

Exploring the Advantages of BIM-IOT Integration in Enhancing Construction Health and Safety

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Abstract

The construction industry faces significant workplace safety-related challenges, with a high rate of accidents and injuries. The use of advanced technologies such as Building Information Modelling (BIM) and Internet of Things (IoT) has reduced the number of such challenges. The objective of this research is to explore the integration of BIM and IoT technologies to improve Occupational Safety and Health (OSH) management in the construction industry. Given the limited research on the practical advantages of BIM-IoT integration for safety purposes, this study aims to address this gap by identifying and analysing these advantages. A Systematic Literature Review (SLR) is conducted, analysing articles published between 2010 and 2025 to identify the advantages of BIM-IoT integration in construction safety management. The findings highlight several key advantages of BIM-IoT integration, including enhanced safety monitoring, real-time decision-making, and improved hazard identification and risk assessment. Furthermore, the integration supports proactive safety measures, such as eliminating hazards during the design phase and improving workers' safety awareness. However, the study highlights the need for further research on regulatory compliance and cost-effectiveness, as well as design-phase hazard prevention, AI-driven safety monitoring, and standardised compliance frameworks to enhance BIM-IoT's impact on construction safety.

Keywords: Advantages, BIM, Construction Safety, IOT, Integration

1. Introduction

Workplace safety has become a critical priority for industries due to its profound impact on employee health and overall productivity, with the construction industry experiencing a disproportionately high rate of workplace accidents (Kim and Chi, 2019). Occupational hazards are a persistent challenge in construction (Heidary Dahooie et al., 2020), where the frequent occurrence of accidents not only diminishes workforce efficiency but also leads to increased absenteeism. Given the significantly higher accident frequency in construction compared to other industries, this sector faces heightened safety risks (Nadhim et al., 2016).

Integration of Digital technologies capable of analysing and effectively communicating safety issues is crucial for improving overall safety performance (Han et al., 2009). In the past decade, research has focused on using digital technologies to reduce health and safety risks on construction sites. Key advancements include computer vision, IoT sensors, wearable devices, BIM, and immersive technologies like augmented and virtual reality, all aimed at improving hazard detection and safety management (Zhang et al., 2017). Despite advancements, single-technology solutions fall short of optimal safety standards, with research showing that a multi-technology approach, integrating various tools, yields more reliable safety outcomes (Wang et al., 2021). Integrating BIM with real-time data from IoT devices enhances construction safety by linking IoT sensor networks to high-fidelity BIM models, enabling various applications (Tang et al., 2019).

In recent years, various studies have explored the application of BIM-IoT integration in safety management; however, there is a lack of research identifying and analysing the advantages of adopting BIM and IoT technologies for improving safety within the construction sector. The key question that needs to be addressed is "What are the advantages of BIM-IoT integration in construction health and safety?" This study seeks to address this gap by conducting a comprehensive review and analysis of studies on the application of BIM-IoT integration in safety management, to identify and extract the advantages this integration offers to safety management.

2. Literature Review

Adoption of digital technologies in construction projects has grown due to the numerous benefits they offer in enhancing safety on construction sites. According to Luo et al (2022), there is a growing trend in research focused on utilising digital technologies to improve construction safety, with Virtual Reality, Augmented Reality, Digital Twins, BIM and the IoT identified as the most effective technologies. While BIM and IoT have been applied in areas like health and safety management, research on their integration is still in the early stages (Dave et al., 2018).

2.1. BIM and Construction Safety

Recent studies have shown that implementing the BIM methodology can improve the working conditions at

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construction sites (Cortés-Pérez et al., 2020). Azhar (2017) found that BIM can be utilised for better construction safety performance. BIM, a growing digital technology, is gaining attention for its role in enhancing safety design and improving construction safety management practices due to its object-oriented nature and effectiveness (Jin et al., 2019; Ding et al., 2014). Based on the literature reviewed, the main application of BIM in the safety management of the construction industry can be summarised in three aspects: interactive training of workers, site layout optimisation, and automatic checks for safety issues (Chatzimichailidou and Ma, 2022).

Several studies have investigated the use of BIM in managing construction safety issues. A classification of BIM-based tools highlighted the application of Virtual Reality for enhancing construction safety, particularly in training activities (Getulli et al., 2018). Another review compared BIM-based approaches with traditional risk management tools, emphasising BIM's potential in risk management, although it lacked a systematic selection of research published after 2015 (Zou et al., 2017). Research on using BIM and related technologies in the design phase focused on improving safety management and minimising design errors, with particular attention to Design for Safety (DfS) and its barriers (Xiaer et al., 2017). An investigation into BIM's shortcomings and its impact on safety involved a survey of field engineers in the construction industry (Alomari et al., 2017). Lastly, the relationship between BIM and worker safety performance was studied by identifying key factors and barriers through a literature review and a survey of practitioners (Ganah and Godfaurd, 2015).

2.2. *IOT and Construction Safety*

IoT has demonstrated significant potential in high-risk Environment, Health, and Safety (EHS) industries, where human lives are at stake, offering safe, reliable, and efficient solutions through fine-grained operation and rich data collection (Wang et al., 2021). In construction, IoT automates safety monitoring and hazard detection, enabling connected devices to transfer and analyse data effectively, making it a suitable technology for facilitating seamless data transmission across systems (Tabatabaee et al., 2022). Several studies have investigated the use of IoT in managing construction safety issues. Yang et al. (2020) developed a tool based on IoT for detecting Personal Protective Equipment (PPE) to ensure that workers are provided with the appropriate PPE before beginning construction activities. Additionally, a protective IoT-based system was created by Kanan et al. (2018) to automatically monitor, localise, and warn construction workers in hazardous areas.

A detailed evaluation of the LoRa protocol demonstrated its suitability for IoT-based safety monitoring, provided battery-related constraints are

addressed (Augustin et al., 2016). A Wi-Fi-based IoT safety surveillance system was proposed to connect field devices like cameras and smoke detectors, offering an innovative safety solution despite challenges such as power supply and mobility (Jiang et al., 2013). Computer vision-based wireless sensing technology monitored workers' compliance with personal protective equipment (Park and Brilakis, 2012), while motion tracking systems detected unsafe postures to reduce musculoskeletal risks (Ray and Teizer, 2012; Seo et al., 2013).

2.3. *BIM-IoT Integration*

Over the past decade, the integration of BIM and IoT has attracted growing interest, with a steady increase in related scholarly publications. These technologies offer complementary strengths: BIM provides detailed, component-level visualisations of construction projects, while IoT enhances safety management by supplying real-time data on-site conditions (Mohd-Nor et al., 2019). By combining these capabilities, BIM-IoT integration supports data-driven decision-making and more proactive safety interventions (Mohammed et al., 2020).

2.3.1. *BIM-IoT integration and construction safety*

According to Tang et al. (2019), prevalent applications integrating BIM and IoT data for health and safety management include safety training and on-site monitoring. Numerous studies have explored BIM-IoT integration for managing construction safety, highlighting its potential to enhance hazard identification, real-time monitoring, and overall safety performance.

Li et al. (2015) developed the Proactive Construction Management System (PCMS) for real-time safety monitoring and feedback, improving safety awareness and efficiency on a Hong Kong site, with global applicability for workforce training. Riaz et al. (2014) developed a BIM and sensor-based safety monitoring solution for confined spaces. Cheng and Teizer (2013) created a framework to stream real-time data to a VR platform for improved safety awareness. Kanan et al. (2018) introduced an IoT-based wearable system to provide real-time hazard alerts on construction sites. Ding et al. (2022) implemented an IoT-BIM system for managing hazardous energy in construction sites. Qian (2021) developed a tunnel monitoring system combining BIM, IoT, and GNSS to enhance safety and construction management. Kim et al. (2016) developed a BIM-based automated safety system to address scaffolding hazards by simulating worker movements and identifying potential risks. The system, integrated into commercial BIM software, successfully detected hazards and improved early safety communication in a real-world project. Scianna et al. (2022) integrated IoT sensors with BIM for real-time bridge deflection

monitoring, linking the physical structure to its digital twin for continuous risk assessment.

3. Research Methodology

A Systematic Literature Review (SLR) synthesises past research through a structured process to identify key themes, gaps, and future research areas while minimising bias and ensuring consistency (Zhou et al., 2015). This study employs an SLR to examine BIM-IoT integration for construction safety management, following a seven-step approach (Figure 1).

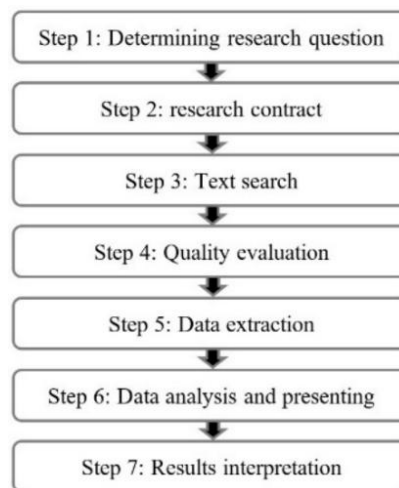


Figure 1: The SLR steps (Wright et al., 2007)

In Step 1, the research question is defined to establish scope and relevance, ensuring a balanced focus (Glasziou et al., 2001). In Step 2, an SLR protocol is developed to provide a structured selection process, covering background, research question, and strategy (Henderson et al., 2010). In Step 3, a comprehensive literature search is conducted, using defined search terms and strict inclusion/exclusion criteria to ensure consistency (Wright et al., 2007). In Step 4, selected studies are evaluated using the CASP checklist to assess quality and relevance. In Step 5, data extraction is carried out using tailored forms to avoid duplicates, with a two-stage screening of titles, abstracts, and key sections. In Step 6, data analysis is performed by grouping key findings based on BIM-IoT integration similarities in construction safety, including design and construction. Finally, in Step 7, the results are presented through descriptive analysis, categorising text data to reveal patterns, and pattern coding, identifying themes to refine insights and develop a theoretical framework (Saldaña, 2021; Miles & Whitehouse, 2013).

4. Findings and Discussion

To identify the advantages of BIM-IoT integration in construction health and safety, the systematic review steps are applied as follows.

Step 1: Determining research questions

- "What are the advantages of BIM-IoT integration in construction health and safety?"

Step 2: research contract

The protocol developed to guide the selection of studies used in this research includes the following steps:

- Background

Since the research explores BIM-IoT integration in construction safety and its advantages, this foundation informs the inclusion and exclusion criteria in the review protocol.

- Research question

The overarching objective of conducting an SLR is to address the following question:

"What are the advantages of BIM-IoT integration in construction health and safety?"

- Research strategy and data sources

To identify the most relevant answers to the research question, the strategy outlined in Figure 2 is applied throughout the SLR process.

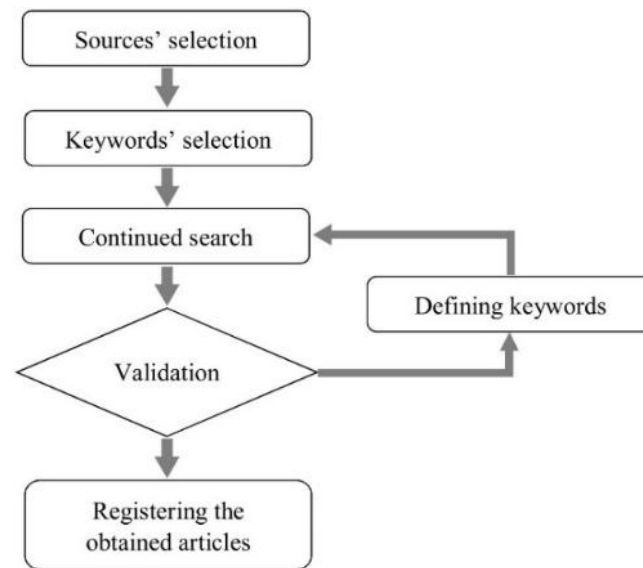


Figure 2: Research strategy

The keywords for the SLR are derived from the research question, focusing on terms like "BIM," "IoT," "Safety," and "Advantages/Benefits". Three major indexed databases —Science Direct, Scopus, and Web of Science (WoS) —are targeted due to their reliable citation indexing and peer-reviewed content.

Step 3: Text search

The authors utilised the following input and output criteria in the selection of articles for the SLR, as illustrated in Table 1.

The search, conducted from August 2024 to January 2025 using keywords, yielded 542 articles (315 from ScienceDirect, 124 from Scopus, and 103 from WoS). After removing duplicates and irrelevant studies, 198 articles remained (Table 2).

At this stage, 198 papers were reviewed based on keywords, abstracts, and full texts, resulting in the selection of 94 articles (Table 3).

Table 1: Background Information of Informants from IGOPLAS

Criteria	Inclusions	Exclusions
Publication timeline	• Between 2010 and 2025	• Before 2010
Document type	• Journal (research articles)	• chapters in a book, books, reports, review papers, conference papers
Type of domain	• BIM-IOT integration in safety management only	• Exclude BIM-IOT integration in other domains (Facility management and ...)
Language	• English	• Non-English

Table 2: BIM-IOT initial search results

Databases	Science direct		Scopus		Web of Science	
Search BIM-IOT	Total articles	Selected articles	Total articles	Selected articles	Total articles	Selected articles
Numbers	315	142	124	32	103	24

Table 3: Keywords and reviewing abstracts

Databases	Science direct	Scopus	Web of Science
Search keywords	51	20	23
Final selected articles	94		

Step 4: Quality evaluation

In this section, the codes are classified as outlined in the results presentation step (Figure 3).

The results of the data extraction process and data analysis are presented in Table 4 (see Appendix 1).

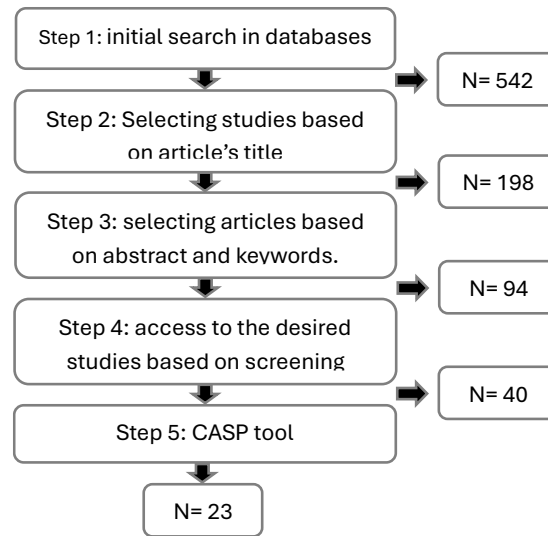


Figure 3: Steps for selection of the articles

The final evaluation used the CASP instrument, assessing 10 criteria like research design and methodology. Articles were rated on a 5-point scale and categorised into quality groups. The qualitative scores were then categorised into very good (41-50), good (31-40), medium (21-30), poor (11-20), and very poor (0-10). Those scoring below 20 were excluded, leaving 23 articles for analysis.

Steps 5 and 6: Data extraction and Data analysis

To extract relevant data, the following questions guide the data extraction process:

- Does the article address BIM-IoT integration in construction safety?
- Are the research objectives clearly stated?
- Does the article provide insights relevant to the research questions?

Step 7: Results presentation and interpretation

The integration of BIM and IoT offers significant advantages for the OSH management (Figure 4). The bar chart visualises the number of references for each advantage of BIM-IoT integration in the OSH management. The findings highlight improved safety monitoring as the most cited advantage (17 references), reinforcing the role of real-time data collection and hazard detection in construction safety. Enhanced real-time decision-making and emergency response, referenced by 12 sources, further highlight the dynamic nature of BIM-IoT integration in preventing accidents and managing emergencies more efficiently. Additionally, enhanced hazard identification and risk assessment are strongly supported by 11 references, underscoring the proactive role of BIM-IoT in identifying and mitigating risks before incidents occur.

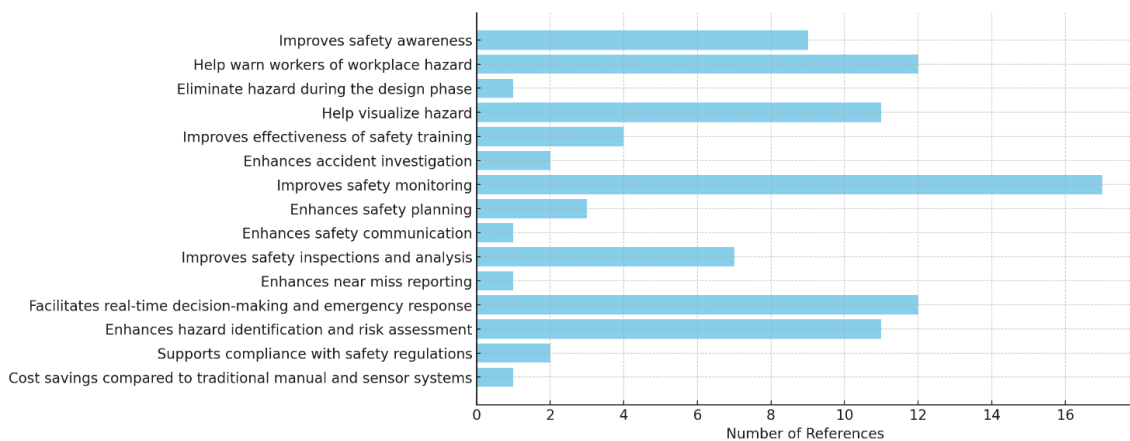


Figure 4: Advantages of BIM-IOT integration for OSH management

Among design-phase benefits, hazard elimination during design received comparatively fewer references, indicating the need for broader adoption despite its recognised potential. Similarly, hazard visualisation (11 references) is frequently cited, underscoring its role in enhancing situational awareness and proactive safety planning. Additionally, improving workers' safety awareness and warning workers of workplace hazards were frequently noted, demonstrating the technology's role in fostering a safety-conscious culture. However, advantages such as enhanced near-miss reporting and compliance with safety regulations were less frequently referenced, suggesting areas for further exploration and improved implementation.

Overall, the results confirm that BIM-IoT integration enhances real-time monitoring, decision-making, and risk mitigation in construction safety. However, further research is needed to optimise its application in hazard prevention during the design phase and regulatory compliance.

5. Discussion

The findings reinforce the significant role of BIM-IoT integration in improving OSH management, particularly through enhanced safety monitoring, real-time decision-making, and hazard identification. These benefits align with previous studies (e.g., Riaz et al., 2014; Ding et al., 2022), which emphasise the ability of BIM-IoT systems to provide real-time insights for proactive safety interventions. The high citation frequency of these advantages suggests strong industry recognition of their value in accident prevention and emergency response.

Despite these advantages, hazard elimination during the design phase received fewer references. This indicates that while BIM-IoT has the potential to enhance safety at the design stage (Hu et al., 2024), its practical implementation remains limited. This gap may be due to insufficient integration of safety data into BIM models or the lack of standardised protocols for incorporating hazard identification into early design workflows. Future research should explore ways to optimise BIM-IoT frameworks for hazard prevention at the pre-construction stage.

Similarly, the low emphasis on regulatory compliance and near-miss reporting suggests a disconnect between BIM-IoT applications and compliance-driven safety

management. While some studies highlight the potential of digital tools to improve safety documentation and compliance tracking (Liang & Liu, 2022), practical adoption appears to lag. Addressing this issue may require policy alignment, stakeholder engagement, and enhanced automation in compliance tracking.

Overall, while BIM-IoT integration has demonstrated strong capabilities in real-time hazard monitoring and emergency response, further advancements are needed to leverage its potential in design-phase safety and regulatory compliance fully. Future studies should focus on bridging these gaps through enhanced data integration, standardisation, and industry adoption strategies.

6. Conclusion and Further Research

This study highlights the significant advantages of BIM-IoT integration in Occupational Safety and Health (OSH) management, with strengths in real-time safety monitoring, emergency response, and hazard identification. The findings confirm that BIM-IoT systems enable proactive safety interventions by leveraging real-time data and visualisation tools. However, despite these advantages, certain areas, such as hazard elimination during the design phase and regulatory compliance support, remain underexplored. The limited emphasis on these aspects suggests that while BIM-IoT holds promise for improving safety from the early design stage, practical adoption and implementation challenges persist. Addressing these gaps requires further research and industry-driven innovations to optimise BIM-IoT frameworks for holistic safety management.

Future research should focus on enhancing BIM-IoT integration for design-phase hazard prevention, optimising predictive safety analytics, and standardising safety compliance frameworks. Further studies are needed to develop automated hazard detection tools, explore AI-driven safety monitoring, and address barriers to industry adoption. Investigating these areas will help unlock the full potential of BIM-IoT for proactive and data-driven safety management in construction.

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Appendix 1**Table 4:** Advantages of using BIM-IOT integration for OSH Management

N	Advantages	References
1	Improve safety awareness	Fan et al (2021), Ding et al (2013), Cheng and Teizer (2013), Kiani et al (2014), Li et al (2015), Ding et al (2022), Parn et al (2019), Chen et al (2021), Riaz et al (2014)
2	Help warn workers of workplace hazard	Fan et al (2021), Ding et al (2013), Kiani et al (2014), Li et al (2015), Parn et al (2019), Liang and Liu (2021), Chen et al (2021), Qian (2021), Hossain et al (2023), Yuan et al (2016), Cheung et al (2018), Riaz et al (2014)
3	Eliminate hazard during the design phase	Hu et al (2024),
4	Help visualize hazard	Sakr and Sadhu (2023), Scianna et al (2022), Fan et al (2021), Ding et al (2013), Cheng and Teizer (2013), Kiani et al (2014), Zhang and Bai (2015), Li et al (2015), Parn et al (2019), Hossain et al (2023), Hu et al (2024),
5	Improves effectiveness of safety training	Fan et al (2021), Cheng and Teizer (2013), Li et al (2015), Teizer et al (2013),
6	Enhancing accident investigation	Scianna et al (2022), Li et al (2015)
7	Improve safety monitoring	Sakr and Sadhu (2023), Scianna et al (2022), Cheng and Teizer (2013), Fan et al (2021), Kiani et al (2014), Zhang and Bai (2015), Li et al (2015), Ding et al (2022), Liang and Liu (2021), Chen et al (2021), Qian (2021), Hossain et al (2023), Riaz et al (2017), Yuan et al (2016), Hu et al (2024), Jiang and Jiang (2024), Cheung et al (2018)
8	Enhancing safety planning	Scianna et al (2022), Fan et al (2021), Pang et al (2024),
9	Enhancing safety communication	Yuan et al (2016),
10	Improve safety inspections and analysis	Sakr and Sadhu (2023), Scianna et al (2022), Fan et al (2021), Li et al (2015), Ying et al (2020), Yuan et al (2016), Riaz et al (2014)
11	Enhancing near miss reporting	Li et al (2015)
12	Facilitating real-time decision-making and emergency response	Sakr and Sadhu (2023), Ding et al (2013), Cheng and Teizer (2013), Zhang and Bai (2015), Li et al (2015), Parn et al (2019), Chen et al (2021), Qian (2021), Yuan et al (2016), Pang et al (2024), Cheung et al (2018), Riaz et al (2014)
13	Enhancing hazard identification and risk assessment	Scianna et al (2022), Kiani et al (2014), Zhang and Bai (2015), Li et al (2015), Qian (2021), Riaz et al (2017), Yuan et al (2016), Hu et al (2024), Jiang and Jiang (2024), Pang et al (2024), Cheung et al (2018),
14	Supports compliance with safety regulations	Ding et al (2022), Liang and Liu (2021)
15	Cost savings compared to traditional manual and sensor system	Hossain et al (2023)