Many scientists have also utilized BIM for construction safety, in which they looked into the use of automation in fall prevention safety screening (Tymvios, 2017; Sijie Zhang et al., 2015). After detailed scrutiny of the published articles relevant to the building information modeling. Akram et al., (2019) identify twenty-four BIM or twenty-one construction safety-significant attributes which they are influenced by the BIM attributes.

Literature review of 27 studies revealed the different BIM technologies used to identify safety hazards

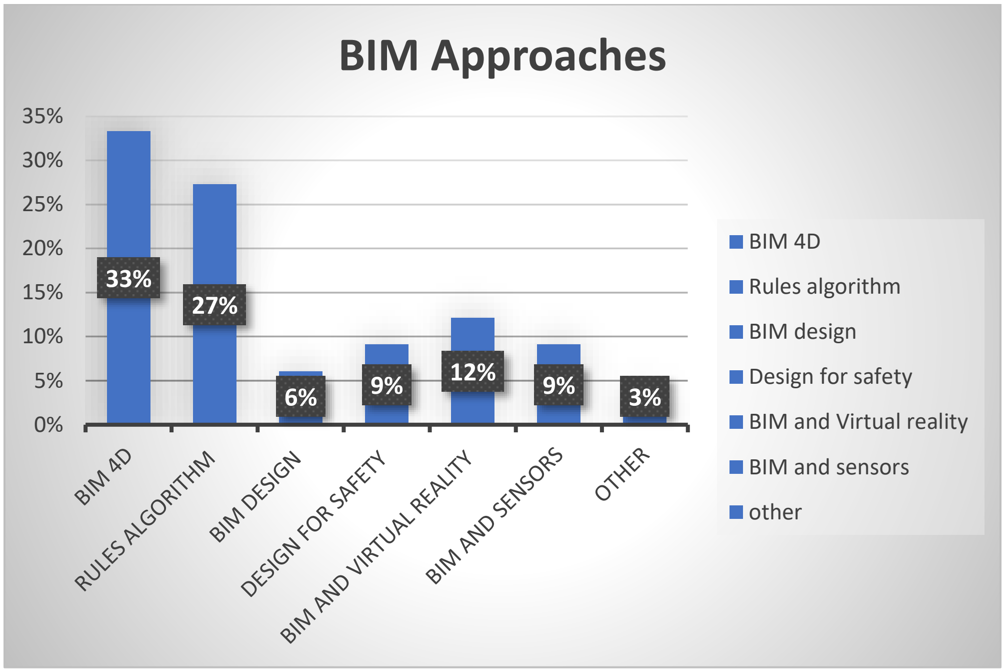

Figure 1 BIM Approaches used for construction safety

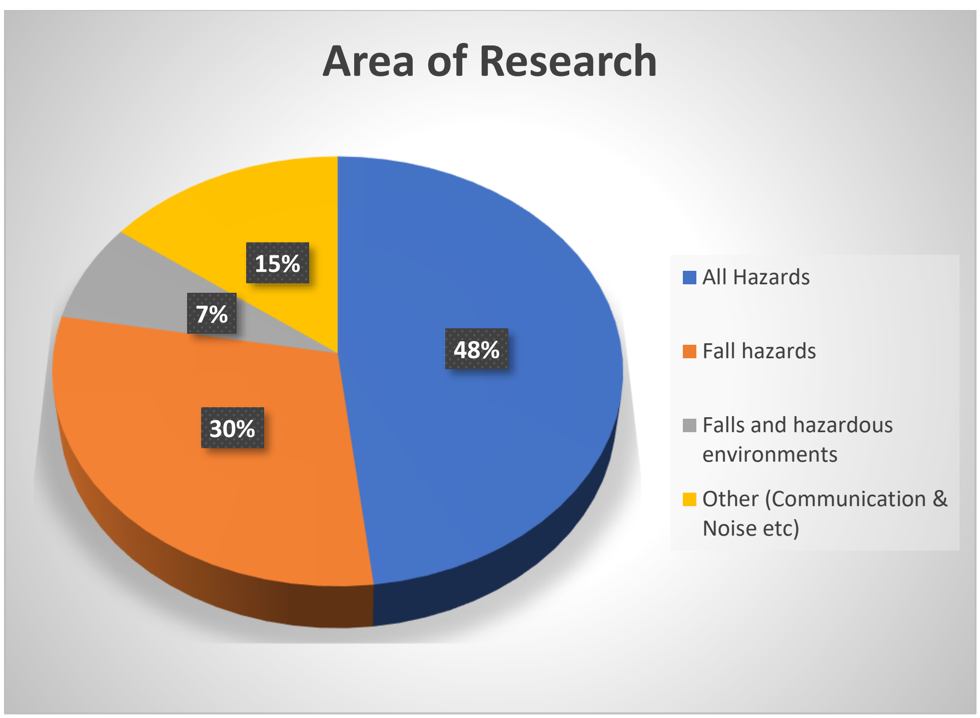

Figure 2 Area of Research

2.4. SAFETY RISK QUANTIFICATION

Risk assessment is a holistic method for the recognition, review, and response to project risks (Ahmad et al., 2018; PMI, 2018; S. Q. Wang et al., 2004). Using multiple variables, including frequency, severity, and exposure, worker safety risk has historically been established. To measure and assess safety risks, researchers have developed many different approaches over the years The Risk assessment techniques are defined into three types qualitative, semi-quantitative, and quantitative (Ahmad et al., 2018; Chien et al., 2014). With the help of the different tools and methods of Delphi method, checklists, brainstorming, risk registers (Patterson & Neailey, 2002), SWOT analysis (ISO, 2009) environmental risk assessment, spreadsheets the qualitative, semi-quantitative, and quantitative techniques applied. The limited statistical data collected that was not sufficient or use.58 Risk management software is used by just 21% of the global AEC industry ("A Survey on Usage and Diffusion of Project Risk Management Techniques and Software Tools in the Construction Industry," 2013). The traditional methods in manual risk management are primarily focused on mathematical or statistical calculations and assessments by experts (Ahmad et al., 2018). That is why needed to enhance the efficiency of the statistical information of the risk assessment. Recognizing and evaluating the safety risk involved with building methods and practices has been observed for some time.

The ergonomic risks related to 65 building processes are examined by Everett. (Arbor, 1999). To forecast the accident probability of typical construction procedures, Lee & Halpin, (2003) used a fuzzy-logic method depended on expert feedback. Jannadi & Almishari, (2003) built a model using expert advice and judgment to quantify the by assessing the risk of major equipment, construction activities, external stimulation, and hazardous substances on construction sites, the potential safety risk may be reduced. The website of the Bureau of Labor Statistics (BLS) to quantify the risk involved with various building trades. In the research, using the level of annual work, the incidence was measured as the fatality rate and annual accidents rate. The amount of time lost the cumulative number of days away from work, hourly pay, and several hours worked in a day were used to estimate the cost of an injury to a given trade, and the cost was approximated by the cumulative number of days away from work, hourly pay, and several hours worked in a day. (Baradan & Usmen, 2006). Frijters & Swuste, (2008) said that By Using likelihood and severity, the safety risk of construction activities was estimated. To determine the importance of the risk to shortlist high-risk events, (Gangolells et al., 2010) used chance and intensity or used the total of all possible exposures for a project to measure the risk. A part of Imriyas et al., (2007) analysis included estimation. Imriyas Developed a model of triple-index of the project hazard index (PHI) and converted it into a system to support the decision. To determine the accuracy and reliability of this system, case studies were conducted, and the results showed a Valuable contribution for risk evaluation. The Researchers concentrated only on physical characteristics (type, volume, height, material) of the activities and most risky operations to measure the PHI.

For the quantification and risk mitigation of construction operations, a risk-based construction worker safety analytical model was developed by Hallowell, (2008). The methodology developed by Hallowell was later utilized to assess the risk of activity connected with concrete formwork construction. Hallowell & Gambatese, (2009) developed quantitative risk scales that take into consideration all conceivable frequency and severity ranges. Mitropoulos & Guillama, (2010) used event forms to assess activities of construction to evaluate the high-risk residential construction activities. (i.e. struck by, fall), costs of claims and information from a contractor of residential industry The likelihood of possible loss-of-control incidents for 14 common activities of construction for the traditional multi-story construction project was evaluated by Rozenfeld et al., (2010). To determine the safety risk of constructing residential architecture elements, risk events were used (Gangolells et al., 2010). The researchers concentrated only on high-risk risk assessment activities and must evaluate the construction activities risk used a specialist group of the project manager (PM), professors, Engineers, and architects. The safety risk of design elements has been measured based on a small number of study studies (Dharmapalan et al., 2015). Hallowell & Gambatese, (2009) characterize severity in terms of the worker's consequences, and frequency in terms of the worker hours number per injury. Several groundbreaking prevention strategies have been adopted, including safety risk management, to minimize unexpected events before they occur. Choe & Leite, (2017)determines the 19 different construction occupations risks. The 4D model incorporates the design elements' risk values taken from the safety slide-rule tool. Test or verify the proposed method by case study.

Hazard Identification and monitoring must be completed prior to the commencement of construction to ensure that safety issues are addressed before the execution activities begin. Another reason to identify and control hazards prior to the commencement of the construction phase is to guarantee that safety concerns are addressed before the site execution activities begin i.e. site layout etc (J. A. Gambatese et al., 2017; Hallowell, 2008; Hallowell et al., 2013).

Most research studies identified and measured specific hazardous attributes or types of risks that occurred during construction. Additionally, no study entails measuring design elements risks associated with their corresponding activities and there are very few studies that measure the risk of the design element. Also, there is no study being conducted that used OHS professional opinion and historical data concurrently.

To cover these gaps, a BIM-SRSS tool is developed along with a Global Safety Risk Repository (GSRR) that continuously improves the Safety Risk data with help of OHS professional input. GSRR is populated in the design phase, by observing actual risk encountered during the performance of site activities involving respective design elements. The developed tool is expected to assist the risk assessment of all work-site hazards efficiently during the design phase. An Automated Safety risk register is generated from GSRR to examine the most hazardous risks and rank them in descending order of their risk score along with corresponding control measures using GSRR.

Chapter 3

3. RESEARCH METHODOLOGY

`This chapter will provide a methodology to achieve the objectives of this research as provided in Chapter 1. Firstly, a comprehensive literature review is done to identify the Critical success factors of Prevention through the design of the Construction industry. How BIM applications cover these CSFs for the successful implementation of the PtD in the AEC industry. The next step is to develop an AI tool or web-based system to calculate the Risk source of the design elements. Finally, this system is validated through safety industry experts' judgment.

3.1. PRIMARILY STUDY

The initial stage of this research includes the Evaluation of the latest research of the ranked journals of Construction Management. Then the importance of AI and BIM in the AEC industries is analyzed through a literature review. In the Construction sector, health and safety are a great concern. Many construction deaths, according to recent reports, are caused by design flaws that could have been avoided with careful planning. (Hossain et al., 2018) The most efficient way to control construction site hazards is to eliminate them at the source (Cooke et al., 2008). Afterward, a detailed literature review on BIM and Safety management is carried out to identify the existing research gap, which resulted in the identification of the research problem and research objectives, s discussed in Chapter -1.

3.2. LITERATURE REVIEW

After the finalization of the research objectives, a detailed literature review is conducted, and its detailed methodology is developed that is already discussed in Chapter-2. The next step involves the identification of critical success factors (CSF) of implementation of Construction Safety by Prevent through Design (PtD). The shortlisting of CSF is done using the content analysis technique. Only 10 factors whose Cumulative Normalized Score was under 60% are considered. All the Critical succuss A framework is developed to achieve these success factors through BIM & Global Risk Repository database. Discussed how BIM used for construction safety in the last few years. A literature review of 27 studies revealed that different BIM technologies were used to identify safety hazards. After the detailed review of the BIM applications for safety need to know about the safety risk Quantification knowledge.

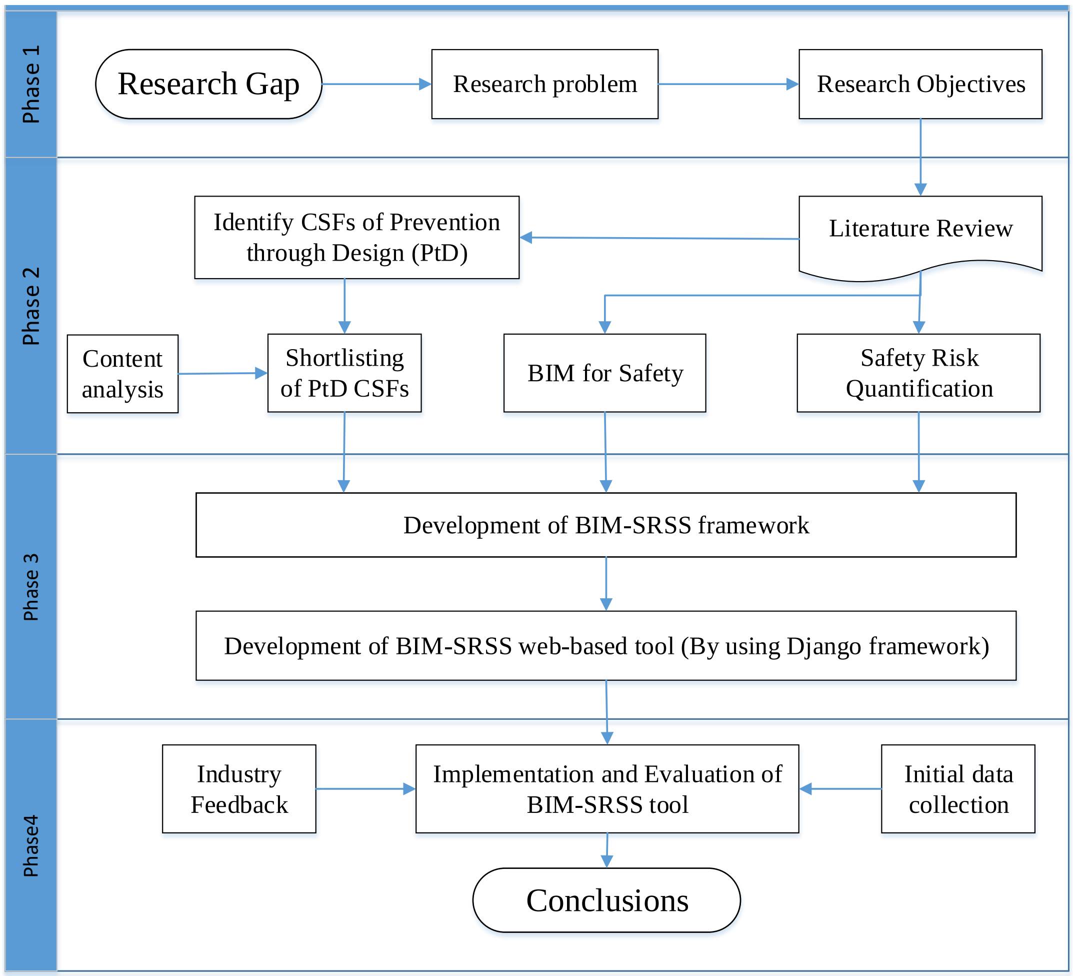

Figure 3 flow chart of Research Methodology

3.3. DEVELOPMENT OF THE FRAMEWORK OR BIM-BASED SAFETY RISK SCORING SYSTEM (SRSS) TOOL

Initially, analysis of the current practices used to improve the construction worker Safety standards or regulations. The majority of the design professionals are unclear about whether to integrate factors of OHS into their design decision-making or not and are worried that doing so can put them at greater legal risk (Cooke et al., 2008). The PtD tool or resource is the most affecting factor in the PtD implantation of the construction industry. There is strong evidence that decisions taken during the planning phase of a project can have a direct effect on achieving better Occupational Health and Safety during the renovation, occupation, repair, and demolition phases of a building's life cycle (Williams, 1998). A thorough risk evaluation of each design aspect of the buildings being built is one way for architects and engineers to enhance design safety results in the building and construction industry. The type and degree of risk on building projects are largely determined by the permanent design elements (Haslam et al., 2005; Hossain et al., 2018). The means and methods used during construction are based on the nature of a project. A risk assessment will be done at the design stage to choose design options that reduce construction safety risk Identifying the risk factors linked with design characteristics (Cooke et al., 2008).

Using historical data, the BIM-SRSS Framework will serve in integrating the management of OHS hazards into the construction planning process. The prototype web-based system's underlying framework, as well as the information acquisition and Risk Assessment modeling processes, are defined.

To overcome the existing PtD tools' limitations, a web-based BIM-SRSS tool is developed for effective PtD implementation. The developed tool uses Django Framework for administration interface and My Structured Query Language (MySQL) for Database processing. The tool is further integrated with the BIM platform using visual programming.

This system calculates the Risk score of the design element by defining its activities taking place at the construction site. Every activity has hazards; initially, a list of these hazards is taken from the literature reviews. In most of the past research, the risk is calculated based on Severity or Probability. Frijters & Swuste, (2008) used probability and severity to assess the safety risk of construction activities. Shortlist the high-risk events, likelihood and magnitude were used to assess the seriousness of the risk, and the total of all possible project's exposures were utilized to assess the project's risk. Exposure is an indicator of the severity of a dangerous condition that varies depending on the project. Choe & Leite (2017) Consider the severity of the incident and historical evidence to determine the probability of 19 construction occupations. The probability and consequences scale is used to rate the risk associated with Construction work. Using this scale, the hazard risk score is calculated as below.

Risk Score = Occurrence Probability x Severity of Consequences

Table 2 Probability of occurrence Scale (Average amount of time between the accident)

Probability of occurrence Scale	Severity Scale
0 (Impossible)	0 (Negligible)
1 (very rare)	1 (Temporary Discomfort)
2 (50 Years)	2 (Persistent Discomfort)
3 (10 Years)	3 (Temporary Pain)
4 (5 Years)	4 (Permanent Pain)
5 (1 Year)	5 (Minor First Aid)
6 (6 Months)	6 (Major First Aid)
7 (1 Month)	7 (Medical Case)
8 (1 Week)	8 (Lost Work Time)
9 (1 Day)	9 (Permanent Disablement)
10 (1 Hour)	10 (Fatality)

The initial values of Probability and Severity are assigned based on expert judgment or from the literature. After completing the risk assessment, we get the initial safety Library. This library is then linked with the design element by the BIM -SRSS web-based system, allowing the designer to change the values as per his/her understanding according to the situation. The Safety Risk scoring system does not learn from the designer's values because the designer has a lack of knowledge of construction Safety. By using this developed tool the designer can rate their projects design element’s hazards based on the priority given to each hazard to improve construction safety. The results of this research could be used by architects and design engineers to improve project safety from design till the operational phase of the project. The BIM-SRSS Safety Risk scoring system is learned or experienced by the input of the HSE professional or the Safety regular authorities.

This system gives suggestions based on learned experience. The system results will improve once it starts processing more data. The provision of The tool system's OHS decision assistance has the potential to increase designers' capacity to integrate OHS knowledge into design decisions and comply with OHS in construction design regulatory requirements.

3.4. BIM-SRSS TOOL VALIDATION

After complete development of the Framework/Tool validation is done in three steps. In the third and final phase, the developed BIM-SRSS tool is applied on a real-time case study and validated by industry experts to analyze the efficacy of the proposed web-based tool as shown in Figure 2 (Ali et al., 2018; Paek, 2001). To evaluate the newly developed tool, objective and subjective assessments have been gathered from experts regarding the implementation barriers and improvements in the said tool (Li et al., 2017; Shen & Marks, 2016).

To initiate the validation process, Risk Assessment data of an already completed and ongoing project is entered into the BIM-SRSS tool. The hazards gathered from risk data are further rated by OHS professionals on the probability and severity linear scale of 0-10.

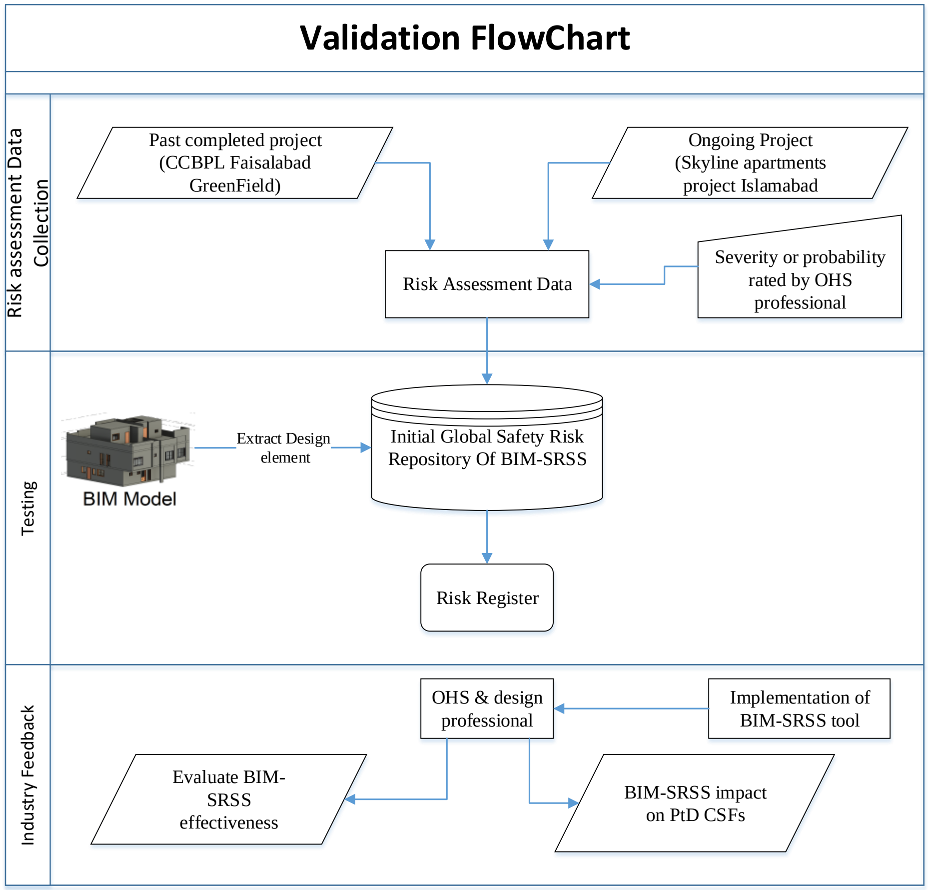

Figure 4 Flowchart of Validation

To make the BIM-SRSS tool easily understandable for the industry professionals and to scrutinize the working of the BIM-SRSS tool, a BIM model of a project is developed then design elements of the uploaded model are extracted and finally risks of the project are identified using global safety risk repository system's database.

Furthermore, feedback regarding the tool is obtained by conducting in-person interviews with the industry experts.

3.5. DEMOGRAPHICS OF INTERVIEWS

Construction professionals having varied experience were targeted, including Design Engineers and OHS Professionals. However, the largest responses were received from OHS Professionals (58.8%) while Design Engineers' responses amounted to (41.2%). Nine responders have an extensive experience of more than ten years in building design and OHS, indicating that 52.9% of responses came from highly experienced professionals. Validation was not given to respondents with less than 5 years of experience. Qualification-wise, 52.9% of responses came from M.Sc. holders, 41.2% responses came from BSc (Back Stepping Controller) holders and 5.9% came from B.Tech holders.

Other demographics considered among the respondents were safety management and BIM short courses & certifications, proving their credibility for validation. 58.8% had NEBOSH certifications,41% had safety training and 41.2% had IOSH certification. 35.3% had done OSHA certification, cumulatively 17.7% had ISO14001 (Environmental Management System) and ISO (Independent System Operators) 2001 (Quality Management System). While 17.7% of respondents had attended BIM, Autodesk Revit, and Project Management workshops and were well versed with Building Information Modelling (BIM) process as seen in Table 3. Insight from these latter respondents makes the validation process more efficient.

The majority of those who responded to the survey had graduate degrees, indicating that their opinions were credible. Information about construction design expertise and OHS expertise is important as It indicates whether the project participants are aware of the project's hazards. The results reveal a moderate to an exceptional understanding of construction safety and BIM process in most of the respondents which reinforce the confidence in the date quality.

Table 3 insight to respondent profiles.

Profile	Frequency	Percentage%
Profession		
OHS professional Design Engineer	10 7	58.8% 41.2%
Experience		
5 to 10 years	7	41%

10 to 15 years 15 to 20 years More than 20 years	5 4 1	29% 24 % 6%
Institute type		
Private Semi-Government Government	11 2 4	64.7% 11.8% 23.5%
Academic qualification		
B. Tech B. Eng./BSc. MS/MSc.	1 9 7	5.9% 52.9% 41.2%
Additional Courses		
OSHA NEBOSH IOSH ISO 14001 and ISO 2001 Safety Training BIM. Autodesk and project management	6 10 7 3 9 3	35.3% 58.8% 41.2% 17.7% 52.9% 17.7%

Chapter 4

4. BIM SAFETY RISK SCORING SYSTEM

4.1. CSF FOR PTD

After reviewing the 32 research articles on PtD, a total of 25 factors were identified and critically analyzed based upon their appearance in the literature. The relative frequency of each factor is calculated based on its appearance in the respective research article to the total number of studied research articles. Furthermore, the normalized score is calculated using qualitative and quantitative assessment of each factor concerning their contribution to existing literature. The normalized score is shown in Table 3. These twenty-five CSFs are further shortlisted to nine (9) most critical factors based on encompassing a 60% cumulative score (Ahmad et al., 2018).

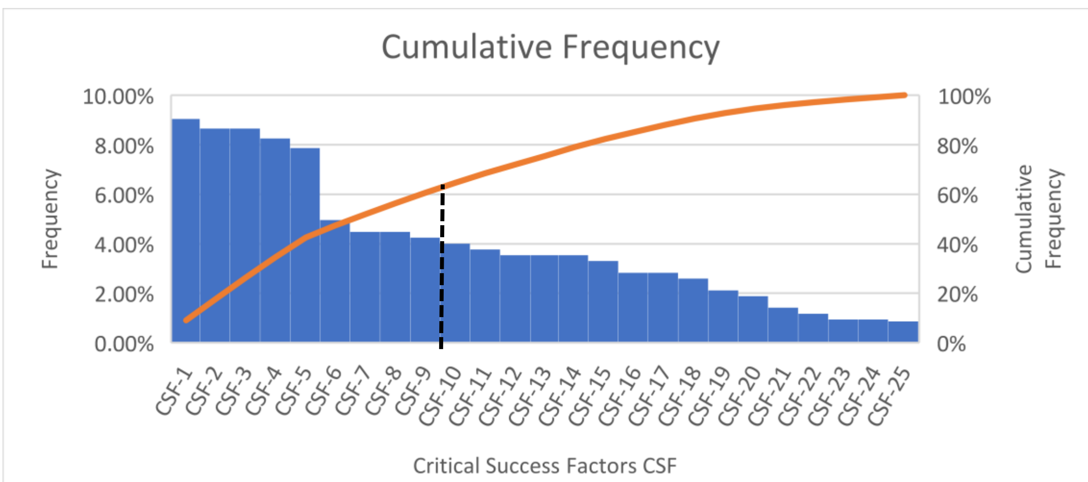

Figure 5 Prioritization of CSFs

Table 4 Critical Success Factors (CSFs) of PtD

Sr#	**Critical Success Factor**	**Total Literature Score**	**Normalized Score %**	**Cumulative score**
CSF1	Accessibility of PtD tools and resources	1.198	9.05%	9.05%
CSF2	Construction safety knowledge	1.146	8.65%	17.70%
CSF3	Education and training	1.146	8.65%	26.36%
CSF4	Designers' ability to perform PTD	1.094	8.26%	34.62%
CSF5	Construction Site Hazards Visualization	1.042	7.87%	42.49%
CSF6	PTD knowledge among stake holders,	0.656	4.96%	47.44%
CSF7	Owner's focus on PTD	0.594	4.48%	51.93%
CSF8	Design Checklists/documents	0.594	4.48%	56.41%
CSF9	Proactive leadership involvement	0.563	4.25%	60.66%
CSF10	Communication between client, designers, and contractors	0.531	4.01%	64.67%
CSF11	Industry Standards/Regulatory requirements	0.500	3.78%	68.45%
CSF12	Legal economics and contractual obstacles	0.469	3.54%	71.99%

CSF13	Legislation bodies	0.469	3.54%	75.53%
CSF14	Designer liability for safety	0.469	3.54%	79.07%
CSF15	Designer construction experience	0.438	3.30%	82.38%
CSF16	Motivation To perform PtD	0.375	2.83%	85.21%
CSF17	Planning and design decisions	0.375	2.83%	88.04%
CSF18	Type of Project delivery method.	0.344	2.60%	90.64%
CSF19	Cultural issues of safety	0.281	2.12%	92.76%
CSF20	Type of material being used	0.250	1.89%	94.65%
CSF21	Designer fee	0.188	1.42%	96.07%
CSF22	Work process being followed	0.156	1.18%	97.25%
CSF23	Safety incentives	0.125	0.94%	98.19%
CSF24	Project complexity	0.125	0.94%	99.13%
CSF25	Specific understanding from theoretical perspectives	0.115	0.87%	100.00%

4.2. BIM-SRSS FRAMEWORK

Figure 6 shows the proposed BIM-SRSS framework to improve construction worker safety by implementing PtD practices. The developed BIM-SRSS system is integrated with BIM to gather the required inputs regarding design elements and corresponding activities. The system is further linked with the database GSRR in particular SQL server. In the first step, a BIM model is developed by using the Revit-2021 BIM platform. The extracted design elements from the BIM model were imported into the BIM-SRSS platform. The system executes the risk assessment systematically and generates a risk register of all the identified design elements using GSRR data. The generated risk register sets out the design elements in descending order with most ‘protracted hazard’ and their related ‘activities’ appear at the top of the risk register. Based on the risk assessment results, if the design element risks not acceptable, then designers can make informed design decisions and changes to the designs of the building to ensure safety throughout its lifecycle. The developed BIM-SRSS system also represents the control measures to mitigate the hazards that consequently lead to improve overall construction site safety of the project. If the design element risk is acceptable then the design is approved for the execution of the project.

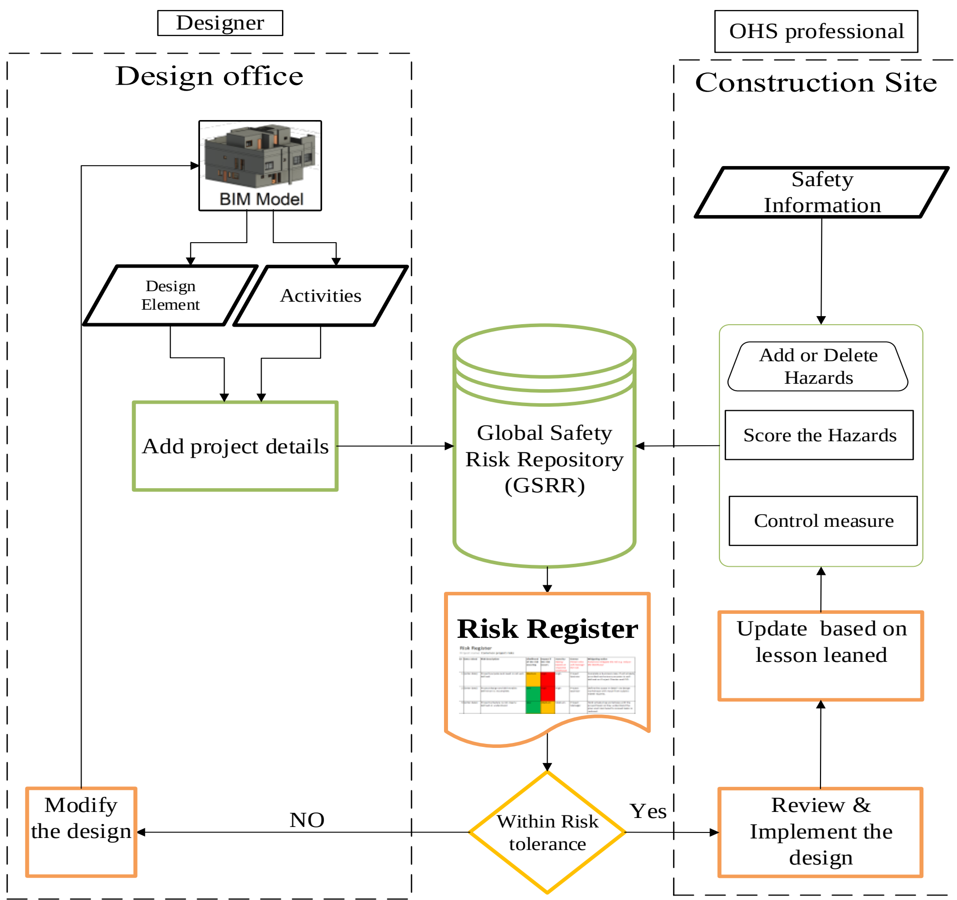

Figure 6 Framework of BIM-SRSS

The OHS professionals contribute significantly to the working of the BIM-SRSS framework and in setting up the GSRR. The insights from OHS professionals lead to the most valuable information about occupational health and safety and work-site hazards. For this valued purpose, BIM-SRSS is set up to allow the OHS professionals to add or subtract hazards and rate their corresponding severity and probability. BIM-SRSS entries of OHS professional's data are saved in a GSRR Database that serves as a knowledge pool for future projects. The database efficiency expounds over time with increasing project data into the GSRR, thus enhancing risk assessment accuracy.

4.3. BIM GRSS

To create a GSRR database, initial data is required that's why risk assessment data of two ongoing building projects i.e. Coca Cola Green Fields Faisalabad, Pakistan, and Skyline Apartments, is collected. The risk assessment data constitutes 20 design elements, 130 activities, and 400 associated hazards as shown in Figure 7. The OHS professionals from the same projects were asked to rate the same hazards related to identified design elements on the '10 x 10 Risk Matrix'.

Moreover, this risk assessment data is stored in the GSRR that acts as a benchmark for future risk assessment of similar projects. The efficacy of risk assessment periodically improves with time by increasing projects' data into the database. GSRR system could be effective as it uses historic data and regularly updates the database as opposed to the conventional risk management tools.

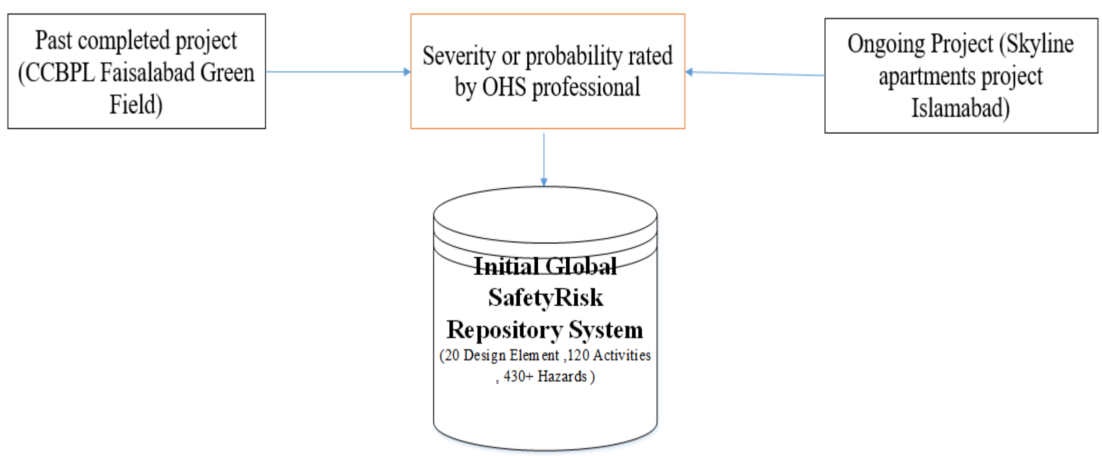

Figure 7 initial GSRR Formation

4.4. BIM-SRSS TOOL

Based upon the short-listed CSFs related to PtD, the BIM-SRSS tool is developed using the Django framework. BIM is characterized by information management, throughout the project it is used as a tool for implementing safe construction practices (Sherong Zhang et al., 2020). With its integration, building information modeling provides an overview of the developed BIM-SRSS tool and its functionalities.

4.4.1. BIM-SRSS Tool Interface

The developed BIM-SRSS tool can be used by design engineers and OHS professionals. The users are required to provide adequate information during tool signup from the dropdown list.

x*y	Probability									
	1	2	3	4	5	6	7	8	9	10
	2	4	6	8	10	12	14	16	18	20
	3	6	9	12	15	18	21	24	27	30
	4	8	12	16	20	24	28	32	36	40
Severity	5	10	15	20	25	30	35	40	45	50
	6	12	18	24	30	36	42	48	54	60
	7	14	21	28	35	42	49	56	63	70
	8	16	24	32	40	48	56	64	72	80
	9	18	27	36	45	54	63	72	81	90
	10	20	30	40	50	60	70	80	90	100

Figure 8 Safety Risk Matrix

To add a new hazard, a design element followed by the associated activity (s) is selected from the list of available design elements as shown in Figure 9. Then assign a severity and probability score to each of the hazards using the linear scale value recommended by (Dharmapalan et al., 2015; Hallowell, 2008). The overall risk score is calibrated by taking the product of probability and severity that represents the degree of each risk in the '10x10 Risk Matrix' as shown in Figure 8. Control measures are suggested by the OHS professional considering the hierarchy of controls that result in ameliorating design and on-site decisions making. Additionally, the BIM-SRSS allows adding control measures via visual data such as pictures, videos and provides web-based linkage with safety standards like OSHA, NEBOSH, etc.

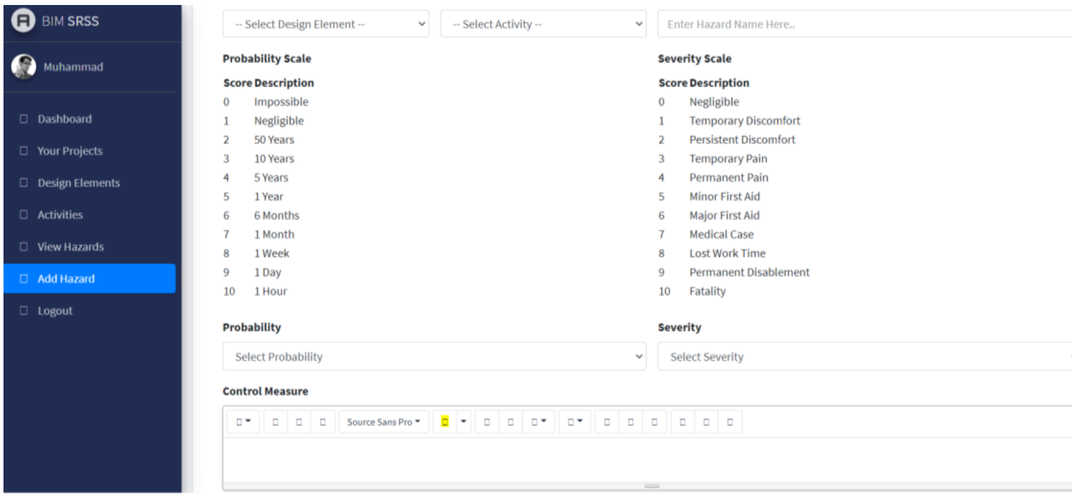

Figure 9 Layout of adding new hazard

4.4.2. BIM-SRSS view hazards

BIM-SRSS aid users to view the hazards associated with their selected design elements by clicking the 'view hazard tab' shown in Figure 10. For instance, the user may select 'concrete pile' or 'Concrete Slab' as a design element and 'installation of steel cage' or 'Concreting' as the activity associated with it respectively. The BIM-SRSS tool will extract the risk assessment data related to the design element and activity using the GSRR. The tool also allows printing the risk assessment that presents the resulted hazards of activity and their risk score.

In this study, the risk score of each hazard has been calibrated and trained periodically from the OHS professional's data regarding risk assessment of design elements. During regular site visits, the OHS professional rated the hazards of each design element concerning corresponding activity(s). The tool shows eight hazards for 'concrete slab' with 'Concreting' in descending order of their risk score. The tool reveals that the "form blowout" is most critical among all the hazards with a risk score of 90 as shown in Figure 11 by Ring diagram.

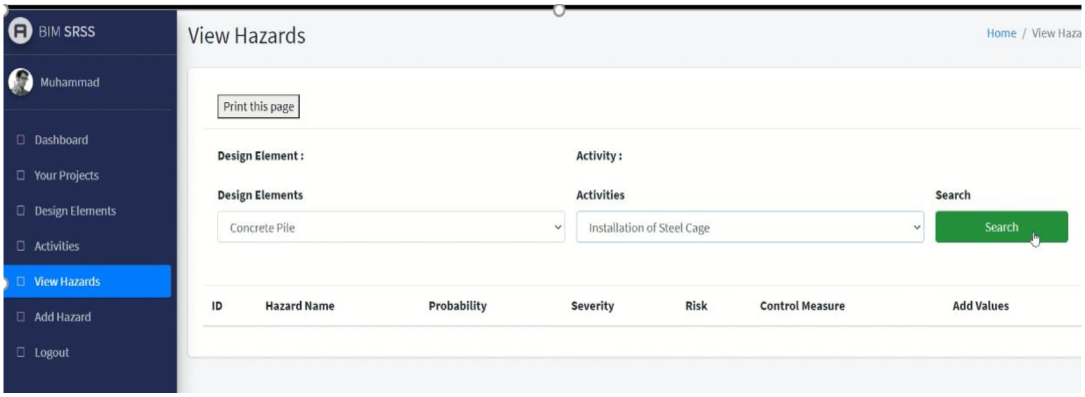

Figure 10 View Hazard in BIM-SRSS tool

The BIM-SRSS system also gave the appropriate PtD control measures according to Hierarchy to Control. E.g in the hazard of 'form Blowout' the BIM-SRSS tool suggests that the designer or the higher management can eliminate the concrete slab and used the precast slab. In the substitution used surer formwork structure like scaffolding or Doka formwork which are more suitable and have very less o failure. In the engineering Control designer can provide safe access & egress, Physical barriers onsite alterations. Administrative control is also discussed in the early-stage to make better-informed decisions or planning. The PPE of related hazards mentioned can easily be managed in the early phase of the project and their accurate cost is included in the detailed estimate of the project.

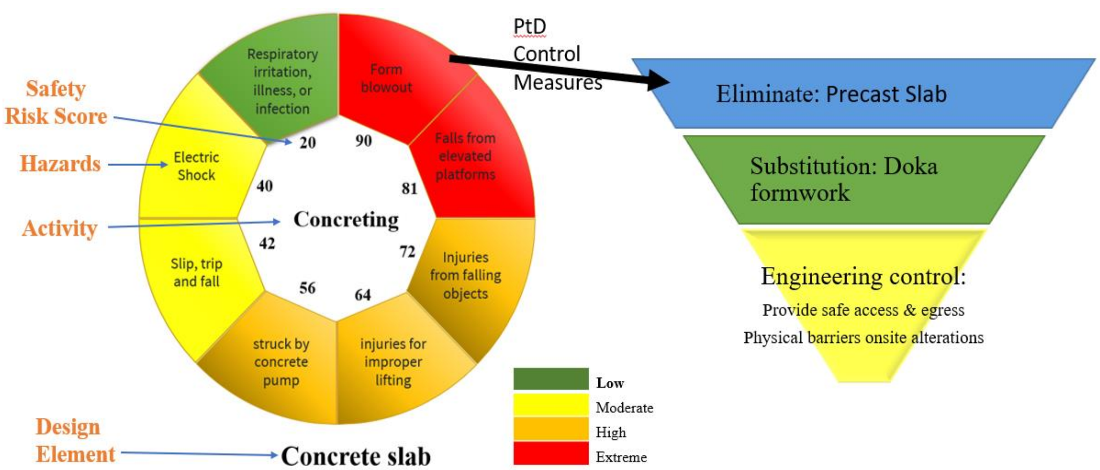

Figure 11 Prioritization of Hazards and PtD suggestions

The BIM-SRSS system also gives appropriate PtD control measures according to Hierarchy to Control. E.g in the hazard of ‘form Blowout’ the BIM-SRSS tool suggests that the designer and the higher management can eliminate the concrete slab using a precast slab. Safe formwork structures such as Doka formwork can be used as a substitute. In engineering, a Control designer can provide safe access & egress and can prevent physical barriers. Administrative control includes proactive decision-making and planning. PPEs of related hazards mentioned can easily manage in the early phase of the project and their accurate cost is included in the detailed estimate of the project.

4.5. ROLE OF OHS PROFESSIONAL

The OHS professionals contribute significantly to the working of the BIM-SRSS framework and in setting up the GSRR. The insights from OHS professionals lead to the most valuable information about occupational health and safety and work-site hazards. For this valued purpose, BIM-SRSS is set up to allow the OHS professionals to add or subtract hazards and rate their corresponding severity and probability. BIM-SRSS entries of OHS professional’s data are saved in a GSRR Database that serves as a knowledge pool for future projects. The database efficiency expounds over time with increasing project data into the GSRR, thus enhancing risk assessment accuracy.

The BIM-SRSS tool provides flexibility to OHS professionals in adding required data input even without a 3D BIM model. If a 3D BIM model is available, its design elements are extracted into an excel file and imported into the BIM-SRSS tool. If the 3D BIM model is not readily accessible, then the design elements and their hazards are entered manually or selected from the GSRR. Unless a particular element is missing in the dataset, the tool also allows the professionals to either add a new design element with their corresponding activity(s).

4.6. ROLE OF DESIGNER

The BIM-SRSS tool is developed to overcome design-related safety concerns. To start with, the designer first completes a BIM design model. Then design elements are extracted from the BIM model using visual programming tools. Next, the designer logs on to BIM-SRSS platform as a designer and enters the project details of the developed model. The BIM-SRSS tool systemically generates a Risk Register of the design element or their associated activities hazards. The designer can then analyze the Risk rating of the hazards if it's within acceptable limits or a design change is needed. If the designer feels that risks are not within acceptable limits, he can change the design of the building and take informed decisions. The PtD control measures are saved for the executive staff.

This study offers a mechanism for designers to utilize the PtD effectively and efficiently to address risk control during the design process. The periodic data input from the OHS professionals related to risks and activities improves the risk assessment and increases overall site safety. Another key benefit of the BIM-SRSS tool is that it has a minimal impact on project design. The whole design process, as well as the designer's ingenuity, is preserved, thus results in rapport construction performance, and subside change orders and disputes. The proposed method further enables the designers with safety-risk awareness that elevates their problem solving and decision-making.

4.7. CASE STUDY BY DESIGNER

Figure 12 BIM model of 'Eighteen Villas'

To test the model, 'Eighteen villas', a housing project, is selected as a case study project. A BIM model of the said case study is created by the designer as shown in

Figure 12 using Autodesk Revit. The working of the BIM-SRSS tool is utilized by extracting the design elements of a model for risk assessment using visual programming as shown in Figure 12.

In the next step, a new project is created into the BIM-SRSS tool. The prerequisite details of the project are entered into the said tool whose risk assessment needs to be performed as shown in Figure 13. The tool gathers the data systematically from its GSRR Database. The data further reveals the risk assessment of 130 hazards related to the design elements as shown in Figure 14. All the working of the BIM-SRSS tool demonstrate to the industry Professional and take their review and discussed in the next chapter.

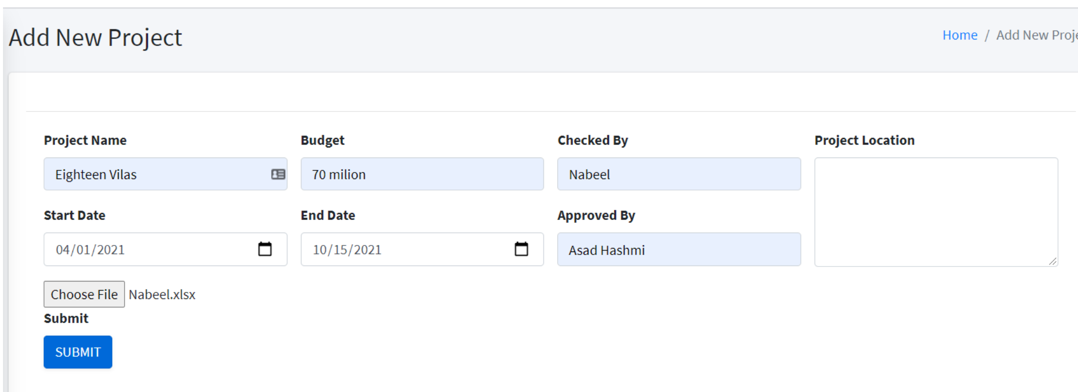

Figure 13 Entering the BIM model design element

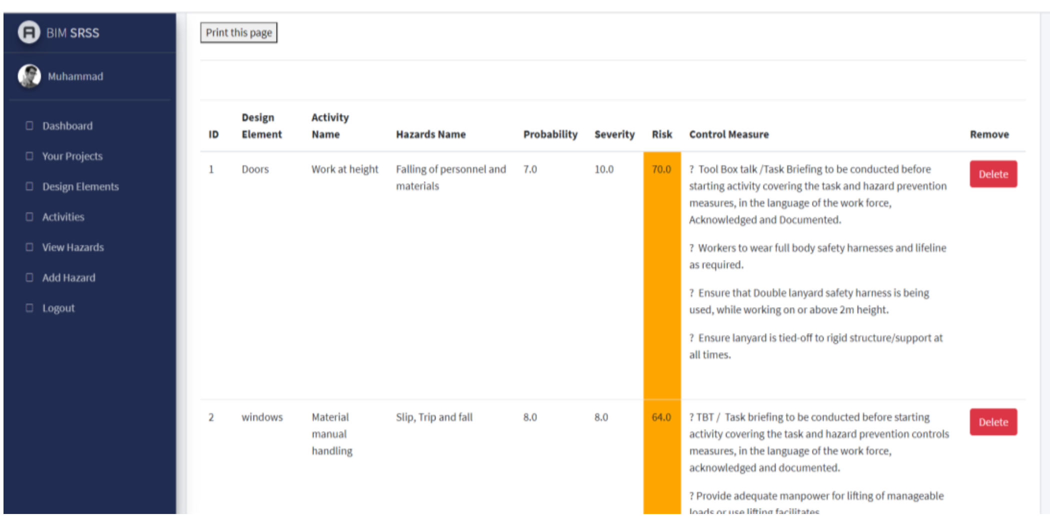

Figure 14 Risk register of BIM model

Chapter 5

5. RESULTS AND DISCUSSION

The findings are presented in the order in which they were discovered, as discussed in this paper's research methodology section.

5.1. BIM-SRSS TOOL EVALUATION BY INDUSTRY

To evaluate the tool, a brief visual demonstration of BIM-SRSS tool functionality was provided to industry experts. Afterward, the experts' queries were addressed and a questionnaire regarding the applicability of the developed tool and improvement in PtD practices was documented. The outcomes from expert review sessions regarding BIM-SRSS tool implementation are shown in. The results reveal that overall safety management practices shall be improved by applying the BIM-SRSS tool in the AEC industry.

The mean value, RII value, and ranking of CSF's that can be effectively resolved utilizing the BIM-SRSS tool that has been developed are shown in Table 5. It is derived from expert opinion, which is gathered on a Five-point Likert scale (5 indicates "strongly agree" and 1 indicates "strongly disagree").

Table 5 BIM-SRSS system Evaluation by industry experts.

Criteria of Evaluation	Minimum	Maximum	Mean value
In the Construction industry, such a system needs for construction safety	4	5	4.82
Do you think this BIM Based SRSS tool user interface is friendly?	4	5	4.53

Do you think BIM Based SRSS tool will reduce project Duration?	3	5	3.71
Do you think BIM Based SRSS tool help reduce the cost of implementing health and safety system within the construction project?	4	5	4.24
Would you like to implement it in your company?	3	5	4.35
Overall, do you think this Proposed BIM-based SRSS system will be effective to improve construction safety management?	4	5	4.65

Table 6 How much impact of BIM-SRSS to improve PTD CSFs? shows the outcomes regarding the shortlisted CSFs and their respective ranking as proposed by the experts. The relative importance index reveals that ‘Accessibility of PtD tool and resources’ and ‘Construction Safety Knowledge’ exhibit the higher ranks among all of the factors.

Table 6 How much impact of BIM-SRSS to improve PTD CSFs?

Sr#	Critical success Factors of PtD	Total Weight	mean Value	RII	Rank
1	Accessibility of PtD (prevention through Design) tools and Resources	79	4.65	0.929	1
2	Construction Safety Knowledge	78	4.59	0.918	2
3	Education and Training of OHS Personnel	76	4.47	0.894	5
4	Designer ability to perform PtD	70	4.12	0.824	8
5	Construction Site Hazards Visualization	72	4.24	0.847	7

6	PtD Knowledge Sharing between Stakeholders	75	4.41	0.882	6
7	Owners focus on PtD	77	4.53	0.906	4
8	Design Checklists/Documents	68	4.00	0.800	9
9	Proactive leadership Involvement	78	4.59	0.918	2

5.2. DISCUSSIONS

The tool validation significantly revealed that the newly designed BIM-SRSS is an efficient tool for implementing PtD practices and improving construction workers' safety. The experts agreed that BIM-SRSS tool "usability" would be very flexible in its entirety for users. Nonetheless, Experts suggested that it would be relatively efficient in implementing BIM-SRSS tool to perform a risk assessment with the availability of BIM model(s). Hence, the auspicious use of BIM in designing and planning of building projects asserts great potential in overall safety risk assessment. The applicability of BIM-SRSS tool concerning CSFs in improving PtD site-safety practices are detailed below.

Considering the CSFs of PtD, the experts valued 'Accessibility of PtD tools and resources as the most critical factor among the rest. In their opinion, the BIM-SRSS tool can augment the design-safety tools and procedures early in the design phase for mitigating site hazards. The existing resources do not employ the historic data and there exists no adequate database of the PtD methods (Sijie Zhang et al., 2011). The developed BIM-SRSS tool allows industry professionals to forecast the risks based on the data stored in the global safety risk repository. Additionally, the tool facilitates precise decision-making based upon an extensive safety assessment database. Moreover, the database regularly improves as the global risk repository volume increases.

Most of the experts rated 'construction safety knowledge' as agreed or strongly agreed. The factor is ranked second highest which shows that the experts auspiciously believed that BIM-SRSS improves construction safety knowledge of designers and OHS professionals. The BIM-SRSS assists the industry professionals by suggesting hazards relating to the project's design elements. Professionals having little or no prior risk assessment expertise can benefit from the global safety risk repository database. The awareness regarding the safety practices ameliorates the experts' ingenuity about ambivalent situations that lead to effective problem solving and decision making. 'Proactive leadership Involvement' ranked the second-highest-rated factor with a mean value of 4.59. The expert's believed that the BIM-SRSS tool delivers precise risk assessment that enables the leadership to proactive decisions.

A slightly positive response is gathered for the factor called "Owner's focus on PtD,". This factor is ranked third (3^{rd}) with RII value of 0.906. The outcomes from literature and industry experts reveal the importance of PtD in improving project occupational health and safety during the project lifecycle. The Owners are authorized to set project goals, direct funds, and oversee safety management activities during the projects' development. The developed BIM-SRSS tool improves the owner's focus on PtD implementation to conform with safety standards on projects.

The past research indicates that the 'Education and Training' of experts is one of the significant barriers to implement the PtD practices in the AEC industry. This notion is further reinforced by the industry experts with a mean score of 4.47, which indicates the adequacy of BIM-SRSS in the training of OHS professionals. With BIM-SRSS, safety training practices can improve robustly by retrieving risk assessment data from their safety risk repository database.

According to the industry experts, 'PtD Knowledge Sharing between Stakeholders' can be improved using the BIM-SRSS tool. The results show a mean score value of 4.41. The tool supports extensive knowledge sharing through its database as opposed to conventional risk assessment practices. The tool integrates the risk assessment performed by different professionals and improves the risk scoring over time as the database volume increase.

A varied response was given by industry experts regarding "Construction Site Hazards Visualization," with a score of 4.24. According to their opinion, the BIM-

SRSS tool implicitly improves the construction site hazards visualization by improving the theoretical perspective of the user regarding site safety risks.

The results from the survey revealed that “Designer ability to perform” PtD is one of the significant factors affecting PtD. BIM-SRSS allows the designers to perform risk assessment early in the design stage smattering knowledge of occupational health and safety. Based on the selected design element, the tool itself can identify its associated hazards using its global safety risk repository database. Besides designers' lack of knowledge about OHS practices, the tool autonomously provides precise solutions to enhance experts' capability to implement PtD.

Though the “Design Checklists/Documents” shows the least significant factor among all with a mean score of 4.0. However, with the application of the BIM-SRSS tool, the “Design Checklists/Documents” are also improved. This includes updated risk assessment data that aids the OHS professional in mitigating safety-risk before their occurrence.

5.3. BARRIERS IN BIM-SRSS IMPLEMENTATION

Almost in every sector, the latest technological applications require overcoming many obstacles during implementation. Similarly, experts identified some barriers while evaluating the developed BIM-SRSS tool. Barriers to BIM-SRSS system implementation and their precautionary measures to overcome those barriers in industry are elaborated in Table 6.

Table 7 Barriers to implementation of BIM-SRSS system

Implementation Barriers	Description
Lack of awareness of the latest construction tools like BIM	To use the developed BIM-SRSS system, it is necessary to have a basic understanding of BIM and hands-on experience with online tools. On the contrary, most of the industry experts are still unfamiliar with BIM. As a result, much effort is required to educate people about BIM

	technology and train them in using online tools to successfully implement BIM-SRSS.
Proper training	To understand the BIM-SRSS tool functionality to industry professionals, regular training sessions/workshop needs to be arranged.
Policy restraint	Industry professionals are prone to use traditional risk management techniques. There exist substantial requirements to update the policy measures in implementing the latest technological applications efficiently.
Cost of implementing the tool.	Industry research, employees training, and market understanding will be required to enact the developed BIM-SRSS system. All these measures require many resources and up-front costs.
Lack of management commitment	Since organizations' top management allocate funds and direct the contractor informing contractual arrangements and decision making. The successful implementation of BIM-SRSS greatly depends upon higher management commitment to improve construction safety management.
Cyber security issues	As data is stored in a global safety risk repository database of BIM-SRSS, there is a risk of data misuse through server hacking. The risk assessment scores might be manipulated that results in equivocal risk assessments outcomes.

5.4. BIM-SRSS IMPROVEMENTS

Table 7 summarizes expert recommendations for improving the BIM-SRSS in the construction industry.

Table 8 Improvements proposed by the industry experts

Future Improvements	Description
Realtime worksite safety monitoring	The BIM-SRSS tool could be used to carry out real-time worksite safety monitoring effectively. The hazard can be linked with the tool based upon the pictorial evidence gleaned from the site. The tool can suggest control measures using the data stored in global safety risk repository database.
Roles and responsibilities assigned assign to manage risk	The risks could be substantially managed by suggesting the roles and responsibilities of the project staff. BIM-SRSS can be used to define and specify the control measures required from each authorized member.
Hierarchy of control	The hierarchy of control plays a significant role in suggesting the control measure for the identified hazards. The on-site problems could be harnessed efficiently by improving the decision-making of middle-level management.
Return of investment	There is a need to figure out the Return on investment (ROI) for BIM-SRSS implementation. Higher management understanding and involvement could catalyze the enactment of the said tool in many organizations.
Security	The tool's database could be made more secure by keeping the security subscriptions updated. Restrictions should be ensured for any anonymous person to access the tool by implementing different access levels.

5.5. STRATEGIES FOR THE ADOPTION OF BIM-SRSS

Considerable effort is required to educate key project stakeholders and remove roadblocks to adequately implement the developed BIM-SRSS on construction projects (Ali et al., 2020). Table 7 and Table 8 summarize and explain the experts' recommendations that pave the way forward to develop effective BIM-SRSS implementation strategies for key construction stakeholders. Besides industry, academia could play a critical role by educating and training the industry experts regarding BIM to effectively execute complex and modern construction projects. Additionally, initial investment return should be computed to determine the long-term benefits using economics analysis such as ‘present worth’, ‘cost/benefit analysis, and ‘internal interest rate’. This would assist in convincing key stakeholders to adopt the BIM-SRSS tool to robustly manage site-safety practices on their projects. To successfully adopt BIM-SRSS, harmonized contractual and legal requirements should be stipulated in the contract. Clients direct the associated parties like consultants and contractors to ensure BIM-SRSS implementation for enhancing work-site safety. It is recommended to include BIM-based Employer's Information Requirements (EIR) in the contract documents (Arshad et al., 2019). With the application of these strategies, hazard stimulation would be significantly mitigated resulting in improving overall site-safety performance.

Chapter 6

6. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

ICT is being widely used in the construction industry to achieve better project performance and increased productivity. BIM is one of the applications of modern technology that assists in project design, planning, and construction. BIM also significantly enhances project management practices in many domains like Facility Management, Sustainability, Risk Management, and Safety Management. However, there is a scant amount of historical data and insubstantial technology application in the risk assessment process that is used to quantify safe design elements in the construction project.

This study adds to the amount of knowledge on the detailed literature review and industry experts' opinions. Moreover, the study proposed a way for designers to put the PtD concept into practise effectively and efficiently to address risk control during the design process. The sporadic data input from the site regarding hazards and activities systematically improves the risk assessment and enhances the overall site safety. BIM-SRSS tool integration with BIM further provides a robust and efficient risk assessment while addressing the constraints of current tools and design processes.

One of the main advantages of the proposed tool entails an innocuous impact on the project design. The whole design process and designer’s creativity remain intact, thus results in rapport construction performance, and subside change orders and disputes. Additionally, designers can apply the developed tool adequately with scant construction risks and safety knowledge. The proposed method further enlightens the designers with safety-risk awareness that elevates their problem-solving and decision-making.

The involvement of OHS professionals requires to be conducted at an early stage of the project to accede valuable insights regarding the frequency of hazards. Consequently, site safety planning could be performed during the inception and planning phase of the project. The precise risk assessment outcomes like information related to high-risk activities or design elements would improve the resource allocation and selection of appropriate PtD control measures. This will aid in improving workers' safety and implementation of PtD practices during the early phases of the project.

BIM-SRSS tool is evaluated by industry experts via qualitative and quantitative assessment techniques. The outcomes entail that the developed tool could improve most of the identified CSFs in PtD implementation. After identifying a few roadblocks to its execution, designers and OHS professionals opted that there is a need for the development of BIM-SRSS in the AEC industry. The experts suggested that future improvements enhance the effectiveness and useability of BIM-SRSS tool development.

The validation of the proposed BIM-SRSS tool from industry experts reveals the great potential to designers and safety professionals to implement PtD practices. It facilitates the designers and OHS professionals to collaborate and share relevant information robustly. Moreover, it allows identifying potential hazards to recognize design and schedule errors to enhance the design quality. The designer could incorporate safety precautionary measures into a design that would enhance site safety practices and decision-making.

6.2. RECOMMENDATIONS

Owing to the limited scope of the study. This study necessitates the use of the 'average method' to predict the safety risk score of hazards from the global safety risk repository. In the case of Big Data, the framework allows to include Deep Learning and Artificial Intelligence (AI) to create self-learning algorithms. The BIM-SRSS is validated by the industry experts using a building project. Nevertheless, the developed tool could also be implemented in other construction sectors like Hydropower, highways, and railway projects

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