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Declaration

All papers in this publication have been through a review process involving a review of abstracts, peer review of full papers by at least two referees, reporting of comments to authors, revision of papers by authors and re-evaluation of the revised papers to ensure quality of content.

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USING DYNAMIC BIM TO IMPROVE CONSTRUCTION SAFETY CULTURE

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Among the various studies that have addressed the application of BIM dynamics in domain of health and safety management, the lack of research regarding the impact of BIM dynamics on safety culture is clearly visible. These days, it is apparent that more and more construction technologies are currently being used for safety and health management. These technologies can be used in different construction applications to mitigate workplace hazards. Among these technologies, BIM and IoT has been shown to have significant potential in high-risk Environment, Health, and Safety (EHS) industries. Several researchers have started to explore the potential synergy between BIM and IOT. Dynamic BIM presents an influential pattern for applications to improve construction safety management. The main purpose of this paper is to demonstrate the necessity of research on the use of dynamic BIM in improving construction safety culture. Hence, the literature review method was used to identify the domains in which dynamic BIM has been applied. Prominent application domains in which dynamic BIM has been applied are construction operation and monitoring, facility management (FM), construction logistic and management, health and safety (H&S) management. Results show that no research has addressed the impact of dynamic BIM on safety culture. Therefore, research related to dynamic BIM and its impact on construction safety culture is necessary.

Keywords: construction safety culture, dynamic BIM, health and safety management, technologies

INTRODUCTION

The construction industry, a high-risk sector, is troubled by frequent accidents and injuries, elevating health and safety concerns (Lingard and Rowlinson, 2015). Traditional practices have been applied to combat high workplace injury and fatality rates in the construction industry; however, safety performance remains inadequate (Nnaji and Karakhan, 2020). Thus, researchers continue to seek alternative strategies to enhance safety performance.

The increasing use of digital technologies in construction safety management, such as building information modelling (BIM), Internet of Things (IoT), virtual reality, and sensors, enables early detection and response to workplace hazards, thus improving overall safety (Ahn et al., 2019; Okpala et al., 2020). BIM, among various digital solutions, is rapidly becoming a prime tool for construction safety management (Sidani et al., 2021), proven effective in improving on-site working conditions and safety performance (Cortés-Pérez et al., 2020; Azhar, 2017). IoT-based applications, along with BIM, are prime tools in environmental, health and safety

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(EHS) industries, especially high-risk ones, providing granular data and rich information for safe, dependable, and efficient workplace solutions (Wang et al., 2021).

Despite efforts to apply recent technologies for construction safety, single-solution approaches have proven insufficient for attaining optimal safety standards (Wang et al., 2022). They suggest that a combined approach using multiple technologies may offer a better solution. This study advocates for the adoption of "Dynamic BIM", a powerful hybrid solution of BIM and IoT, for effective and efficient safety management in construction. This solution integrates real-time IoT data with BIM models, enabling responsive monitoring of safety-related information. Although the research in this area is still developing, the potential benefits of Dynamic BIM make it an exciting prospect for construction safety management (Tang et al., 2019).

Dynamic BIM holds significant potential for construction safety management, but its efficacy must be understood to unlock its full potential. Despite prior research in various areas, such as energy management and health and safety management (Dave et al., 2018), further study is required to explore its feasibility and effectiveness in construction safety management. There is a need to understand:

- Whether any studies have specifically examined the role of Dynamic BIM in influencing or shaping safety culture within construction organizations?

This study aims to highlight the importance of investigating the role of Dynamic BIM in improving construction safety culture. To accomplish this, a comprehensive review of Dynamic BIM research will be conducted, with a particular focus on identifying studies that specifically address the impact of Dynamic BIM on safety culture within the construction industry. The paper is organized as follows: Section 2 presents a literature review; Section 3 describes the research methodology; Section 4 classifies the domains and subdomains of Dynamic BIM usage based on reviewed papers and presents the results; finally, Section 5 concludes the study and proposes future trends for further research.

LITERATURE REVIEW

A strong construction safety culture leads to improved safety performance, while multiple factors can cause poor safety performance and lead to accidents on sites (Khalid et al., 2021).

Construction safety culture

The construction safety culture is the safety-focused atmosphere within the construction environment that is created by safety management practices and behaviours of workers and management personnel (Olugboyega and Windapo, 2019).

To fully grasp the concept of construction safety culture, it is crucial to understand its various dimensions, as suggested by Biggs et al. (2013). Little (2002) identifies four topics (ownership and commitment, system and procedures, training and competence, and communication) and 14 elements to promote a safety culture in UK construction. Ho and Zeta (2004) conducted a study on safety culture in the Hong Kong construction industry, identifying four essential culture factors for safety: environment, behaviour, organization, and people. Latief et al. (2017) identified eight safety cultural dimensions in construction projects, including leadership, policy, strategy, employee, process, behaviour, safety culture expenses, and contract system.

While understanding safety culture dimensions is essential, a more significant gap in the literature concerns how construction safety management elements can be integrated into construction safety culture. Zhou et al. (2012) suggest that new technologies, such as BIM, can bridge this gap, enabling a more integrated approach to construction safety management and safety culture.

BIM

BIM technology offers an integrated digital approach to construction, transforming the traditional fragmental practices (Othman et al., 2021) by providing comprehensive data about building products to various organizations throughout the construction process. This fosters collaboration and reduces fragmentation in the industry (Liu and Cao, 2021). BIM's object-oriented nature of BIM and comprehensive information capabilities have led to increased research and application in design for safety and construction safety management practices (Jin et al., 2019; Eleftheriadis et al., 2017; Ding et al., 2014).

Research on integrating BIM with health and safety is expanding, as evidenced by studies such as Gatoli et al. (2017), who investigated how BIM can capture and represent prevention measures for construction elements and their interrelationships. Azhar (2017) studied the integration of 4D safety planning into BIM, while Kim et al. (2016) explored automating scaffolding risk assessments, highlighting the growing application of BIM in construction safety management. Ganah and John (2017) explored the integration of safety rules and planning into BIM, while Shen and Marks (2016) proposed the use of a color-coding system in BIM to designate the intensity of safety risks associated with each element. Esteban et al. (2014) observed that health and safety planning is often separate from work planning, leading to issues with job-related hazard management, a finding corroborated by Frijters et al. (2008). BIM method allows construction simulation, work planning communication with the three-dimensional model, and acquire a four-dimensional model (Martínez-Aires et al., 2018).

IOT

IoT is a network of interconnected devices with sensing and actuating capabilities that enables data exchange across platforms, allowing for the creation of a common operational image that facilitates innovative applications (Gubbi et al., 2013). IoT technologies encompass diverse elements, including multiple technologies for sensing, recognition, communication, data processing, energy storage, and safety mechanisms (Colakovic and hadzialic, 2018). IoT technology is one of the most useful technologies in the construction industry, providing automated monitoring of safety in construction sites, detection of hazards, and facilitation of data transfer between devices (Tabatabaee et al., 2022).

Several studies have demonstrated the potential of IoT technologies to enhance construction safety. For instance, Kim & Kim developed a warning system for hazardous machine proximity, while Ruz et al. proposed a similar Radio Frequency identification (RFID)-based system for danger zone warnings. Qiuping et al. explored the use of IoT in emergency management for underground construction, and Wang et al. proposed a real-time information system for risk modeling based on IoT technologies. The literature discusses another example of IoT applications in construction safety, including: Teizer et al. for worker tracking near heavy equipment, Li et al. for tracking workers in dangerous areas and fall prevention, Kelm et al. for PPE inspection at construction entrances, Sun et al. for monitoring dangerous activity process conditions, and Mishra et al. for tracking dangerous materials (Grazia et al., 2020).

Integrating BIM and IoT

Integrating IoT technologies into construction management can represent a novel, innovative approach for transforming construction safety practices (Yeo et al. 2020). IoT, supported by BIM technology, can provide warnings of safety events (Kong and Ma, 2020), while facilitating the deployment of various sensors to monitor safety hazards in construction sites (Jia et al., 2019). While IoT can potentially integrate various technologies for construction safety, theoretical and practical limitations, such as a lack of robust construction safety theory and practical challenges in implementing the technology, hinder the full potential of IoT-based integration (Wang et al., 2022).

Recent research on BIM and IoT data integration indicates that both data sources complement each other, providing a richer understanding of construction safety (Tang et al., 2019). Multiple researchers are already investigating the potential of combining these data sources to improve safety (Dave et al., 2018). Research on dynamic BIM shows contemporary trends that compensate for the existing limitations in the respective applications (Tang et al., 2019). Mohammed et al. (2020) discovered that research on the integration of BIM and IoT has been steadily gaining traction in the last six years, as evidenced by the increasing number of publications on the topic. They noted that dynamic BIM research has been growing since 2015 (Fig 1), indicating a growing interest in combining BIM's static data with IoT's real-time data to enhance construction safety.

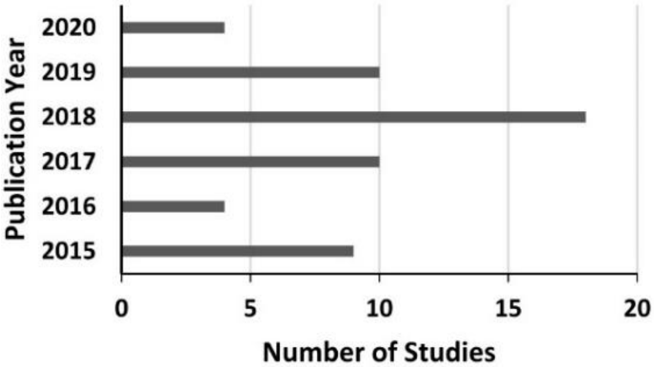

Figure 1: Number of publications per year

Liu et al. (2019) leveraged BIM and IoT sensors for structural fault detection in water engineering, Arslan et al. (2019) proposed a BIM-Bluetooth sensor-based system for indoor hazard avoidance, Chen et al. (2021) investigated the integration of BIM, IoT, and AR for on-site safety and skills improvement, and Velinzhadshubi et al. (2021) implemented BIM-IoT for real-time temperature imbalance detection during building operation and maintenance. BIM and IoT integration have been explored for managing prefabrication construction, as evident from studies like Zhong et al. (2017).

Despite previous research exploring the relationship between BIM, IoT, and their integration for health and safety management, very few studies have focused on the impact of Dynamic BIM on construction safety culture. Hence, this study aims to fill this research gap and emphasize the importance of Dynamic BIM in improving construction safety culture.

RESEARCH METHODOGY

A literature review was conducted to determine the importance of investigating the potential of Dynamic BIM for improving construction safety culture, with the aim of highlighting the significance of this research in advancing construction safety practices. The literature review is an essential academic task, allowing researchers to demonstrate their knowledge of existing research in a field, as well as identify gaps and contradictions in that knowledge, which can then be addressed by new research, contributing to the advancement of the field (Jesson et al., 2011).

This paper is organized into three main steps: first, a comprehensive literature review was conducted to gain a comprehensive understanding of the topic, including common safety cultural dimensions in construction. Second, previous studies investigating the use of BIM, IoT, and their integration for safety management or culture were reviewed. Third, based on the identified research gap and to address the research question, a thorough review of dynamic

BIM was conducted, identifying domains and subdomains where dynamic BIM has been utilized in previous research.

To identify and categorize relevant research in dynamic BIM, the following steps were taken: (i) a comprehensive search of academic research databases, including Scopus, Web of Science, and ScienceDirect; (ii) removal of duplicates and irrelevant articles; (iii) content analysis and classification of the remaining articles; (iv) discussion of the analysed articles. This review was focused on the integration of IoT devices with BIM for the smart built environment. After screening the articles' abstracts and keywords, 44 articles were selected for the final analysis. The 'Results and Discussion' section presents the results of the content analysis of the selected articles, which revealed the domains where dynamic BIM has been utilized.

RESULTS AND DISCUSSIONS

Through a comprehensive review of the existing literature and an analysis of selected articles that addressed Dynamic BIM, this section categorized the domains in which Dynamic BIM has been applied, resulting in four dominant domains: Construction Operation and Monitoring, Facility Management, Construction Logistic & Management, and Health & Safety Management.

Dynamic BIM for various domains

Drawing on the research content of the reviewed articles, Tang et al. (2019) and Mohammad et al. (2020) suggested several domains and subdomains to facilitate in-depth analysis. Table 1 summarizes the classification of the reviewed articles by domains. Representative research works are discussed for each domain and subdomain.

Table 1: Categorization of reviewed articles by domains

Number	Domains	Subdomain	References
1	Construction Operation and Monitoring	On-site environmental monitoring	[27,44,46,24]
		Resource monitoring	[65, 21, 3,68]
		Collaboration and communication	[19,33]
		Performance and progress tracking	[19,82]
2	Facility Management (FM)	Building Operation and Maintenance (O&M)	[5,9,39,59,66]
		Building performance management	[13,56,31,18,14,32]
		Energy management	[16,57,40]
		Disaster and emergency response	[47,50,11,7,10]
3	Construction Logistic and Management	Automation in prefabrication	[81,34,60,61,48]
		Lean construction	[73,67,17]
4	Health and Safety (H&S) Management	H&S training	[74,49]
		On-site monitoring for H&S	[3,68, 42,79,80,38]

Domain 1: construction operation and monitoring

By connecting BIM with sensors, Dynamic BIM facilitates the exchange of real-time data and communication, providing a range of benefits in construction project monitoring, including enhanced visibility, faster decision-making, and improved overall performance (table 2).

Table 2: Subdomains of construction operation and monitoring

Subdomains	Evidence	References
On-site environmental tracking	On-site environmental tracking uses BIM with sensors. One of the notable applications was to visualize the site in real time through virtual reality.	[27]
	Real-time sensory inputs were integrated with BIM to compute the real-time equipment operation monitoring, compactor movement monitoring [44] and automatic crane tracking [46,24].	[44,46,24]
Resource monitoring	Dynamic BIM and BLE sensors can be leveraged to monitor the real-time movement of construction site resources, including labors, materials, and equipment, thereby improving project management and safety.	[65,21,3, 68]
Communication and collaboration	Real-time integration with BIM and IoT can improve construction operations.	[33]
	Real-time construction data from IoT tags, sensors, and mobile devices can be integrated with BIM model to enable timely integration between parties.	[19]
Construction performance and progress monitoring	By integrating real-time data captured from sensors, such as actual performance, project status, construction activity, and physical context, with BIM, it becomes possible to effectively monitor the construction process and update the construction plan accordingly.	[19]
	GPS sensors and RFID were used for location data collecting of construction elements for contrast versus BIM models.	[82]

Domain 2: facility management

Dynamic BIM can provide automatic ways for operation and maintenance, performance and energy management and developing crisis preparedness and response strategies (table 3).

Table 3: Subdomains of facility management

Subdomains	Evidence	References
Building operation and maintenance	Dynamic BIM tools can create useful platforms to help access real-time data, create and update digital properties, and manage space.	[5]
	Integrate BIM models with physical building components through RFID tags to track assets.	[9]
	Live data extracting, visualizing of issues through AR or BIM to asset management [39,59,66].	[39,59,66]
Building performance management	Temperature and humidity monitoring through Dynamic BIM (Indoor Environment Quality) [56] and improving user comfort [31].	[56,31]
	Real-time monitoring and evaluation of building performance using semantic web technologies.	[13,18,14, 32]
Energy management	The facility manager can view BIM models, data of inquiry sensor, and receive activation recommendations “near real-time” through the web-based energy management solution.	[57]
	Dynamic BIM-software/system architecture integration for real-time energy consumption and building status monitoring.	[16]
	BIM and WSN integration to monitor energy and benchmarking, feedback & control.	[40]
Disaster and emergency response	Detecting and displaying the internal location of victims in BIM.	[50]
	Calculation of real-time evacuation paths from BIM models and sensor/mobile device location data.	[11,7]
	Efficient and safe evacuation of people with Dynamic BIM APIs and mobile devices.	[10]
	Emergency response by use of BIM, IoT and GIS.	[47]

Domain 3: construction logistic and management

Dynamic BIM and automation technologies can be employed to optimize construction logistics and management, particularly in the areas of prefabrication and lean construction, improving efficiency, productivity, and reducing waste (table 4).

Table 4: Subdomains of construction logistic and management

Subdomains	Evidence	References
Automated Prefabrication	Dynamic BIM devices and tools are useful for prefabricating, tracking, visualization, and automated assembly.	[81,34,60, 61,48]
Lean construction	Real-time information exchange is possible using IoT devices such as sensors, and automatic identification system networks. Connecting and communication with BIM and systems, persons and devices across the construction supply chain and lifecycle can be automated and streamlined.	[73,67,17]

Domain 4: health and safety management

Health and safety are always exposed to risks related to the H&S conditions of workers and occupants. IoT is useful for accurate tracking of activities related to workers' health and safety risks. BIM datasets contain wealthy information about equipment and organizational state that can provide conditions for sensor-based data. Integration of BIM and sensors have been implemented for health and safety issues. Dynamic BIM enables real-time data retrieval, risk identification, visualization, and notifications within BIM models, enhancing proactive decision-making and project management. Applications that integrate BIM and IoT data for Health and Safety (H&S) management commonly include: (table 5)

Table 5: Subdomains of health and safety management.

Subdomains	Evidence	References
H&S training	Some research proposed health and safety training systems using BIM and sensors together. Proposed health and safety training systems leverage IoT sensors for location data collection, which is analyzed by BIM models to evaluate safety and productivity. The findings are then visualized in real-time or post-event VR environments for improved health and safety practices.	[74,49]
On-site monitoring for H&S	Sensor networks and BIM model integrated to avoid risk in construction sites.	[3,68,38]
	BIM models, structure monitoring sensors and RFID tags enable visualization of damaged components to monitor structural health.	[42,79,80]
	Portable warning devices, combined with environment monitoring systems, can be used for early warning of dangers and safety enhancement.	[21]

According to Mohammad et al. (2020), Dynamic BIM is an emerging field with significant potential in various applications. Of the 55 studies analyzed, it was found that, 67.27% of studies focused on Construction Operation and Monitoring, 21.83% of studies focused on Facility Management (FM), 5.45% of studies focused on Construction Logistic & Monitoring and 5.45% of studies focused on Health & Safety (H & S) Management (table 6).

Table 6: Application domain in the field of Dynamic BIM

Domains	Number of studies	%
Construction Operation and Monitoring	37	67.27%
Facility Management (FM)	12	21.83%
Construction Logistic and Monitoring	3	5.45%
Health and Safety (H&S) Management	3	5.45%

To provide comprehensive insights, a thorough analysis of selected studies was conducted. From the selected studies, we found that integration of BIM and IoT devices such as sensors have been implemented for health and safety management issues. We also found that the prevalent application of dynamic BIM in the safety management domain includes the two subdomains of safety training and safety on-site monitoring.

Despite the significance of health and safety management in construction, our analysis revealed that it was less explored compared to other application domains in Dynamic BIM research, indicating a potential area for future studies. To answer the research question, our analysis uncovered that although the studies on Dynamic BIM and IoT application in health and safety management were few, they primarily focused on two subdomains: safety training and safety on-site monitoring. This demonstrates that the domain of safety culture, an essential aspect of health and safety management in construction, has yet to be fully explored and requires further research attention.

CONCLUSIONS

The literature review revealed that BIM and IoT integration is a recent development, filling gaps in their individual applications. Despite the emerging nature of this research field, the integration of BIM and IoT has shown significant potential to improve safety management in construction. Most studies are at a conceptual stage, indicating that further research is needed to fully explore the application of Dynamic BIM for health and safety management. Dynamic BIM offers an innovative and promising approach to improve construction safety, setting a trend for future research and application in this field. Our review of the literature indicates that the following are the prominent application domains for dynamic BIM, which have been explored in recent studies:

- Construction Operation and Monitoring
- Facility Management (FM)
- Construction Logistic and Management
- Health and Safety (H&S) Management

Based on the literature review, it is evident that while previous research has acknowledged the relationship between dynamic BIM and safety management, the effect of dynamic BIM on safety culture has not been addressed in depth. This research gap highlights the need for further exploration of dynamic BIM's impact on construction safety culture. Thus, research on dynamic BIM and its influence on safety culture in construction projects is essential for improving overall safety in the industry.

Based on our findings, future research on the impact of dynamic BIM on safety culture in construction projects and organizations can address the following areas:

- Impact of Dynamic BIM on construction safety culture
- Analysis of BIM-IoT integrated model approaches for enhancing construction safety culture
- Development of a framework for enhancing construction safety culture using optimized BIM-IoT integration approaches

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