Enhancing Safety and Risk Management in Residential Construction through BIM Integration

Ibrahim Ahmed Mahdi
Civil Engineering Department, College of Engineering, University of Baghdad, Iraq
Ibrahim.Mahdi2201M@coeng.uobaghdad.edu.iq (corresponding author)

Mustafa A. Hilal
Civil Engineering Department, College of Engineering, University of Baghdad, Iraq
mustafa.helal@coeng.uobaghdad.edu.iq

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ABSTRACT

Despite the global advances in digital tools that enhance the construction safety, the residential projects in Baghdad continue to experience high accident rates, largely due to the political instability, economic limitations, and resistance to adopting new technologies. Building Information Modeling (BIM) has significant potential to support the proactive risk management in these projects, yet its use remains limited. This study demonstrates that BIM can improve the safety by enabling real-time hazard monitoring, strengthening the collaboration among stakeholders, and embedding safety standards from the earliest design stages. To adapt the international practices to the local conditions, it addresses challenges, such as high implementation costs, weak infrastructure, and the absence of clear regulations. Based on the findings, practical strategies, including government mandates for public projects, phased BIM adoption, and cloud-based solutions are proposed to reduce the resource constraints. Ultimately, the research outlines a pathway for applying BIM in high-risk environments, though its success will depend on the future improvements in safety documentation and IT capacity.

Keywords-Iraq; Building Information Modeling (BIM); construction safety; risk management; residential projects; barriers

I. INTRODUCTION

The construction industry is inherently hazardous, with accident, injury, and fatality rates considerably higher than in most other sectors. Residential projects pose additional risks due to their complex and dynamic nature. In Baghdad, Iraq, these risks are compounded by the political instability, economic constraints, and a lack of standardized practices. Such challenges worsen the safety issues and slow the adoption of advanced technologies, like BIM [1]. BIM, a digital representation of a facility's physical and functional characteristics, is one of the most transformative technologies in modern construction, offering significant potential for improving safety and risk management. This study aims to evaluate how effectively BIM can be applied to enhance the safety and risk management in Baghdad's residential construction sector [2]. While BIM has already demonstrated widespread benefits worldwide, its adoption in Baghdad remains limited. The city's rapid urbanization and growing demand for housing further underscore the urgent need for practical safety and risk management solutions [3].

II. IMPORTANCE OF SAFETY AND RISK MANAGEMENT IN CONSTRUCTION PROJECTS

The use of BIM has grown, largely because it helps address major challenges in construction, such as cost overruns, delays, and safety concerns. Safety and risk management are especially critical in residential construction, where workers face disproportionately high accident risks [4]. Traditional safety systems are often fragmented and reactive, with measures applied only after accidents occur. This approach highlights the need to integrate preventive safety practices into the design and planning stages [5]. BIM offers a proactive alternative by enabling the project teams to identify hazards during the planning and design phases. It can simulate the construction processes, allowing risks to be detected early and mitigation strategies to be developed before work begins. This shift from reactive to proactive management can significantly reduce the accidents and improve site safety [6]. By embedding safety data directly into the project models, BIM supports real-time monitoring and provides a comprehensive view of the potential hazards at every stage. Safety managers can use BIM to plan escape routes, detect fall hazards, and confirm compliance with regulations before construction starts [6]. Another advantage is the improved communication. BIM centralizes the safety information in a single platform, ensuring that all stakeholders are informed of the hazards and the measures needed to address them. Research in Iraq has shown that BIM-based systems, combining risk and value management, can quantify the cost impact of the risks and integrate mitigation measures directly into the workflows [5]. Similar international studies reinforcing these findings are summarized in Table I.

TABLE I. SUMMARY OF BIM SAFETY AND RISK MANAGEMENT IN PREVIOUS STUDIES

No	Country	Project / context	Exact BIM safety quote	Reference
1	Kazakhstan	National AECO Industry Analysis	"BIM-enabled clash detection assists design professionals and contractors by simulating a digital space before construction, helping to prevent and resolve clashes before they emerge on construction sites."	[6]
2	Italy	Vicenza Water Reservoir	"Excavation operations were carried out in sections with self-sinking metal shoring for protection."	[7]
3	China	Qinhuai River Ship Lock Excavation	"The 3D model collision detection was implemented using Navisworks to eliminate conflicting designs."	[8]
4	UK	Wembley Stadium (Sisk)	"4D BIM models significantly improve health and safety planning by revealing hazards during both design and construction stages."	[9]
5	UK	Crossrail Elizabeth Line, London	"System Safety Plan implemented a Project Wide Hazard Record database—an industry first."	[10]
6	Turkey	Falls-from-Height Study	"This case study assesses the potential of 3D and 4D models in construction safety management."	[11]
7	Portugal	Falls from Height Prevention	"A 4D BIM model (Revit + Navisworks) was developed to simulate construction sequences and integrate temporary safety measures such as guardrails, scaffolding, and hole covers, supporting safer planning and fall prevention."	[12]
8	Malaysia	Development of a BIM-Based Safety Management Model	Proposed an automated BIM-based system to identify safety rule violations, improving hazard identification and decision-making.	[13]
9	Iraq	Fall Prevention Plans for School Building	A 4D BIM model was created in Revit and Synchro to simulate construction sequences and enable early detection and automated planning of safety measures (e.g., guardrails, safety nets).	[14]

III. TRADITIONAL SAFETY AND RISK MANAGEMENT APPROACHES

Traditional construction safety management has been predominantly reactive, focusing on mitigating hazards only after they have manifested. Many of these safety precautions involve general safety procedures that may not necessarily be applied to the unique risks involved in a project site. These are always hands-on, such as random safety inspections, employee training, and the use of Personal Protective Equipment (PPE). However, these methods sometimes fail to prevent accidents because they do not track imminent dangers in real-time [15]. Many traditional safety management methods are compartmentalized, with no connection found between the design, planning, and field construction. This separation causes a lack of communication and feedback between these groups, leaving room for the overlooked risks, delayed safety interventions, and, in the long run, higher accident rates. For instance, a safety issue identified in the design may not be adequately communicated to the field directors, and the risks may remain during construction [15]. In terms of risk management, the process of identifying, assessing, and mitigating the risks is associated with a project. Thus, much construction work still employs antiquated methods, such as paper risk registers, which are troublesome in keeping the current and distributing information among teams. Consequently, the poor risk management leads to more delays, cost overruns, and safety accidents [18].

IV. INTEGRATION OF SAFETY PRACTICES WITH BIM

Integrating BIM and construction safety procedures marks a significant step forward in the proactive safety and risk management. In BIM, this approach is further embedded by placing safety data within the project model, enabling all "players" to identify and address the potential risks before construction begins [17]. The project team can utilize BIM visualization tools to simulate various scenarios, detect potential hazards, and optimize the construction sequences while incorporating safety measures. One key benefit of using BIM for safety management is its ability to facilitate real-time data sharing and coordination among the project teams through a cloud-based system [9]. Unlike traditional safety management approaches, where information is compartmentalized, BIM functions as a central repository where safety protocols, risk assessments, and mitigation plans can be accessed in real-time. For example, site managers can view BIM models to determine the optimal placement of safety railings, fire exits, safety signage, etc., within the design. BIM can also integrate risk management tools that identify potential hazards, such as clashes between construction elements or dangerous work permits. These automatic safety features significantly reduce the likelihood of human errors, which are the primary cause of accidents on construction sites. BIM allows project teams to identify and mitigate hazards during the design phase, thereby decreasing the costly rework and delays and enhancing the overall safety performance [19].

V. METHODOLOGY

A. *Research Design*

This research employed a quantitative, cross-sectional questionnaire methodology to assess the construction professionals' perspectives on their role in safety and risk management, as well as the barriers to its implementation in Baghdad. The design was chosen so that it could easily gather real-world data from the target demographic, which would then be used for statistical analysis.

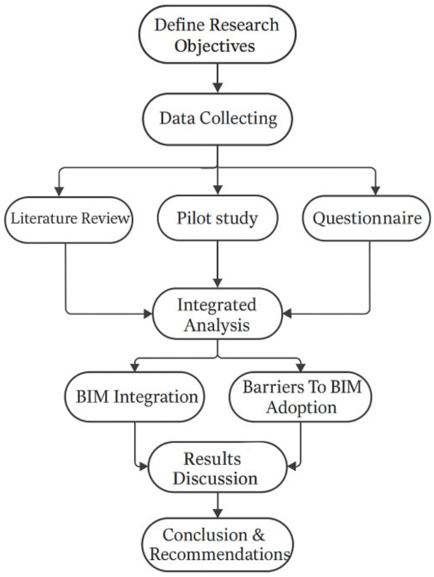

Fig. 1. Methodology flow chart.

B. Sample Size and Selection Criteria

- Targeted demographic: Engineers, project managers, safety experts, and contractors involved in the residential construction projects across Baghdad. The demographic characteristics of the target respondents are shown in Table II.
- Sampling selection method: A random sampling by professional roles (engineers: 40%, project managers: 30%, safety experts: 20%, contractors: 10%).
- Sample Size: 83 respondents (95% confidence level, ±10% margin of error), with a 78% response rate (107 invited, 83 completed).

TABLE II. RESPONDENT DEMOGRAPHICS

Role	Frequency	Percentage
Project Managers	25	30.1%
Civil engineers	33	39.8%
Safety experts	16	19.3%
Contractors	9	10.8%
Years of experience		
< 5 years	18	21.7%
5–10 years	42	50.6%
> 10 years	23	27.7%

C. Sampled Projects

The surveyed projects included a diverse range of residential developments across Baghdad. These comprised the Downtown Baghdad Project, currently under construction as a luxury apartment building, and the Al Akhowa Complex from the public sector. Other notable projects were the Al-Mansour Towers in western Baghdad, which offer a residential mix, and Bismayah New City, a large-scale, government-supported modern housing initiative near the capital. Additional residential complexes included Rafaah, Al Yamamah City, and Rayaheen, with the latter being a mid-sized, family-focused development. Vertical housing was represented by the Najmat Baghdad Residential Complex, while Al-Rabee and Hawraa Baghdad also contributed to the sample. High-rise and mixed-use projects, such as Al Naseem, along with the Zahraa Al-Saydiya Complex in Al-Saydiya, offering modern services, further illustrated the variety of residential construction efforts examined in this study.

D. Structured Questionnaire Formulation

To collect reliable and relevant data for this study, a structured questionnaire was developed. To meet the research objectives, the 14-item questionnaire was split into two main sections:

- Section one (8 items): Focused on the integration of BIM in safety and risk management.
- Section two (6 items): Assessed the barriers to the BIM adoption in Baghdad.

The answers were recorded using a 5-point Likert scale, with 1 indicating "strongly disagree" and 5 indicating "strongly agree." Content validity was confirmed through expert evaluation by three construction management professionals (CVI = 0.89). The results of Cronbach's alpha reliability analysis showed that both parts of the questionnaire are reliable, with Section 1 achieving a score of $\alpha = 0.91$ and Section 2 achieving a score of $\alpha = 0.84$. An analysis was conducted on the entire dataset from the first survey, which included 83 respondents. The results of Cronbach's alpha reveal satisfactory values, with $\alpha = 0.716$ for Section 1 and $\alpha = 0.717$ for Section 2, indicating consistent internal reliability in the final responses.

E. Data Collection

Questionnaires were distributed both in person during site visits and online through Google Forms between February and June 2025. The study ensured the participants' anonymity while clearly outlining its objectives to encourage honest and reliable responses.

F. Data Analysis

The Relative Importance Index (RII) was used to calculate and rank the integration and barriers of BIM using:

$$RII=\frac{\sum W}{A \times N} \quad (1)$$

where W is the Weight assigned to each response (1 to 5 for Likert scale), and A is the highest possible weight [5]. Finally, N is the total number of respondents.

VI. DISCUSSION

The results of this research show that BIM holds considerable promise for enhancing the safety and risk management capabilities of residential construction projects in Baghdad. A total of 83 construction professionals actively involved in residential projects across Baghdad, Iraq, participated in the survey, yielding a 78% response rate. The results indicate that the professionals strongly agree (RII = 0.90–0.96) that BIM enhances the hazard identification, real-time monitoring, and collaboration, all of which are crucial for reducing the number of accidents. These findings align with global studies, such as [10] in China, which showed how 3D model clash detection and automated fall-risk assessment can improve the hazard identification; the UK's Crossrail and Wembley Stadium projects [9, 10], which highlighted how 4D models support the proactive hazard planning and safety induction processes; and U.S.-based studies, including [19], which emphasized the value of BIM-integrated real-time monitoring technologies for preventing the falls from height and improving the on-site risk assessments. Despite the evidence of the BIM advantages, many challenges persist regarding its implementation in Iraq. Major implementation challenges include the high cost of BIM implementation (RII = 0.87), which is comparable to studies in the Middle East, where the cost limits its adoption. The political instability and a lack of government backing (RII = 0.88) add to these challenges. On the other hand, countries like the UK have well-established regulatory systems, including the Construction Design and Management (CDM), that encourage their adoption. These results are in line with [20], where it was highlighted that Iraq's BIM adoption is constrained by unclear policy frameworks and insufficient institutional support, further compounding the implementation difficulties. Furthermore, Iraq lacks any rules that would enable this process. Insufficient IT infrastructure (RII = 0.87) is a common challenge in developing countries, which limits the effective use of BIM technologies. Interestingly, the lack of knowledge (RII = 0.63) and low client demand (RII = 0.65) were considered less critical problems than the financial and infrastructure issues. This suggests that while education and market preparedness are significant issues, they are not the primary concerns. In some countries, such as the UAE, BIM has been mandated for design coordination; however, its application in the construction safety remains limited. Similar challenges are seen in Pakistan and India, where the high costs, poor infrastructure, insufficient training, and weak regulatory frameworks hinder adoption [21, 22]. Research from Nepal indicates that government-supported BIM training programs could help address the skill shortages and promote safer construction practices, offering strategies that may be applicable in other resource-constrained regions [23]. Studies in Egypt and Iran identify the lack of training, high costs, resistance to change, and weak institutional support as key barriers [24]. In Malaysia, researchers have reported that the limited expertise, low client demand, and inadequate government backing are the main obstacles to leveraging BIM for safety improvements [25]. Meanwhile, early research in Iraq suggests that 4D BIM models aligned with the local safety regulations, such as OSHA standards, can effectively identify and reduce the hazards on construction sites [26]. The results of the questionnaire are summarized in Table III.

TABLE III. BIM SAFETY AND RISK MANAGEMENT INTEGRATION

BIM risk and safety management integration	RII	RANK	Cronbach's alpha (α)
Real-time threat response	0.96	1	0.716
Real-time safety monitoring	0.93	2	
Proactive incident reporting	0.93	3	
Risk scenario simulation	0.93	4	
Early risk identification	0.92	5	
Visualization of safety hazards	0.92	6	
Accident minimization	0.92	7	
Enhanced team collaboration	0.9	8	

VII. CONCLUSIONS

BIM has the potential to significantly transform the construction sector, particularly in residential projects, where the safety and risk management are critical. This study focuses on Baghdad, Iraq, where the BIM adoption remains in its early stages and the construction safety performance is often underdeveloped. Through a comprehensive literature review and a structured questionnaire survey, the research seeks to bridge the gap between theoretical knowledge and practical application, with attention to common challenges in developing countries. Although BIM has advanced globally, its practical use in Iraq is constrained by several barriers, including a shortage of technical expertise, weak policy support, and limited awareness among the industry professionals regarding its safety benefits. Nevertheless, the study highlights that with strong government backing and industry collaboration, the BIM integration for safety management is achievable. Experiences from countries, such as the UAE and Qatar, demonstrate that such initiatives can yield valuable lessons for Iraq and similar contexts. The successful implementation of BIM for safety depends not only on the technology, but also on the organizational readiness, investing in staff training, fostering a strong safety culture, and embracing change. The findings point to future opportunities, especially in automating risk detection through BIM. For example, BIM software can identify hazards during the design phase, while real-time data tools, such as drones, can support the proactive risk mitigation. Despite these insights, the study is limited by the absence of detailed project-level data and reliance on manual processes in current BIM safety workflows. Addressing these gaps in future research will help advance toward a fully integrated, automated BIM-based safety management system, one that adapts in real time and evolves with the construction industry's changing demands.

APPENDIX – THE QUESTIONNAIRE

A. *Demographics*

Demographic information			
18-24	25-34	35-44	55 and above
Gender			
Male		Female	
Education level			
Diploma	Bachelors	Master	Ph.D.
Position			
Project manager	Civil engineer	Safety manager	Contractor

B. *Questions*

Each question had a 5-Likert scale answer spectrum, from Strongly agree to Strongly disagree.

1) *BIM Risk and Safety Management Integration*

1. BIM integration in construction projects leads to the early identification of risks.
2. BIM facilitates the visualization of the safety hazards before construction begins.
3. BIM ensures a stable platform to monitor the safety protocols in real-time, onsite.

4. BIM enhances the collaboration among construction site architects, engineers, and safety managers.
5. The integration of BIM into safety management minimizes the accident occurrence during construction.
6. BIM integration enables the proactive reporting of incidents, which leads to prompt corrective action to avoid future accidents.
7. BIM allows for the simulation of different scenarios in terms of risk to create appropriate contingency strategies.
8. BIM enables the effective response to new threats by offering updated, real-time risk data to support timely mitigation.

2) Barriers to BIM Adoption in Developing Countries

1. The high cost of BIM implementation stands in the way of its adoption in Iraq's construction industry.
2. Political instability and lack of government support limit the implementation of BIM in Iraq.
3. Unawareness among construction professionals regarding the BIM's advantages prevents its widespread implementation.
4. The traditional views and reluctance to adopt new technologies, like BIM, prevent its adoption.
5. Iraqi construction industry currently lacks the adequate IT infrastructure to support the BIM implementation.
6. The lack of client demand for BIM discourages companies from making investments in its adoption.

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