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The use of building information modelling (BIM) in the management of construction safety: The development towards automation hazard identification and assessment

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Abstract

The construction industry faces safety management challenges that impact its reputation and workforce well-being. Despite existing safety regulations, safety violations persist, necessitating innovative solutions. This thesis explores the potential of Building Information Modeling (BIM) as a tool to improve safety practices throughout the project lifecycle. A literature review identifies key safety factors and BIM features, revealing their interconnections and potential for synergistic improvements. A questionnaire survey and semi-structured interviews with 55 construction professionals from diverse regions revealed that over 45% of respondents reported positive outcomes from BIM implementation in their projects. A comprehensive framework is developed to integrate BIM-based safety improvement strategies into various project phases, providing practical guidelines and recommendations for construction professionals to enhance safety practices effectively and efficiently. The research emphasizes the significance of BIM adoption in the construction industry, promoting better safety outcomes and elevating safety management practices. The proposed framework offers valuable insights for stakeholders, encouraging the widespread adoption of BIM technology and its seamless integration with safety practices for improved project safety and overall construction efficiency.

Keywords: Building Information Modeling; Construction; Safety regulations; Risk Assessment; Hazard Prevention

1. Introduction

Construction is a crucial sector with significant economic and social impacts. However, it is complex due to its constantly changing nature, worksite-related accidents, and the severity of these accidents. Unsafe working conditions can negatively impact the reputation of those involved in construction projects and hinder further development.[1] Despite the implementation of laws and regulations like the Occupational Safety and Health Act (OSHA), National Institute for Occupational Health (NIOH), and Health and Safety Executive (HSE) in countries like the US, India, and the UK, accidents continue to pose significant challenges in the global construction sector. Factors contributing to these incidents include the ever-changing work environment, worker conduct, insufficient coordination, and deficiencies in risk management. To address these issues, innovative methods like Building Information Modeling (BIM) can be adopted and implemented. BIM is a digital tool that generates and organizes precise 3D models for construction projects, enabling seamless information sharing and integration among stakeholders. This integrated approach can enhance safety in construction projects in the UK.[2]

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2. UK safety regulations and BIM technology

The UK's construction sector faces significant safety challenges despite the implementation of laws and regulations. The Health and Safety Executive (HSE) oversees health and safety regulations, including the Building (Design and Management) Regulations (CDM Regulations) of 2015 and the Health and Safety at Work Act of 1974 and the Management of Health and Safety at Work Regulations of 1999.[3] These laws aim to provide a secure working environment in the construction industry, requiring employers, employees, and other parties to safeguard the well-being and security of workers and individuals affected by construction operations. The Construction (Design and Management) Regulations (2015) address these challenges by imposing legal obligations on clients, designers, principal contractors, and contractors to manage health and safety throughout the project. The Health and Safety Executive (HSE) advocates for the use of Building Information Modelling (BIM) in the construction sector to address safety concerns and promote optimal methodologies. BIM enables the creation of digital models that simulate the construction process, facilitating collaboration, clash detection, and identification of potential safety hazards.[4] By prioritizing safety in all tasks, construction projects in the UK can benefit from enhanced coordination, improved communication, and better risk management. Effective safety management can prevent construction accidents, and BIM provides a collaborative platform for stakeholders to share and integrate information effectively. Clash detection allows for potential conflicts between building elements to be identified and resolved in the design phase, minimizing safety risks during construction. BIM also enables visualization and simulation, allowing project teams to identify and mitigate safety hazards before they occur. Real-time data and monitoring systems further support safety analysis and performance tracking.[5]

3. Implementation of safety regulations and BIM technology

To manage building safety risks in line with HSE's Plan, Do, Check, Act approach, consider factors like identifying potential risks and creating preventive measures. However, safety planning is often not integrated into project planning and execution, leading to hazardous conditions, life-threatening situations, and cost and time delays at construction sites.[6] To address these issues and derive a comprehensive framework for managing building safety risks, the following approach can be adopted:

- **Plan**: Safety planning should be an integral part of project planning and execution. This involves identifying potential hazards, assessing risks, and developing preventive measures. It is essential to consider relevant codes, regulations, and industry best practices during the planning phase[7].
- **Do:** Implementation of safety measures should be executed during the construction phase. This includes providing adequate training to workers on safety procedures, ensuring compliance with regulations, and promoting a safety-oriented culture on the construction site[8].
- **Check:** Regular monitoring and inspections should be conducted to assess the effectiveness of implemented safety measures. This involves evaluating compliance with safety protocols, identifying any deviations, and taking corrective actions promptly[9].
- **Act:** Continuous improvement is crucial in managing building safety risks. Lessons learned from incidents, near misses, or safety audits should be used to update safety plans and procedures, enhance training programs, and implement necessary adjustments to mitigate risks[10].

The Plan, Do, Check, Act framework is a systematic approach to managing building safety risks in construction projects. It integrates safety planning from the early stages, emphasizes proactive measures, and promotes a safety culture within the industry. However, current safety management systems are not performing well due to their reactive nature.[11] Neglect in safety planning, information unavailability, and unregulated project task execution lead to worksite hazards that endanger life and cause cost and time delays.[12] Most hazards and accidents go unreported, making it difficult for project safety planners to plan and work without this information. Additionally, contractors often neglect safety manuals or disregard them on work sites. The main issue is the reporting procedure for work accidents by managers and workers. Poor communication between work staff and administration staff, particularly illiterate workers, also contributes to communication issues. Safety and communication are interlinked and pose challenges for task planners due to the dynamics of work sites and working behaviors.[13]

3.1. BIM technologies used in Safety Administration

3.1.1. Clash detection

Clash detection is crucial for safety management in construction projects, and Building Information Modeling (BIM) offers significant advantages. BIM combines design and construction aspects into a digital model, enabling the identification and resolution of conflicts between building components like structural elements and services installations.[14] This proactive technique helps to mitigate safety risks and create a more secure working environment. BIM also enables the identification and resolution of potential safety hazards during the design phase, minimizing the risk of accidents, injuries, and disruptions during construction. Studies have shown the effectiveness of BIM in clash detection for safety management, with an integrated BIM-based framework for hazard risk identification in construction incorporating clash detection as part of the safety management process. This approach helps identify potential hazards and develop preventive measures, ensuring a safer and more efficient construction process.[15]

3.1.2. Hazard Identification and Risk Assessment

BIM is a powerful tool that provides a comprehensive view of a project, enabling stakeholders to identify potential safety hazards more effectively. Its detailed 3D model includes architectural, structural, mechanical, and electrical components, providing a holistic view of the project. This allows stakeholders to visually assess the spatial relationships between different elements and identify potential hazards during construction or operation.[16] BIM also integrates safety data, such as hazard databases, material properties, and safety regulations, allowing real-time analysis of potential risks. For instance, by associating material properties with building elements, BIM can assess the fire resistance of structural components, aiding in fire hazard identification. BIM also aids in risk assessment, linking hazard data with BIM elements, analyzing and quantifying risks associated with specific hazards. It can simulate different scenarios and evaluate potential consequences of hazards, helping stakeholders prioritize risks and develop mitigation strategies. A study by Li et al. (2015) found that BIM eased risk assessment and hazard identification, enhancing safety performance in the Hong Kong construction sector.[17]

3.1.3. Visualization and Simulation for Safety Planning:

Building Information Modeling (BIM) is a powerful tool that enhances safety planning in construction projects by providing visualization and simulation capabilities. BIM allows stakeholders to visualize and simulate various aspects of the construction process, enabling proactive safety planning and risk mitigation.[16] This immersive experience helps identify potential safety hazards and visualize the flow of construction activities. By visualizing the project in advance, stakeholders can proactively address safety concerns and make informed decisions to enhance safety measures. Simulation is another key feature of BIM, allowing stakeholders to create virtual simulations that mimic the construction process, allowing them to assess safety risks and evaluate the effectiveness of safety measures. These simulations can encompass various scenarios, such as construction sequencing, equipment utilization, and worker movements.[18] By simulating different construction activities and sequences, BIM can identify potential safety conflicts and assess their impact. Simulations can also help assess the accessibility and safety of work areas, facilitating the identification of potential fall hazards or material handling risks. BIM-enabled simulations can also simulate emergency scenarios, optimizing escape paths, identifying bottlenecks, and improving emergency response strategies.[19]

3.1.4. Data Integration for Real-time Safety Monitoring

Building Information Modeling (BIM) is a powerful tool for real-time safety monitoring in construction projects. It centralizes and integrates data from various sources, including on-site sensors, IoT devices, and wearables, providing a holistic view of the project's safety status. BIM enables visualization and analysis of safety data in a centralized and dynamic manner, providing a clear understanding of potential safety risks and enabling proactive decision-making to address safety concerns promptly.[20] The study explores safety factors and BIM features, identifying effective strategies for improving safety. A comprehensive approach will be developed using questionnaire surveys and open-ended questions, involving industry professionals with in-depth knowledge in safety management and BIM implementation.[21] The data will be strategically distributed into different project phases, ensuring systematic integration of safety considerations throughout the construction process. BIM is crucial for integrating safety in construction sites due to increasing concerns about technology advancement and safety enhancement. Collaborative efforts among project stakeholders can improve safety management outcomes.[22] BIM can create a clear link between safety considerations and construction planning, improving communication on safety. However, there is a lack of comprehensive research on BIM adoption, encompassing technology, processes, and personnel.[23] A proactive strategy is essential for achieving safety through automation. Understanding the relationship between safety factors and BIM can help devise an efficient strategy for its implementation. Effective safety management requires the use of BIM's functionalities.[24]

Objective and Scope

The construction industry faces challenges due to manual labor and lack of technology, leading to communication gaps and financial losses. Building Information Modelling (BIM) technology can enhance safety performance by integrating project phases and aiding dispute resolution. Clarifying BIM safety issues and traits can reduce worker safety concerns. The study aims to facilitate the industry in adopting technology-driven approaches to address construction site safety.

This study examines safety conditions in the construction sector and the potential of Building Information Modelling (BIM) to improve safety management procedures and reduce accident and fatality rates. It will assess literature, case studies, and expert perspectives, and create a framework for safety improvement initiatives. BIM's capabilities, such as clash detection, visualization, and simulation, will be explored to proactively identify and address safety concerns. The research aims to contribute to existing knowledge on BIM's potential in improving safety outcomes in construction projects.[25]

4. Literature Review Methodology

A thorough literature analysis that has been broken down into four separate sections has been used to analyze the state of Building Information Modelling (BIM) and construction safety management. These phases are depicted in Figure 1 and are further elaborated upon below.

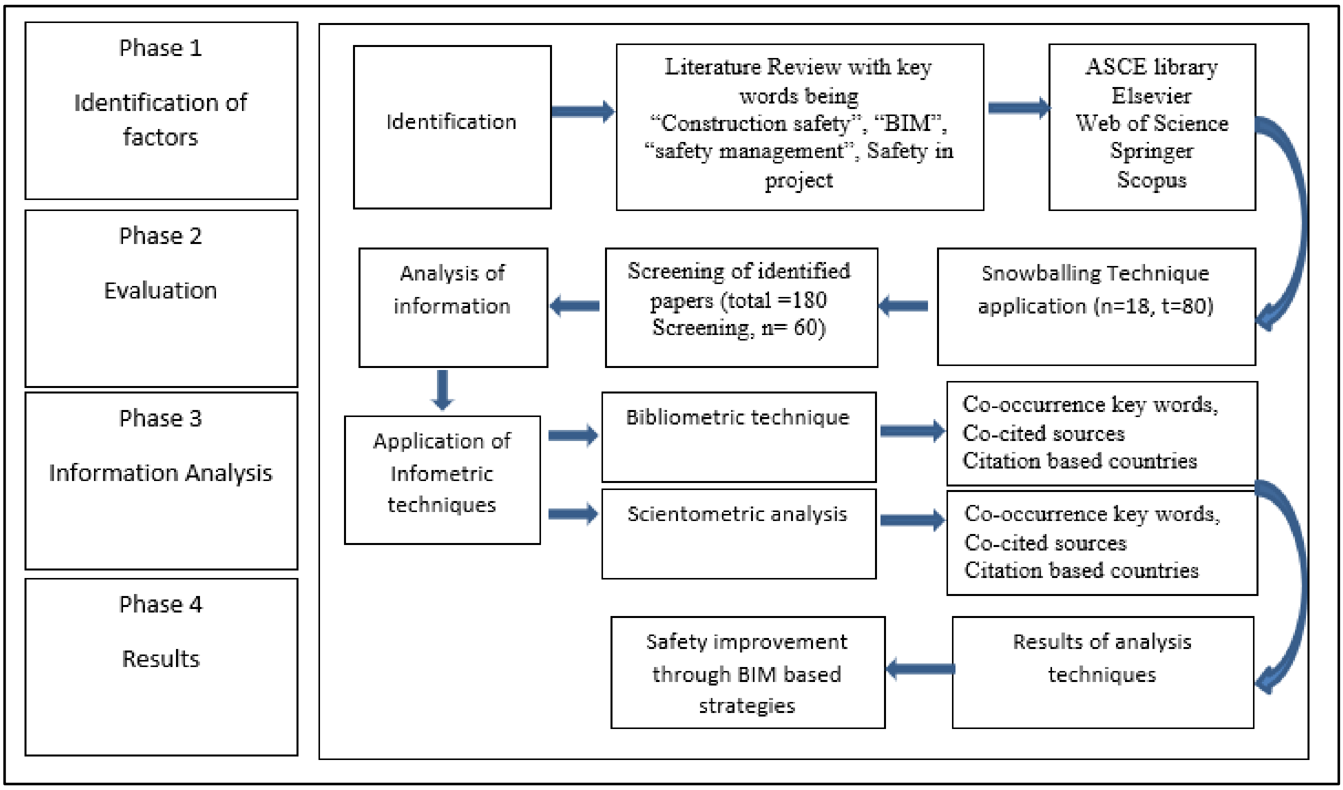

Figure 1 Flowchart Literature Review

The project involved searching for relevant scholarly publications and databases using search engines like Elsevier, Scopus, and Google Scholar. The search was restricted to articles released between 2010 and 2018, and keywords like "Construction safety" and "Building Information Modelling" were used. The researchers selected 180 materials, including books and journal and conference articles. In phase two, only peer-reviewed articles were reviewed, as they are renowned for their meticulous review processes and offer more accurate information.[26] Seventy journal articles were chosen for further examination, and the snowballing technique was employed to expand the scope of relevant research beyond primary construction engineering and management journals. This led to the incorporation of 18 papers from other publications, resulting in a total of 80 papers. In the third phase, infometric analysis was the main focus, combining bibliometric and scientometric methods to quantitatively examine information. Science mapping was used to ease bibliometric analysis, visualize the physical components of scientific research, and gain insights into the organization of scientific domains and disciplines.[27] Various visualization tools were used, and the features and limitations of different software were assessed, leading to the selection of VOSviewer and Gephi for the study. Table 1 depicts features of selected science mapping tool.

Table 1 Features of Selected Science Mapping Tool

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

VOS viewer is a popular visualization program for scientific exploration, but Gephi is preferred for network analysis and graphical representation. Scopus data was collected for seamless bibliometric analysis, allowing for other datasets to be used. The main bibliometric studies were co-occurrence of keywords, co-citation of cited sources, and citation-based nations. A content study using scientometric analysis was conducted to explore the link between Building Information Modelling (BIM) and safety management components.[28] A relationship matrix was created, resembling a D3 chord diagram with interactive hover functionality. The diagram demonstrates the intricate interplay of data points and provides a clear graphical representation of interactions between traits. Articles were further divided into lifespan phases using Scientometric analysis to understand concentrated periods. These findings informed recommendations for expanding ongoing research projects.[29]

4.1. Analysis of relevant articles

The articles were thoroughly reviewed and analyzed using quantified systematic techniques and cutting-edge software platforms. The focus was on bibliometric analysis, a technique that allows scientists to map and visualize vast datasets. Tools like VOSviewer and Gephi were used for the analysis. Raw information was imported from Scopus, laying the groundwork for an in-depth exploration of the literature. The in-depth results are discussed in subsequent sections.[30]

4.1.1. Keywords based

Keywords reveal knowledge domains within a field. A co-occurrence map of author keywords was created using VOSviewer, a scholarly tool. The map uses fractional counting for normalization and bibliographic data from Scopus. The map reveals profound relationships and patterns within the knowledge domain. The 51 keywords met the minimal level of co-occurrence criteria, and similar phrases like "building information modeling" were merged into a single keyword. This inspired technique paved the way for a stunning network, unveiling the primary study areas in the captivating fields of construction safety and BIM.[31]

For the network visualization, link strength was used to determine weights, and average normalized citations were used to determine scores. Each keyword's font size indicates how often it appears, with bigger font sizes suggesting the terms with the greatest influence. As a result, "building information modeling" was the most frequently used keyword, followed by "safety," "construction safety," and "data".[32]

The Architectural, Engineering, and Construction (AEO) industry is facing a surge in accidents due to schedule overlapping, which is largely due to the limitations of traditional scheduling approaches.[33] These methods lack 3D tools and uniform resource distribution, leading to inadequate workspace management and chaotic site conditions. To address this, researchers are exploring the integration of Building Information Modeling (BIM) into scheduling and planning. BIM has the potential to revolutionize the industry by offering innovative solutions to tackle challenges and improve safety. A prototype developed by Zhou, Ding, and Chen (2013) integrates safety with detailed information models and construction site activity scheduling, enhancing risk identification and elimination throughout the project lifecycle.[34] BIM applications like rule checking help monitor building performance without design modifications. However, there is limited research on the relationship between BIM and safety, and there is no weighted correlation between safety and developing technologies like cloud computing.[35]

4.1.2. Cited sources analysis

Co-citation analysis was carried out, according to Hosseini et al. (2018), to categorize the most important journals or data sources in the field of building information modelling (BIM) and construction safety. The goal of this study was to aid scholars working in this field by highlighting important publications. Authors wishing to publish their works in this field might also benefit from using this material.[36] For co-citation analysis, which entailed computing weighted degrees for cited texts, a bibliographic map was produced using VOSviewer. 89 out of 1680 sources were chosen because they met the established criteria after using fractional counting and setting a minimum citation criterion of 4.

The algorithm's gravity feature centralized esteemed sources, adding quality to the visual representation. The network included 46 nodes and 356 edges, highlighting key journals in the construction sector's safety and technological applications domain.[37] The visualization reflects the strength of linkages, with thick edges and dark-colored linkages indicating collaboration. Automation in Construction, Journal of Computing in Civil Engineering, Safety Science, and Advanced Engineering Informatics are notable examples of sources with thick edges and dark-colored linkages.[7] Advanced Engineering Informatics and Safety Science specialize in separate fields, while Fire Safety Journal gets less citations due to its focus on fire safety design. The centrality of sources' degrees and weighted degrees provide insights into the importance and influence of various sources in the construction sector. Automation in Construction has the highest weighted degree centrality, while the Journal of Building Information Modelling has the lowest number.[38]

Table 2 Degree centrality and weighted degree of sources

Sr. no.	Sources	Weighted Degree	Degree
1.	Automation in Construction	154.7359	19
2.	Journal of Computing in Civil Engineering	59.3578	19
3.	Safety Science	46.7284	19
4.	Advanced Engineering Informatics	44.6746	18
5.	International Journal of Project Management	19.9094	20
6.	Journal of Construction Engineering and Management	17.7699	22
7.	Visualization in Engineering	16.7519	18
8.	Journal of Safety Research	16.7345	18
9.	Journal of Information Technology in Construction	15.7426	22
10.	Computer-Aided Civil and Infrastructure	11.4124	17
11.	Construction Management Economics	9.7888	15
12.	Journal of Management in Engineering	7.3748	17
13.	Construction Innovation	6.1385	15
14.	Engineering, Architecture and Construction	5.9688	16
15.	Professional Safety	5.6757	8
16.	Building and Environment	5.4036	17
17.	Procedia Engineering	5.3023	17
18.	Journal of Civil Engineering and Management	5.1391	18
19.	Fire Safety Journal	4.8961	10
20	Building Information Modelling	4.5343	13

4.2. Snowball sampling

Additionally, the snowballing strategy was used by looking at the pertinent citations in the present dataset in order to ensure thorough coverage of pertinent articles outside of the chosen journals (Badampudi, Wohlin, & Petersen, 2015).[39] Review publications from the years Oraee et al. (2017), Schanes, Dobernig, & Gözet (2018), Stingl & Geraldi (2017), and Zahoor et al. (2016) have all used this strategy.[40] For instance, Stingl and Geraldi (2017) employed the snowballing sample strategy to include 10 more papers in their study after doing a survey of important project management publications. Similar to this, using this method for our study led to the inclusion of 17 more papers, as shown in Table 3.

Table 3 Number of documents regarding construction safety and BIM

Source	Documents
Automation in Construction	12
Safety Science	5
Journal of Construction Engineering and Management	8
Journal of Information and Technology in Construction	6
Journal of Computing in Civil Engineering	3
Visualization in Engineering	4
Advanced Engineering Informatics	6
Computer-Aided Civil and Infrastructure Engineering	2
Others (snowballing)	34
Total	84

The completed dataset comprises 84 pertinent papers collected from various databases. An observable trend reveals a significant increase in articles, particularly around the year 2015, indicating a growing focus on BIM research. Notably, Elsevier stands out as a primary publisher, contributing a substantial volume of content on technological applications, while the remaining databases are still in their developmental stages. Figure 2 shows trend of published articles for construction safety and BIM.

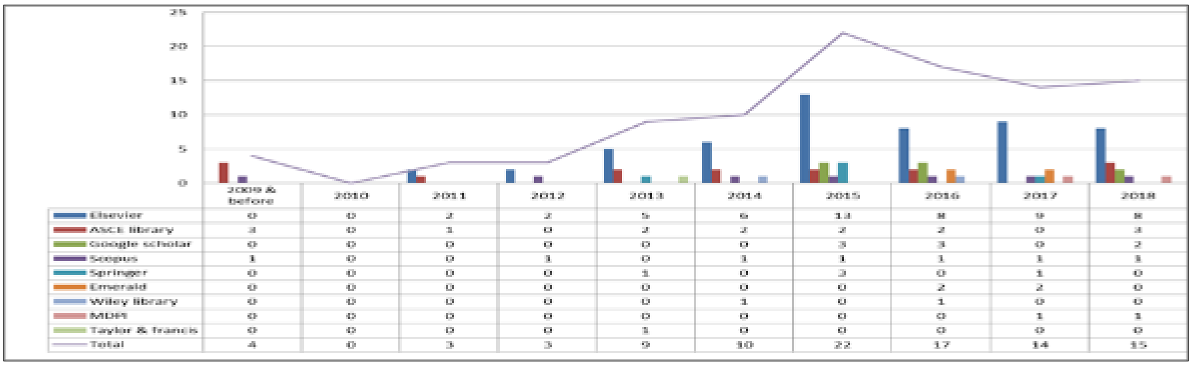

Figure 2 Trend of published articles for construction safety and BIM

4.3. BIM Technology

In the context of this thesis research, the identification of BIM attributes was meticulously carried out through an extensive review of relevant literature. The potential to enhance safety management cannot be understated, as it allows stakeholders to gain visual insights into worksite conditions and proactively anticipate potential hazards.[39] Furthermore, automated rule-based checking has garnered significant traction in recent research, capturing the interest of numerous scholars in their respective studies. One noteworthy investigation by Hongling, Yantao, Weisheng, and Yan (2016) explores the integration of design safety codes and Occupational Safety and Health Administration (OSHA) regulations with BIM, resulting in the automatic identification of safety issues.[41] Their findings underscore the efficacy of automated checking in saving valuable time and labor costs, which would otherwise be invested in safety management improvements. Finally, while the attributes of MEP (mechanical, electrical, and plumbing) and structural analyses undoubtedly hold critical roles within the broader scope of BIM, their significance in the context of this research area remains relatively limited, as evidenced by their notably lower frequencies. As this thesis delves into the exploration of BIM attributes and their relevance in safety management, it is essential to acknowledge the scholarly foundation established by the aforementioned studies. The academic rigor and meticulous examination of these attributes pave the way for a comprehensive understanding of BIM's potential in enhancing safety practices within the construction industry.[42]

4.4. BIM application in safety management domain

The primary aim of this review is to ascertain the attributes pertaining to BIM and construction safety, necessitating a thorough examination of all the chosen articles. As a result, a comprehensive analysis of the final dataset was conducted, specifically focusing on the attributes associated with BIM and safety, rather than solely their interrelationship. Within the relevant literature, the study identified a noteworthy set of 18 attributes related to construction safety and 29 attributes linked to BIM.[43] To assess the relative significance of these safety attributes, a quantitative score was calculated based on their frequency of occurrence, as depicted in Figure 3.

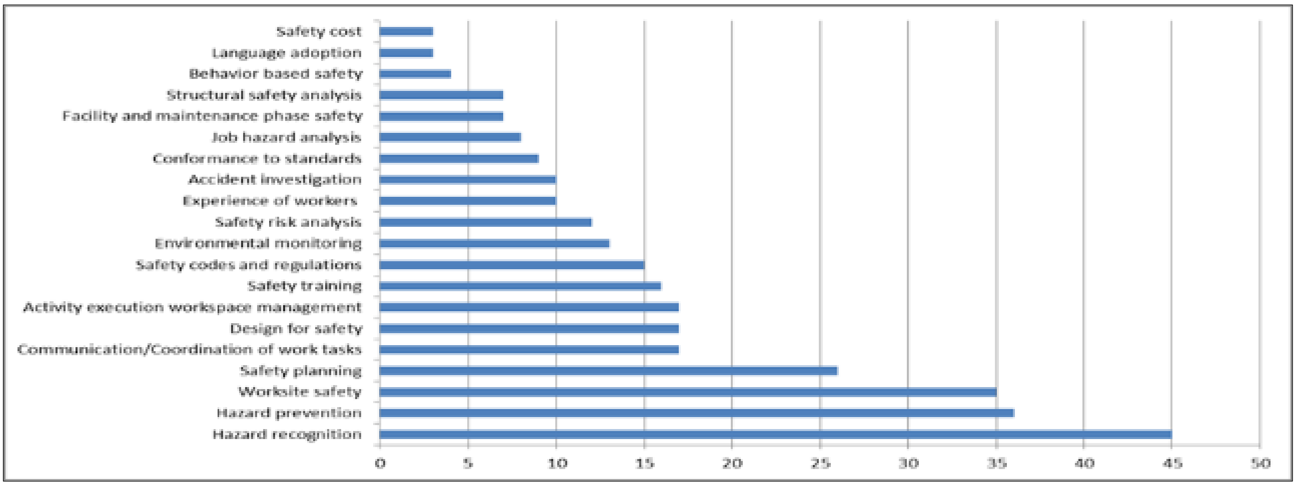

Figure 3 Frequency of safety factors

Building Information Modelling (BIM) implementation is primarily concerned with hazard identification and mitigation. Safety planning is a crucial initial step in enhancing safety, and worksite safety is a significant focus due to construction accidents. Factors like safety cost and language adoption are less significant in BIM and safety literature, but they still have an indirect relationship with technology. Effective safety planning could potentially reduce safety-related expenses and improve communication effectiveness, especially for immigrant workers. Comprehensive safety training can address these challenges.[44]

4.5. Relationship of BIM and safety domains in literature

A relationship matrix was created to identify the links between selected Building Information Modeling (BIM) features and construction safety. Hazard recognition is the most important safety aspect, with its largest width and extensive connections to various BIM features. Early hazard detection is essential for a secure working environment and increasing project success. Hazard prevention is a prominent concern and exhibits a strong association with BIM features.[44] Strategies must include worker training, adherence to safety standards and laws, and measures to reduce project interruptions and compensation costs. Visualization is the most important BIM component, as the workforce often lacks the technical ability to understand outcomes without visual representation.[45] Hazard recognition and automated rule-based verification have a good link, highlighting the successfulness of this method in boosting construction safety. Researchers have created frameworks for automatically verifying safety regulations, allowing hazards to be identified without relying solely on visualization and safety experts' knowledge.[46]

Clash detection and 4D simulation are also strong connections for danger recognition. Moon, Dawood, et al. (2014) developed a method for automatically detecting workspace clashes using 4D simulations, aiming to reduce workspace conflicts. Marzouk and Abubakr (2016) developed a framework for choosing the kind and position of a tower crane at construction sites, employing 4D simulation for clash detection during crane operations.[47]

4.5.1. Hazard recognition

Real-time location system monitoring is a promising approach to managing resource locations on construction sites, addressing the challenges of manual monitoring and potential errors. This technology enables the identification and tracking of resources like personnel, materials, and equipment. It is particularly relevant for jobsite monitoring for safety enhancement. Researchers are focusing on improving hazard recognition practices by integrating real-time monitoring and location-based sensing. A study by Teizer (2015) provides valuable insights into the reliability of localizing and monitoring construction resources.[48] Another study by Dong, Li, and Yin (2018) identifies and assesses personal protective equipment (PPE) using pressure sensors and localization technologies within Building Information Modeling (BIM).[49] This system not only tracks workers' locations but also detects hazardous situations, issuing warning signals, and determining areas requiring PPE use.

4.5.2. Hazard prevention

Building Information Modeling (BIM) has become a crucial tool for enhancing safety management practices in the construction industry. BIM allows safety professionals to create detailed 3D models, enabling them to conduct virtual simulations and analyze potential hazards in a controlled environment. This approach allows for the exploration of various construction scenarios, evaluation of safety measures, and proactive identification and addressing of potential risks before the construction phase begins. BIM-based safety management offers numerous advantages, including early detection and elimination of potential risks, improved coordination and communication among stakeholders, and a culture of safety.[47] Research studies have consistently shown the positive impact of implementing BIM-based safety management, with studies demonstrating improved hazard identification, risk assessment, and communication among stakeholders. BIM and Geographic Information Systems (GIS) can also be used for construction safety management, enabling a data-driven approach to hazard prevention and informed decisions to enhance site safety. Overall, BIM-based safety management contributes to a more robust and proactive approach to hazard prevention in construction projects.[50]

4.5.3. Visualization

Visualization is a crucial aspect of Building Information Modeling (BIM), addressing safety aspects and enhancing its capabilities. However, its linkages with environmental monitoring and activity execution workspace management are weaker, highlighting the need for further research in these areas. BIM holds potential for enhancing visualization capabilities to monitor workspace environments, especially in confined spaces with hidden hazards like temperature and humidity levels. Integrating BIM's visualization feature with wireless sensing technologies allows for comprehensive environmental monitoring.[51] Activity workspace management is also crucial, as ineffective management can lead to safety hazards and compromised quality. Visualization and simulation algorithms can help minimize conflicts and streamline resource allocation.

4.5.4. Benefits of BIM based safety management

Safety planning is crucial for effective safety procedures, including hazard identification and prevention. Monitoring and reporting of risks and near-misses to construction site staff is essential for developing effective mitigation techniques. Visualization is a powerful tool for improving near-miss reporting and workplace safety planning. Zhang, Sulankivi, et al. (2015) created an automated method for identifying safety risks, along with a safeguarding mechanism for their mitigation.[52] The high incidence of fatalities and injuries on construction sites results in high costs and lost productivity, affecting a project's safety cost. BIM can significantly lower accident-related costs by enhancing construction safety. However, a comprehensive framework for utilizing BIM capabilities to improve safety management is lacking in the literature. Further research is needed to examine workplace safety cultures and interactions between employees and safety superintendents.[53] Comprehensive solutions for adoption in the project lifecycle have been found, essential for promoting a safety culture and establishing proactive safety procedures within the construction sector. Table 4 shows BIM based Safety Improvement Strategies

Table 4 BIM based Safety Improvement Strategies

Code	Strategies	References
S1	BIM based contract provision	[54]
S2	Defining BIM goals based on the project scope	[55]
S3	Engaging a competent team	[56]
S4	BIM modelling and information exchange between stakeholders	[57]
S5	Clarify and consider implementation costs, including hardware and software requirements	[58]
S6	Hiring safety professionals well-acquainted with BIM processes and workflows	[59]
S7	BIM modelling during the schematic design phase	[60]
S8	Utilizing BIM-based visualization for the purpose of hazard identification and prevention	[61]

S9	BIM help in enhancing activity execution workspace management	62
S10	Safety evacuation plans using BIM should be prepared for the worksite	14
S11	Safety training sessions that utilize models, walkthroughs, and 4D simulations to illustrate safety concerns	63
S12	Effective execution planning for high-risk construction activities employing 3D models and 4D simulation	64
S13	Explanation, Distribution and Communication of work task within the project team in the 3D and 4D Environment	65
S14	Identifying hazards in cramped worksite spaces using 3D walkthroughs	66
S15	Using BIM-based visual presentations to enhance communication throughout all project stages	67

5. Research Methodology

The study will comprise of a comprehensive methodology including four stages which are depicted in the flow chart designed below. The step wise hierarchy of each phase is shown in following figure:

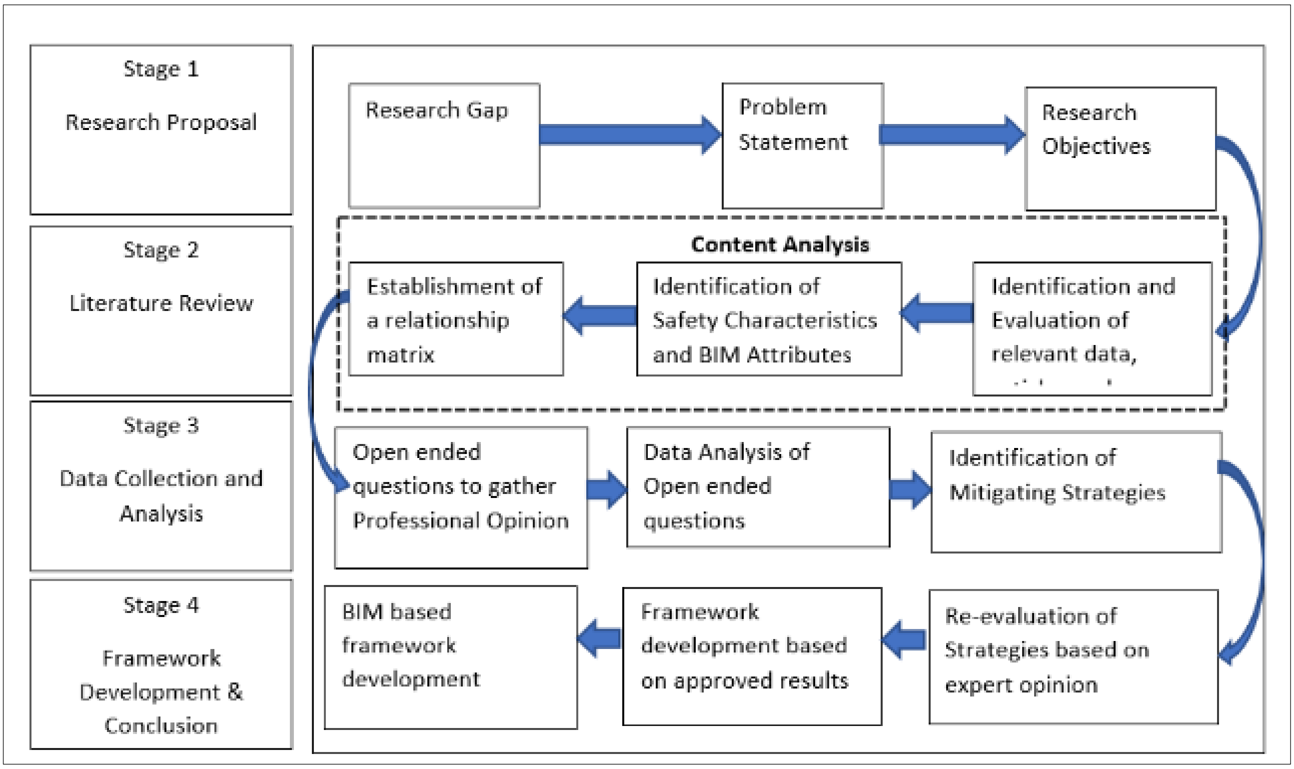

Figure 4 Research Methodology Flowchart

5.1. Research Design

The initial step involves examining the most recent published articles related to construction management. The articles emphasize the importance of Building Information Modeling (BIM) in the construction industry, highlighting gaps in research on safety management. Despite numerous studies, safety conditions in the industry remain unsatisfactory. This study aims to identify the correlation between BIM and safety management, identifying effective approaches for integrating BIM into the project lifecycle and elevating safety standards.[68] By analyzing the dynamic relationship between various factors, the research aims to address the knowledge gap in safety management.

5.2. Literature review

After establishing the research objectives, a thorough and comprehensive literature review is needed. To extract the necessary information, a systematic process called content analysis is employed, as previously outlined in studies by (Abbasnejad & Moud, 2013).[1] This method is widely used by researchers to analyze a substantial amount of textual data in a systematic and structured manner, as demonstrated by (Ahmad et al., 2018).[69] Using content analysis, the significant attributes related to BIM and safety management will be shortlisted and identified. This process involves carefully reviewing and extracting relevant information from the literature to gain insights into the key features of BIM and their impact on safety factors within the construction industry.

5.2.1. Search Strategy and Keywords

To conduct an effective literature review, a well-defined search strategy is required. This includes determining the databases to search, choosing appropriate keywords, and defining inclusion/exclusion criteria. Some common databases for construction-related research include Google Scholar, Scopus, PubMed, and academic libraries. These are used in the study to shortlist and identify relevant papers and articles. Keywords for the literature will include variations of the following terms:

- Building Information Modeling (BIM)
- Safety implementation
- Construction industry
- Construction safety
- BIM impact on safety
- BIM adoption and safety
- BIM and safety best practices
- BIM for hazard identification
- BIM safety guidelines

Data Extraction and Synthesis

Once the relevant literature is selected, the important information will be extracted from each paper, such as research objectives, methodologies, key findings, and conclusions. Content analysis involves organizing and summarizing the information in a structured manner.

Identify Themes and Trends

During the literature review, there will likely be identify common themes, patterns, and trends related to BIM and safety implementation. These themes will guide the formulation of research questions and the development of the questionnaire.

Identify Gaps and Limitations

The review of existing literature is essential in identifying research gaps and limitations in the methodologies employed in prior studies. By analyzing earlier works, the current research can build upon existing knowledge and make a meaningful contribution to the field. The literature review guides the study in addressing specific areas that need attention and refining the approach to ensure rigor and relevance. A feature-factor matrix will be created to evaluate the relationship between Building Information Modeling (BIM) features and safety factors.[70] This matrix will be used to evaluate BIM interactions with safety management issues and make decisions in future construction projects. The results will guide the identification of strategies to improve safety standards in the construction industry. Understanding the connections between BIM features and safety factors can help researchers establish effective approaches to integrate BIM-based safety practices throughout construction project lifecycles.

5.3. Questionnaire development

A convenience sample technique was used for the study on BIM-based safety practices in the construction sector. In the study, the impact of Building Information Modeling (BIM) on safety practices has been assessed in the construction industry. Participants will be selected from professional networks in the supply chain and construction industries. A questionnaire survey will be conducted online using platforms like Google Forms, with each component asking respondents to rate the impact on a five-point Likert scale. A semi-structured interview form will be created based on the results, and open-ended questions will be included to gather more in-depth qualitative information. A mixed-methods study design will be used, combining quantitative and qualitative research techniques. A questionnaire survey will be conducted to gather quantitative information about the scope of BIM implementation on safety practices. A five-point Likert scale will be used to score the criteria, producing quantifiable data. Statistical techniques such as Shapiro-Wilk, Kruskal-Wallis, and Cronbach's alpha tests will be used to analyze the data. The study will conclude by listing the causes and preventative measures related to BIM-based safety practices in the building sector. The results will be displayed in tables and graphs, along with normalized and total scores for each element. Conclusions and recommendations will be based on these findings, demonstrating the mixed-methods approach's ability to provide a comprehensive assessment of BIM's impact on safety practices in the construction sector.

5.4. Questionnaire Organization

In organizing the questionnaire for the study on BIM-based safety practices in the construction industry, the study will commence with an introduction and cover letter to highlight the research's significance and ensure respondents of confidentiality and voluntary participation. A section will be included to collect demographic information, such as country, designation, education, and work experience.[71] To ensure coherence, the questionnaire was structured around specific research objectives and themes, with questions progressing logically from general to specific. A mix of question types, including close-ended and open-ended questions, was utilized to collect quantitative and qualitative data. The questionnaire was carefully crafted to ensure question clarity, avoiding bias and ambiguity. The study will maintain an appropriate questionnaire length to sustain respondents' interest and minimize fatigue.

5.5. Questionnaire Approach

The study on BIM-based safety practices in the construction sector was conducted using a mixed-methods research strategy, which works well with the overall research design. The study design's primary goal is to examine how the adoption of BIM has affected safety procedures in the construction sector, and the mixed-methods technique is ideally suited to accomplish this goal.

- **Comprehensive Understanding:** The use of both quantitative and qualitative methods allows the researchers to gain a comprehensive understanding of the research topic. The questionnaire survey provides quantitative data on the magnitude of impact, while the open ended questions offer qualitative insights into the respondents' perspectives and experiences. This combination of data sources ensures a holistic view of the BIM-based safety practices strategies.
- **Addressing Research Gaps:** The mixed-methods approach enables the researchers to address potential research gaps effectively. While quantitative data can provide statistical evidence of the impact of BIM implementation on safety practices, qualitative data can offer deeper insights into the specific challenges, strategies, mitigation strategies and contextual factors influencing the implementation process.
- **Enhancing Validity and Reliability:** By utilizing both objective quantitative measures and subjective qualitative narratives, the study enhances the validity and reliability of the research. Quantitative data provides objective measures of the impact, while qualitative data allows the researchers to capture the nuances and complexities of the topic.
- **Practical Implications:** The mixed-methods approach is particularly valuable when conducting research with practical implications. In this study, the combination of quantitative and qualitative data will provide a more nuanced understanding of the impact of BIM on safety practices, helping to inform practical recommendations for construction industry professionals.

5.6. Respondent selection

The subject selection and sampling procedure for the study on BIM-based safety practices in the construction industry will be chosen to showcase a comprehensive representation of developing and developed countries and this will help in accessibility of relevant respondents while maximizing the efficiency of data collection.

5.6.1. Subject Selection Justification

Construction and supply chain professionals were selected as the subjects for this study because they possess firsthand experience and expertise in the field, making them well-suited to provide valuable insights into the impact of BIM implementation on safety practices. Their perspectives and experiences are crucial in understanding the challenges and opportunities related to safety in the construction industry, particularly in the context of adopting BIM technologies for safety management protocols.

5.6.2. Sampling Procedure Justification

Convenience sampling was adopted as the sampling procedure for this study due to its practicality and efficiency. Convenience sampling was used to select respondents within construction professionals' professional networks, allowing for timely and cost-effective data collection. This approach ensures a diverse representation of respondents in terms of job roles, experience, and types of organizations, capturing a broader spectrum of industry perspectives. Despite its limitations, convenience sampling was justified as the study aimed to understand the impact of BIM on safety management and hazard mitigation among a specific group of professionals, rather than aiming for a fully representative sample.

5.7. Data Collection and Analysis

Data collection will be conducted using a participatory approach, specifically through the administration of an online questionnaire survey. The primary method employed for data collection and validation in this study will involve conducting interviews, which aligns with the approach utilised by Azhar (2017b). Participants will also be prompted to offer supplementary tactics by means of an open-ended inquiry in the questionnaire. Following the completion of data collection, the data will undergo assessments to determine its reliability, normality, and correlation. These assessments will be conducted using Cronbach's alpha, Shapiro-Wilk, and Kruskal-Wallis tests, respectively. Furthermore, the Cronbach's alpha coefficient will be utilised to evaluate the reliability of the given data. This coefficient ranges from 0 to 1, with a higher value indicating greater levels of internal consistency within the data (Hemanta et al., 2012). In order to assess the level of consensus among professionals, a statistical analysis will be conducted. This analysis will involve calculating the arithmetic mean (m) and defining specific ranges to categorise the degree of agreement. These ranges are as follows: Agree ($5 \leq m \leq 4$), Neutral ($4 < m \leq 3$), and Disagree ($3 < m \leq 1$). Further investigation would be warranted for strategies that fall within the Agree range, as suggested by Tixier et al. (2017). In order to ensure the attainment of representativeness, the determination of the minimum necessary sample size will be conducted. The determination of the sample size (n) in this study followed Cochran's (2007) formula: $n= m\hat{}2*p*q/y\hat{}2$. In this formula, m represents the factor of confidence level derived from the normal distribution table, p denotes the sample mean, q represents 1 minus p, and y represents the margin of error. The sample size was determined to be 41 by substituting the given values of m = 90%, ±10% marginal error, and a sample mean of 50%.

5.8. Framework Development

The framework aims to use Building Information Modeling (BIM) to improve safety in construction projects. It categorizes strategies based on project lifecycle phases, ensuring safety considerations are integrated throughout the entire process. A process map was created to automate safety improvement using BIM, serving as a blueprint for a BIM plugin. This plugin would streamline the process and promote safety measures. Interviews with industrial experts with over 15 years of experience validated the framework's practicality.[72] Feedback from these experts was used to refine and modify the framework to align with real-world practices and challenges. The study's conclusions will summarize the findings and implications of using BIM for safety enhancement in the construction industry. The study emphasizes the importance of collaboration between academia and industry to enhance safety standards in construction projects. The findings will be discussed with industry professionals and potential for further research.

6. Data Analysis and Results

The questionnaire survey was distributed via google forms and emails to a sample of over 150 construction professionals representing diverse geographic regions, with 55 respondents this is a 37% response rate from participants. In contrast, a prior investigation in the corresponding domain of expertise carried out by Zou et al. in 2017 employed a more limited sample size of 36 individuals to evaluate the degree of intentionality regarding identified strategies.[73] The provided figure illustrates the demographic characteristics of the participants, showcasing their varied geographical origins. It is worth noting that a considerable proportion of the participants (15%) are based in the United Kingdom, indicating a substantial level of acceptance and implementation of Building Information Modelling (BIM) within this geographical area. Furthermore, it was found that all participants hailing from the United States, the United Arab Emirates, and other countries in the Gulf region possessed a high level of proficiency in Building Information Modelling (BIM)[74]. The individuals stated that their respective organizations employ Building Information Modelling (BIM) for the purpose of managing building projects, but do not utilize it as a means of enhancing construction safety. The primary reason for this phenomenon can be attributed to a limited understanding and experience in utilizing technology for the purpose of implementing management strategies. Figure 5 depicts regional distribution of respondents

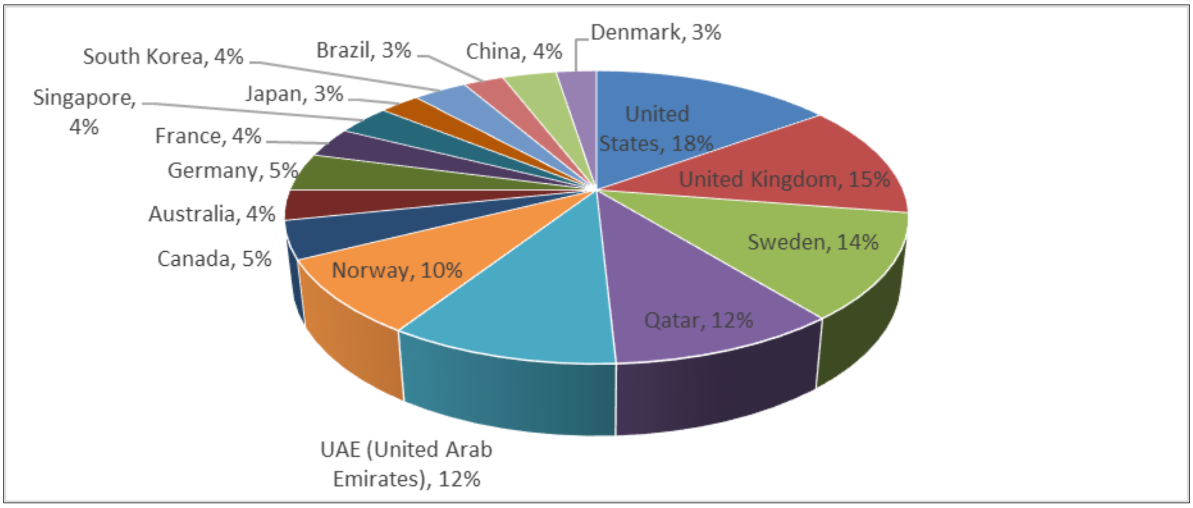

Figure 5 Regional Distribution of Respondents

The majority of respondents are affiliated with consultant and contractor organizations as they play a pivotal role in implementing safety measures in construction projects. Hence, their viewpoints were essential to consider. Additionally, a significant proportion of respondents possess more than 5 years of experience. The data mentioned in the study are responses gathered from respondents that chose to answer this study via email and google forms. This deliberate selection ensured the inclusion of participants with some level of familiarity with BIM, with 55.25% of them reporting an advanced understanding, while none of the respondents had no understanding of BIM.

Table 5 Respondents Information

Total Respondents = 55	
Profile	**Percentage**
Nature of Organization	
Client	15 %
Architect	25 %
Contractors	20 %
Consultants	30 %
Academia	10 %
Years of experience	
1 to 5 years	15.50 %
6 to 10 years	27.10 %
11 to 15 years	30.70 %
16 to 20 years	13.80 %
21 and above	12.80 %
Qualification	
B. Tech	12.25 %
B.Sc/B Eng.	33.10 %
MS/M.Sc/M/A	23.50 %
Ph.D.	21.65 %
Others	9.50 %

Level of Understanding of BIM	
Advanced	55.25 %
Good	21.15 %
Basic	14.70 %
No understanding	9.90 %

In the current job landscape, the majority of respondents (45%) work as BIM Managers, highlighting the high demand for professionals in this pivotal role. The survey also indicated representation from other BIM job positions, with BIM Project Managers comprising 13%, BIM Modelers at 10%, BIM Coordinators at 8%, BIM Technicians at 7%, BIM Specialists at 6%, BIM Engineers at 6%, and BIM Architects at 5%. This diversity of job positions underscores the growing significance of BIM technology in the construction and architecture industries, with BIM Managers leading the way in overseeing and implementing effective BIM strategies. Figure 6 exhibits designation of respondents.[75]

Table 6 Designation of Respondents

No	Designation	Total number of responses	Designation	Percentage
1	BIM Manager	25	BIM Manager	45.00%
2	BIM Modeler	6	BIM Modeler	10.00%
3	BIM Coordinator	4	BIM Coordinator	8.00%
4	BIM Technician	4	BIM Technician	7.00%
5	BIM Specialist	3	BIM Specialist	6.00%
6	BIM Engineer	3	BIM Engineer	6.00%
7	BIM Architect	3	BIM Architect	5.00%
8	BIM Project Manager	7	BIM Project Manager	13.00%
	Total	55		

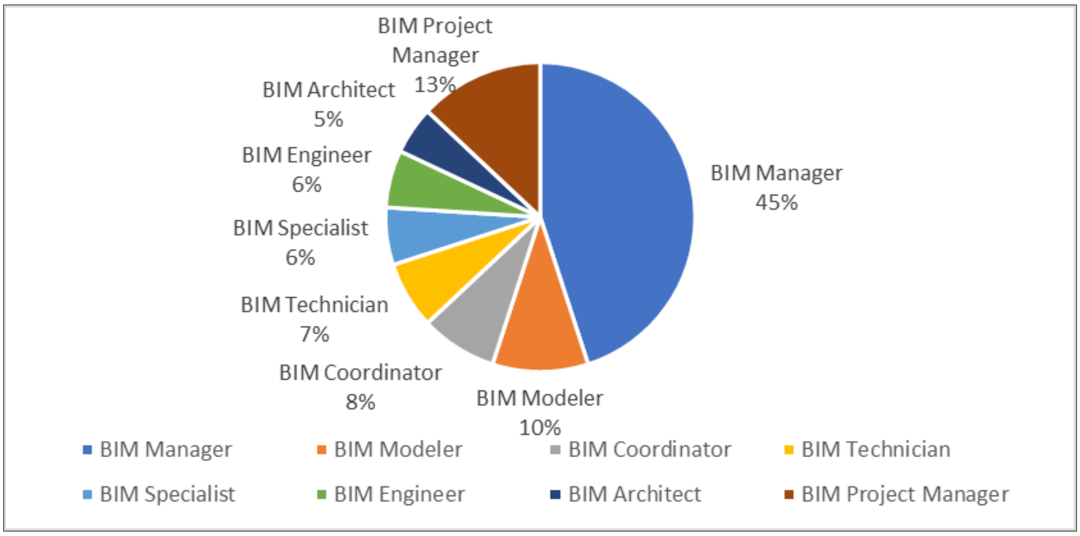

Figure 6 Designation of Respondents

The study found that 90% of construction organizations actively use Building Information Modelling (BIM), with a smaller percentage having limited knowledge or not using it in their projects. The primary project delivery method was public-private partnership (PPP), followed by design-bid-build (DBB). Construction management was preferred by 14%, design-build by 8%, and integrated project delivery by 10%. BIM plays a crucial role in enhancing project efficacy and fostering collaboration.[76] Safety concerns were reported by 17 out of 55 participants, with 15 experiencing infrequent hazards and 23 experiencing rare issues. The majority of respondents (60%) reported positive impacts from BIM implementation, indicating the positive influence of BIM on construction projects.

The survey findings support the benefits of Building Information Modelling (BIM) technology in the construction industry, highlighting its potential to improve project efficiency and effectiveness. The study used Cronbach's alpha assessment to ensure data reliability, resulting in a high reliability coefficient of 0.9465. Convenience sampling was used to gather data from construction professionals about BIM and its impact on safety practices. The researchers distributed the questionnaire survey through online platforms, industry networks, and professional associations, allowing for quick data collection.[77] A normality check was conducted using Shapiro-Wilk and Kolmogorov-Smirnov tests, revealing a non-parametric distribution of the data. The Kruskal-Wallis H test was used to explore potential differences among independent samples based on organizational type and regional classification. The majority of respondents exhibited similar perceptions, except for one specific strategy: Adoption of BIM in contracts. The results showed significant variation based on the nature of respondents' organizations, underscoring the importance of tailoring contractual obligations to suit individual companies. Contract documents play a vital role in resolving project issues in compliance with laws and regulations. However, the incorporation of BIM into the contractual process remains a contentious subject among stakeholders, indicating the need for further examination and clarity in this domain.

Moreover, the study delved into the test fields to investigate potential variations in opinions based on regional distribution, recognizing that safety practices and BIM adoption levels may differ across various regions.[78] Analyzing the data from the survey of 55 construction professionals, the researchers found no significant differences in the perception of safety measures based on regional distribution. To establish this, the Kruskal-Wallis H test was conducted, effectively comparing the responses of participants from different regions and considering the potential variations in safety practices and BIM adoption levels across various locations. The results indicate a consistent view on safety measures concerning BIM adoption, irrespective of the respondents' regional backgrounds.

Table 7 Kruskal-Wallis H Test Results for BIM-based Safety Implementation by Region

Region	**Mean Rank**
Europe	30.25
North America	27.45
Middle East	26.87
Asia	25.61
Australia	27.12

The mean ranks for each region, ranging from 25.61 to 30.25, indicate the average response rankings of construction professionals in Europe, North America, the Middle East, Asia, and Australia regarding the implementation of BIM-based safety measures. The p-value obtained from the Kruskal-Wallis H test was 0.196, surpassing the significance level of 0.05. Consequently, these results suggest that there are no statistically significant differences in safety measure perceptions among construction professionals from different regions when it comes to BIM-based safety implementation.[79] Although Europe exhibits the highest mean rank of 30.25, overall, construction professionals from all regions hold similar views regarding the effectiveness of BIM in enhancing safety practices within the construction industry. In essence, the findings of the Kruskal-Wallis H test highlight vital aspects of respondents' perceptions, especially regarding BIM-based contracts and safety implementation. The study underscores the importance of considering contextual factors, organizational characteristics, and regional disparities in shaping attitudes towards BIM adoption and its associated practices. Addressing these aspects is crucial for fostering broader and more impactful BIM implementation across the construction industry.

6.1. Framework for BIM based Safety Implementation

In order to enhance safety measures within the construction industry, it is recommended that organizations adopt a self-regulatory approach that encompasses the development and implementation of safety management systems

(Arayici et al., 2011). According to Liu (2013), the establishment of a strong commitment to safety within an organization has a significant positive impact on the promotion of a safety culture. This commitment fosters collaboration and cooperation between the administration and the workforce, leading to improved teamwork. The active involvement of top management in an agile project is crucial for its successful completion and should be emulated by lower-level staff members. In the current context, the process of exchanging information is often susceptible to errors as a result of the participation of multiple parties. Hence, there is a necessity for the development of a system that facilitates the provision of precise information and enables advancements in coordination. This entails the adoption of a digital approach to enhance safety measures at the organizational level. The researchers concluded that BIM's implementation possesses the potential to impact all processes within a project organization, underscoring the notion that it should not be perceived merely as a standalone software tool but rather as an integral component of the entire construction process. As a result, a conceptual framework has been meticulously devised, drawing upon the findings and analysis derived from this study, as illustrated in the accompanying diagram.[80] This framework seamlessly integrates Building Information Modelling (BIM) across the various stages of the construction project lifecycle, aiming to enhance the implementation of safety measures. Although Building Information Modelling (BIM) is still in its nascent stages according to Azhar (2017), the framework recommends preliminary adoption steps that can lay the groundwork for meeting essential project requirements during the conceptual phases, thereby contributing to the improvement of safety measures.[81]

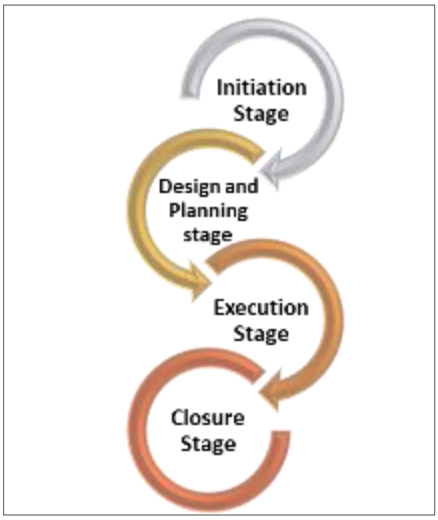

Figure 7 BIM Based Safety Management Strategy

Construction professionals emphasize the importance of integrating Building Information Modeling (BIM) into contracts to address legal and contractual issues associated with its implementation. A survey found that 85% of construction professionals believe that BIM integration in contracts can help address these issues. Experts also advocate for the inclusion of stringent safety clauses in contracts when using BIM, emphasizing the need for a BIM-based contractual framework throughout the project lifecycle. A study by Arshad et al. (2019) found that 72% of respondents agreed that allocating risk ownership to stakeholders is crucial for successful BIM adoption and addressing legal risks.[82] Defining BIM goals based on the project scope is crucial, and mature organizations should develop a BIM Execution Plan (BEP) during the initial phases to ensure successful implementation. Handling a competent team with advanced understanding of BIM is necessary to achieve project objectives and develop a BIM implementation strategy. Hiring safety professionals well-acquainted with BIM processes and workflows is also essential for monitoring project situations and tailoring policies according to project requirements. BIM modeling during the schematic design phase enables early project visualization, allowing closer observation of safety issues and encouraging the development of prevention strategies for identified hazards. Emergency evacuation plans using BIM should be prepared for the worksite. In addition to safety training, coordination issues contribute to delays, clashes, and accidents in the construction industry. BIM offers a collaborative working environment, and a comprehensive safety framework is necessary to address all safety issues throughout the project lifecycle, including facility maintenance.

6.2. Hazard Identification Process

The research placed a strong emphasis on examining the significance of Building Information Modeling (BIM) in enhancing safety management practices within the construction industry. Expert discussions and in-depth analysis revealed that BIM plays a crucial role in safety management. Despite the potential benefits of utilizing Building

Information Modeling (BIM) for safety management in the construction industry, there were notable challenges in seamlessly integrating comprehensive safety information into BIM's visualization and communication protocols. As a solution to overcome this hurdle, the study developed a theoretical process map outlining the steps for a fully automated safety management framework. This theoretical approach aims to streamline the integration of detailed safety data into BIM, facilitating more efficient safety practices and communication within construction projects.[83] The aim was to effectively incorporate safety practices and relevant codes into the BIM model. The process map, as illustrated in Figure 8, outlined the inputs, functions, and outputs of the framework, providing a clear understanding of its architecture. In this envisioned framework, BIM was positioned as the central platform, offering flexibility and openness to utilize various BIM modeling tools. The model development included essential technical information, encompassing architectural, structural, and MEP (mechanical, electrical, plumbing) designs, along with potential schedule data.

As a decision support tool, active involvement of BIM allowed stakeholders and technical experts to engage constructively in safety management through this framework.[84] To enrich the hazard database integrated into the BIM system, a wide array of sources was tapped, encompassing published literature, safety reports from past projects, insights from experienced safety managers working on-site, and relevant OSHA (Occupational Safety and Health Administration) regulations specifically addressing hazards. Regular updates to the hazard database were recommended to account for the uniqueness of each project and its associated risks. The integration of safety management into BIM through this envisioned framework offered a comprehensive approach to enhance safety practices in construction projects.[85] By streamlining safety management processes and boosting overall effectiveness, the study contributed to the improvement of safety measures within the construction industry. The findings provided valuable insights into leveraging BIM for safety management, fostering safer construction practices, and optimizing project outcomes.

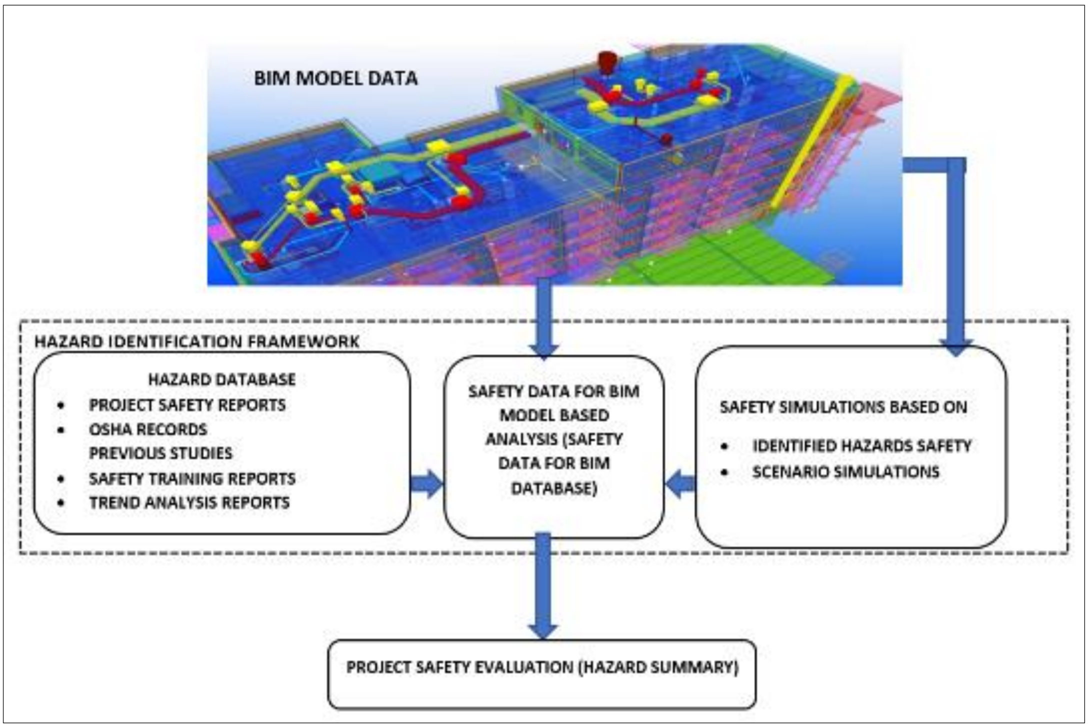

Figure 8 Hazard Identification Process

The research aimed to develop a safety management framework for the construction industry using Building Information Modeling (BIM) technology. The study found that BIM is crucial for effective safety management, but the integration of safety information into BIM visualization and communication protocols is still a work in progress. To address this, a theoretical process map was created to integrate safety data with BIM functionalities. The framework aims to integrate safety practices and codes into the BIM model, showcasing potential hazards and control measures. The process map is designed to be easily understood and enables the use of various BIM modeling tools.[86] The framework also includes technical details like architectural, structural, and MEP design, as well as schedule data. BIM plays a vital role in decision support, requiring stakeholder engagement and periodic updates to accommodate unique risks. The framework generates a project safety database, enabling safety personnel to visualize potential hazards and implement preventive measures.

The study investigates the impact of Building Information Modeling (BIM) on safety practices in the construction industry. The researchers used a mixed-methods approach, analyzing data using Scopus database and VOS viewer software. They found that while many construction professionals have advanced understanding of BIM, some still face challenges in implementing it for safety improvements. The study emphasizes the importance of integrating BIM into contracts, establishing clear objectives, and enlisting a proficient team. The findings suggest that organizations should embrace BIM as a safety management tool, invest in training programs, and foster a culture of continuous improvement to ensure safer working conditions.

7. Conclusions

The paper demonstrates about the importance of safety implementation in the construction industry, focusing on the transformative capabilities of Building Information Modeling (BIM). The research strategy used a combination of quantitative and qualitative elements to gather data from construction experts worldwide. The analysis revealed insights into the regional distribution of respondents, their understanding of BIM, and their organizations' utilization of BIM for safety improvement. The study highlighted the high demand for BIM Managers and the diverse job positions related to BIM, emphasizing the technology's growing significance in the industry. The study developed a comprehensive framework for BIM-based safety implementation, which guides organizations in integrating safety practices throughout the project lifecycle. The framework addresses factors such as BIM integration in contracts, defining BIM goals based on project scope, forming competent BIM teams, and utilizing BIM for safety planning and coordination. The development of an automated plugin to integrate safety aspects with BIM demonstrates the practicality and feasibility of implementing safety measures through BIM technology. Construction organizations are recommended to adopt the proposed framework and plugin to enhance safety conditions in their projects. Future research could explore the integration of sensing technology, such as drones, to provide real-time data for BIM. Continuous monitoring and evaluation of the framework's effectiveness in different construction projects would help refine and optimize its implementation.

Limitations and Future Research

In the pursuit of an all-encompassing examination into the fusion of BIM (Building Information Modeling) and safety practices within the construction domain, this study has left no stone unturned. Nevertheless, in the spirit of transparency, it must be acknowledged that, like any endeavor, this investigation is not immune to certain constraints. One such limitation pertains to the sample size, which, while deemed suitable for the present research, holds the potential for further enrichment through the incorporation of a broader, more diverse array of construction experts hailing from various regions and cultural backgrounds.

Future research could focus on exploring the long-term effects of BIM adoption on safety practices and project outcomes. Additionally, investigating the effectiveness of different BIM-based safety training programs and evaluating their impact on safety performance could be a valuable avenue for further exploration.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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