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BIM AND IOT INTEGRATION FOR CONSTRUCTION AND LOGISTICS MANAGEMENT: A STATE-OF-THE-ART REVIEW

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ABSTRACT

Considered a promising avenue for achieving improvements in construction and logistics management, the integration of Building Information Modelling (BIM) and the Internet of Things (IoT) has proposed the ability to revolutionize the Architectural, Engineering, Construction, and Facility Management (AECFM) industry. Many studies have been examining different applications of BIM and IOT integration, specifically within the context of industry 4.0 through recent years. However, the existing literature appears to be fragmented due to the absence of review and categorization, leading to difficulties for practitioners and researchers in identifying trends and gaps. This paper delves into the convergence of BIM and IoT within the field of construction and logistics management by reviewing and categorizing the current cited literature derived from various journals using OpenAlex. On the one hand, the results suggest the utilization of RFID and LoRa for logistics, tracking, and inventory management with BIM and IoT as the most frequent topic. On the other hand, the implementation of BIM and IoT for simulating emergency evacuation scenarios is the least mentioned topic. The main foci within each topic-subcategory are also highlighted and described respectively.

KEYWORDS

Building Information Modeling, Internet of Things, Construction Management, Logistics Management

INTRODUCTION

Nowadays, we are witnessing a significant improvement in the productivity of several industrial sectors as the outcome of digitization. As a result of this promising outcome, the utilization of digital tools to design, build, and operate buildings and infrastructure assets is also becoming a common practice in the Architecture, Engineering, Construction, and Facility Management (AECFM) industry (Borrmann et al., 2018). To address the new challenges originated by the change of practice as an outcome of digitalization, Building information modeling (BIM) offers a model-centric information storage and distribution approach for construction projects, similar to other model-based product development approaches in many other industries (Kagermann, 2015). Additionally, the Internet of Things (IoT) is another industry 4.0 concept gaining more

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attention from practitioners by the day, based on the Global Standards Initiative (GSI) recommendation for the Internet of Things, IoT has been defined as the global infrastructure for the information exchange network that can facilitate the interconnecting physical and virtual assets (things) based on communication protocols such as the Radio-Frequency Identification RFID, Wireless Sensor Network technologies, Low Energy Bluetooth, and other developing protocols (Bayani et al., 2017). In other words, IOT provides a standard platform and a unified language for IOT-enabled devices to exchange information and communicate with each other and with external networks. IoT contributes to a variety of aspects within the AEC industry with instances such as smart user-centric environmental quality adjustment or energy consumption optimization using IoT-enabled components for building systems. Utilization of IoT for tracking products, assets, and materials in various stages of procurement for construction projects would have considerable effects on efficient delivery and waste reduction through improved management and coordination of construction projects consequently, the use of IoT and BIM for tracking and logistics optimization is an instance of lean construction approach in practice (Dave et al., 2016). The utilization of BIM and IoT for procurement and progress tracking is an example of how integrating product-centric information models and IoT technology can address the challenges with supply chain automation and logistics optimization in lean construction (Araújo et al., 2021).

The convergence of BIM and the Internet of Things (IoT) holds a huge potential to revolutionize construction and logistics management (Dilakshan et al., 2021; Khurshid et al., 2023). Numerous studies have highlighted the significant achievements in the integration of IoT with BIM or other centralized information management approaches. For instance, Chow et al. (2006) introduced a resource management system for warehouse operations using RFID technology, emphasizing efficient resource allocation and real-time management. Adiono et al. (2017) introduced a rapid Warehouse Management System (WMS) utilizing Radio-Frequency Identification (RFID) as a means of information exchange for inventory reporting management, demonstrating the efficiency-enhancing capabilities of IoT in inventory management. Biswal et al. (2018) extended this concept to consumables supply chains in India, emphasizing the potential of IoT in enhancing distribution logistics. Given the diverse aspects by which BIM and IOT integration contribute to construction management and logistics optimization, a growing interest in research in this field can be observed (see Figure 3). Despite this trend, the existing literature related to BIM and IoT integration is fragmented leading to difficulties for practitioners and researchers in identifying research trends and potential gaps. Additionally, few papers have focused on providing specific focal categories towards BIM and IoT integration for construction and logistics management context. Therefore, in terms of research goals, this research aims to identify potential research gaps by systematic categorization and review of the state-of-the-art research foci on BIM and IoT integration in the context of construction and logistics management. The contribution for this research is providing a valuable resource for practitioners and researchers interested in this field.

RESEARCH METHODOLOGY

The methodology selected for this research is literature review, which involves systematic examination and synthesis of existing literature on a specific topic. The initial inspiration for the research methodology comes from the scoping review framework (Arksey & O'Malley, 2005). Unlike the expansive nature of scoping reviews, the state-of-the-art review in this study reflects a deliberate focus on providing the latest and comprehensive understanding of BIM and IoT in construction and logistics management. This research prioritizes a more detailed exploration of recent literature, aiming to capture the dynamic trends, challenges, and opportunities in this evolving field.

By applying the state-of-the-art review methodology, detailed procedures conducted in this study are displayed (see **Error! Reference source not found.**).

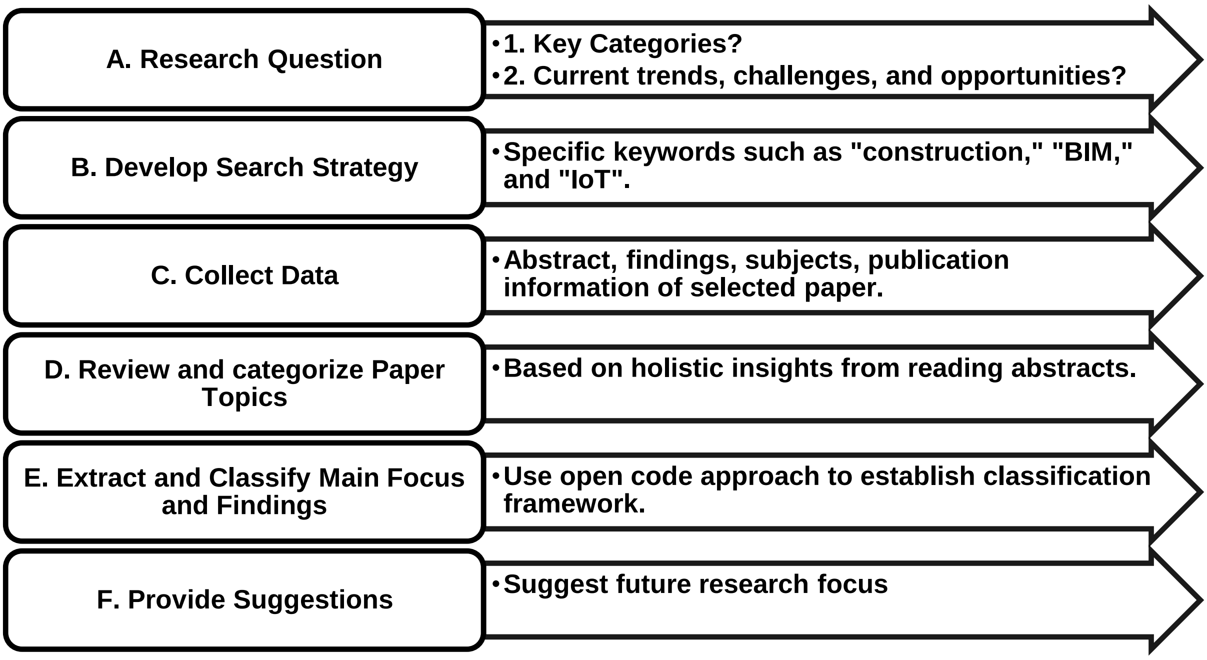

Figure 1: Process Flow Demonstrating Research Methodology

The research goals for this paper are (1) to systematically categorize and review the existing literature on the combined use of BIM and IoT in construction management logistics, (2) to identify research gaps and areas where further improvements and innovation are needed, and (3) to provide a valuable resource for practitioners and researchers interested in this field. Considering these goals, this paper is going to find answers to the following questions: What are the key categories of research for BIM and IoT implementations in construction and logistics management? What are the current trends, challenges, and opportunities for future research in this field?

After research goals and questions are determined, comes the selection of the reference database. Considered a user-friendly interface with various functions for researchers, OpenAlex is one of the free research databases that enable interactive filtering with organized and structured data, allowing researchers to identify and export query results for research.

As for the inclusion and exclusion criteria, all indexed papers in the Open Alex database are tagged with multiple concepts, based on the title, abstract, and available text. An automated classifier algorithm trained on the Microsoft Academic Graph (MAG) database serves as the tagging tool for the articles. The tags provided by Open Alex, which are named “concepts,” in this paper are listed as “Building information modeling,” “Internet of Things,” “Scheduling (production processes)”, “Engineering management”, and “Operations management”. (see Figure 2). Considering that the scope of research is limited by BIM, IOT, and Management adding the term “Logistics” to the inclusion criteria resulted in the removal of a sizable portion of citations from the literature. The research team decided not to include this term because adding it to the filters would have resulted in the omission of many studies with relation to construction logistics that didn’t necessarily use the term logistics in their subjects and abstracts. Consequently, a wider range of subjects was evaluated, and the additional unrelated works were filtered out of the literature during the abstract review based on the qualitative judgment of the researchers.

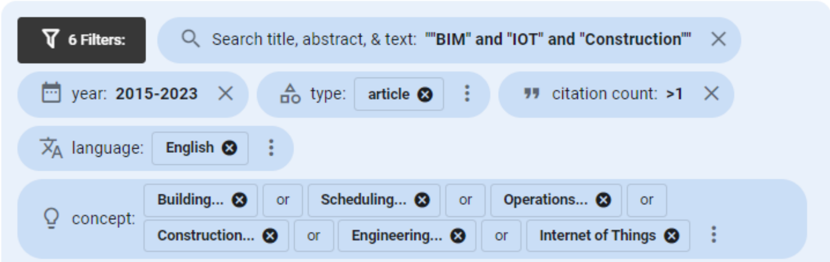

Figure 2 Inclusion and Exclusion Criteria for OpenAlex

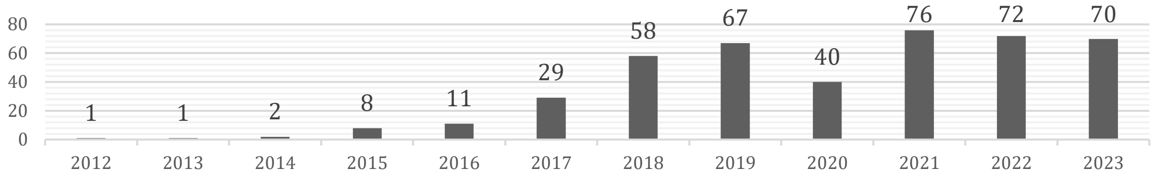

Figure 3: Publications by year including all English-published articles with BIM & IOT & Construction in the title, abstract, text, or concept (report from Open Alex)

Using the inclusion and exclusion criteria mentioned above, here are the search results demonstrating the number of publications (see Figure 3). As shown in the diagram, a significant increase in terms of the publication numbers occurred in 2015. Consequently, the publication time duration is limited from 2015 to 2023. Also, considering citation counts as a quality assessment of peer-reviewed publications, articles without citations were removed from the dataset.

While creating the categories for the articles, a rigorous method is employed to systematically organize and categorize the diverse information. The initial step involves assembling a spreadsheet dataset that encompasses articles associated with specific article IDs and corresponding bibliographical data including topics, summary of focus, and findings. After removing out-of-scope search results, reports, and duplicate items from the data, which consists of 404 papers, seventy-six articles with citations are chosen for full-text review. In the next stage, similarities among different topics and focus points of the articles are identified and the foundation for summarizing the common subject is established. Each article is assigned to only one category and subcategory.

Finally, an iterative categorization approach is implemented, where articles are initially grouped based on shared characteristics and subsequently refined to eliminate redundancies and ensure coherence. Using the open coding method (Cho & Lee, 2014), the categories are named thematically to encapsulate the subjects they represent, and the entire process is thoroughly documented for transparency and reproducibility. The results capture the diverse facets of the BIM and IoT implementations in construction and logistics management within the context of the Architectural, Engineering, Construction, and facility management (AECFM) industry.

LITERATURE REVIEW

As a result of the full-text review and open coding, this section discusses the categorization of literature based on areas of focus that emerge from the exploration of research papers with combined implementations of BIM and IoT in construction logistics and management (see **Error! Reference source not found.** and Figure 4). Categories and subcategories are proposed, based on specific applications and multifaceted ways in which BIM and IoT integration interact with various aspects of the construction and logistics management areas. In the following paragraphs, the logic behind categories and subcategories are explained respectively with additional examples provided from the literature. At this point, it is necessary to clarify that the categorization is merely the result of an open coding process and qualitative thematic analysis of studies by the authors. Furthermore, to provide future researchers with additional dimensions for potential gap spotting, The research topics were also categorized based on thematic connections with established classifications such as project management body of knowledge PMBOK (Project Management Institute, 2017) knowledge areas Each knowledge area represents a distinct domain of knowledge and practice within the broader discipline of project management. By breaking down project management into these specific areas, the PMBOK Guide facilitates a structured approach to understanding and managing projects. This approach allows project managers to focus on key aspects such as scope, time, cost, quality, human resources, communication, risk, procurement, and stakeholder engagement, ensuring comprehensive coverage and effective management throughout the project lifecycle. Additionally, the studies within each subcategory were also tagged based on topic relationships with common building lifecycle phases. The primary phases utilized for categorization purposes are Pre-construction (I), Construction (II), and Operation/Maintenance (III), Additionally, it is necessary to consider that in some cases the integrated implementation of BIM and IoT addresses the Entire building Lifecycle (IV) of buildings.

Table 1 Classification of Literature for BIM and IoT Implementations

Category	Sub-Category	Area of Focus	Phase	PMBOK Knowledge Area	References
Implementation and examination of New Technologies with the help of BIM and IoT	Cognitive Technologies	Operation and Maintenace Monitoring	III	Quality	(Santarelli et al., 2019; J. Xu, Lu, & Li, 2019; J. Xu, Lu, Xue, et al., 2019)
	Prefab and Manufacturing	Prefabrication, Supply Chain	I	Resource	(Wang, Altaf, et al., 2020; Wang, Wang, et al., 2020)
	Big Data	Estimation and Predictive maintenance	III	Cost	(Chu et al., 2021; Halmetoja, 2019)
	Distributed construction	Novel Offsite Construction Approaches	II	Time	(Dallasega et al., 2018; Pang et al., 2019)
	Digital Twin Applications in construction and maintenance	Procurement & Interactive Coordination of resources in Construction and Operation	III	Procurement	(Esmaeili & Simeone, 2023; Liu et al., 2023; Peladarinos et al., 2023; Rezaei et al., 2023; Rossi et al., 2019; Sepasgozar, 2021)
	Smart Building Systems	System Monitoring & Inspection	III	Integration	(Afzaal & Shoaib, 2021; Cantarero et al., 2018; Rahman et al., 2020; Vivi et al., 2019)
Integration/Optimization of information with the help of BIM and IoT	Blockchain & BIM Integration	Model-Based Traceability of Changes	IV	Scope	(Chung et al., 2022; De La Pena & Papadonikolaki, 2019; Fitriawijaya et al., 2019; Lu et al., 2021)
	Digital Twins & IoT Integration	Model-Based Real-Time Tracking and Procurement	IV	Procurement	(Chang et al., 2018; Esmaeili & Simeone, 2023; Nath, 2022; Tang et al., 2019)
	BIM Adoption Challenges Within Industry 4.0	Seamless Flow of Information	IV	Integration	(Al-Sinan et al., 2023; Begić et al., 2022; Mahajan, 2022; Yilmaz et al., 2023)
	BIM Adoption in Developing Countries	Process Implementation	IV	Integration	(Dosumu et al., 2023; Maqbool et al., 2023)
	BIM for Facility Management	Model-Based System Monitoring & Inspection	III	Integration	(Kameli et al., 2020; Lauria & Azzalin, 2023; Moreno et al., 2022)

Table 2 (continued) Classification of Literature for BIM and IoT Implementations

Category	Sub-Category	Area of Focus	Phase	PMBOK Knowledge Area	References
Construction Safety With BIM and IoT	Safety & Emergency Management	Safety For Workers and Equipment	II	Risk	(Park et al., 2018; Ribeiro et al., 2022; Sassi et al., 2022)
	Emergency Evacuation	Simulation Of Disaster Response	III	Risk	(Birajdar et al., 2020)
Construction Logistics and Transportation Optimization With BIM and IoT	IoT in Parts Transportation	Procurement Tracking	II	Resources	(Ben Neila et al., 2021; Sepasgozar et al., 2019; Tazikova & Struková, 2021; Treiblmaier et al., 2020; G. Xu et al., 2019)
	RFID and LoRa (long-range, low-power data transmission)	Procurement Tracking	II	Procurement	(Dervishaj et al., 2023; Gaba et al., 2018; Juraboev & Díaz, 2024; Kameli et al., 2020; Ragnoli et al., 2022; Teizer et al., 2018)
	Information and Communication Technologies (ICT)	Management Information System	IV	Communications	(Hammad et al., 2021; Li et al., 2022)
	AI & Supply Chain Innovations	Coordination In Distributed Construction	III	Resource	(Orooje & Latifi, 2021; Tien et al., 2022; Villa et al., 2022)
Facilitating User Comfort	Occupant Feedback & Digital Twins	Improve Occupants' Satisfaction	III	Stakeholder	(Dave et al., 2018; Donkers et al., 2022; Mao et al., 2018; Stojanovic et al., 2019; Su & Kensek, 2021)
Sustainability With BIM and IOT	Circular Economy in Construction	Sustainable Waste Management Solutions	III	Integration	(Batista et al., 2022; Sassanelli et al., 2021; Tao et al., 2018)
	Sustainable Construction Practices	Sustainable Construction Solutions	II	Integration	(Ben Neila et al., 2021; Klymenko et al., 2021; Mao et al., 2018; Petschen et al., 2023; You et al., 2020)

Within the category of “New Technologies”, the sub-category of Cognitive Technologies (J. Xu, Lu, & Li, 2019; J. Xu, Lu, Xue, et al., 2019), is about the utilization of cognitive IoT and digital twins for efficient facilities management. Prefabrication and Manufacturing Technologies, (Wang, Altaf, et al., 2020; Wang, Wang, et al., 2020), is about BIM and IoT for real-time data synthesis, optimizing off-site construction processes. Other subcategories include the integration of Big Data with BIM and IoT for improved facility management (Chu et al., 2021; Halmetoja, 2019). Distributed Construction (Dallasega et al., 2018; Pang et al., 2019), which holds the studies on BIM and IoT for real-time logistics planning and monitoring, contributes to distributed construction. Digital Twin Applications (Esmaeili & Simeone, 2023; Peladarinos et al., 2023; Rossi et al., 2019), showcases reduced costs and improved efficiency of construction management through BIM and IoT integration. Finally, Smart Building Systems, presented in articles (Cantarero et al., 2018; Rahman et al., 2020), propose building system architectures with IoT, utilizing BIM.

The category of “Integration/Optimization,” is about the utilization of BIM and IoT to facilitate collaboration and integration, especially within the context of construction management. Blockchain & BIM Integration sub-category (Chung et al., 2022; Fitriawijaya et al., 2019; Lu et al., 2021), contains references proposing transparency and traceability in supply chain management, ensuring accurate digital representation and enhancing trust with information exchange platforms. Digital Twins & IoT Integration (Chang et al., 2018; Esmaeili & Simeone, 2023; Tang et al., 2019), focuses on real-time data gathering, reducing costs and enhancing decision-making through the integration of BIM and IoT with digital twins.

The sub-category of BIM Adoption Challenges Within Industry 4.0, (Begić et al., 2022; Mahajan, 2022; Yilmaz et al., 2023), assesses digitalization and automation across construction project life-cycle phases, emphasizing the impact of technologies like BIM and IoT on the future of construction and the adoption challenges within the context industries already embracing initial BIM adoption stages. On the other hand, the subcategories of BIM Adoption in Developing Countries, (Dosumu et al., 2023; Maqbool et al., 2023), delves into challenges such as network infrastructure, standardization, and interoperability with implementing BIM in developing countries, recommending awareness and policy enactment. BIM for Facility Management sub-category, (Kameli et al., 2020; Lauria & Azzalin, 2023), contains various integrations of BIM and IOT specifically with RFID as a means of tracking and information exchange, for optimizing building maintenance.

Moreover, the category of safety is divided into two main sub-categories “Emergency management” and “Emergency evacuation,” where BIM and IoT are employed for simulation and management of user safety or critical circumstances. Safety & Emergency Management (Park et al., 2018; Ribeiro et al., 2022; Sassi et al., 2022), introduces BIM-based systems for disaster management, explores immersive visual technologies for safety training, and reviews emerging technologies for health and safety standards. Emergency Evacuation (Birajdar et al., 2020), reviews recent advancements in building fire detection and evacuation systems, emphasizing the role of BIM and IOT in enhancing safety protocols and simulation of immediate disaster response.

The category of “Logistics” explores the potential of BIM and IoT in Parts and Transportation management for construction. With parts transportation sub-category proposing cloud-based fleet management platforms and investigating the potentials of the Physical Internet for sustainable logistics networks (Ben Neila et al., 2021; G. Xu et al., 2019); RFID and LoRa technologies integrated with BIM models for efficient asset tracking, real-time monitoring, and location sensing in construction logistics (Gaba et al., 2018; Idrissi Gartoumi & Koumetio Tékouabou, 2023; Juraboev & Díaz, 2024; Kameli et al., 2020; Ragnoli et al., 2022); Information and Communication Technology (ICT), including studies defining BIM-based and IoT enabled information exchange platforms in the construction industry(Hammad et al., 2021; Li et al., 2022); And artificial intelligence Supply Chain Innovations category, (Orooje & Latifi, 2021), which reviews the integration of AI in BIM-IoT for healthcare facility maintenance management, emphasizing the transformative impact of technology on supply chain operations.

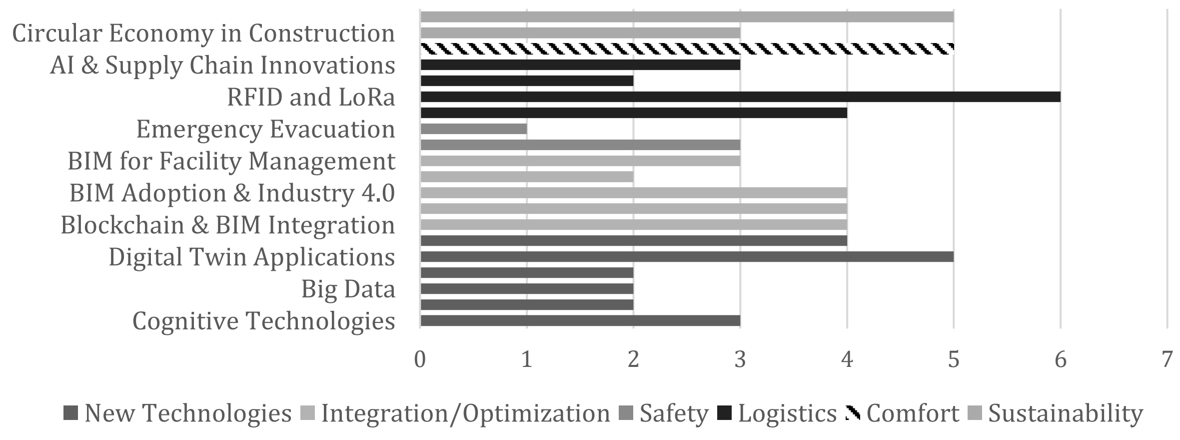

Figure 4: Categorization of Research Focus

The "Comfort" category is addressed through the interaction of IoT-enabled Occupant Feedback & Digital Twins, focusing on comprehensive building lifecycle management. Through the integration of real-world data, IoT sensors, and predictive models using BIM and BIM-Asset Management (BIM-AM) systems papers within this subcategory have implemented BIM and IOT to optimize air quality, enhance energy efficiency, improve building performance, and occupant comfort. (Dave et al., 2018; Donkers et al., 2022; Mao et al., 2018; Stojanovic et al., 2019; Su & Kensek, 2021)

"Sustainability" in construction is explored through two sub-categories of Circular Economy in Construction/Facility Management and Sustainable Construction Practices. Circular Economy in the built environment sub-category (Batista et al., 2022; Sassanelli et al., 2021; Tao et al., 2018), is more inclined toward the operation and maintenance phase, encompasses studies utilizing BIM-enabled simulation approaches for demolishing and disassembly processes, proposing real-time greenhouse gas emission monitoring systems using BIM and IOT, and integrating BIM-IoT-FM for sustainable water consumption. Sustainable Construction Practices, however, are about sustainability concerns in the earlier procurement and construction phases of buildings. This subcategory is also examined by studies investigating the potentials of the Physical Internet (PI) for sustainable logistics networks (Ben Neila et al., 2021); By proposing an informatization scheme for real-time monitoring of illegal behaviors in Construction and Demolition (C&D) waste disposal (You et al., 2020); and finally through the examination of the role of digitalization in manufacturing companies' sustainability-accounting framework, promoting sustainability in the corporate strategic decision making (Klymenko et al., 2021).

Figure 5 demonstrates the categorization of the article focus areas based on project management body of knowledge (PMBOK) knowledge areas, and their relationship with the provided themes of BIM and IoT applications in construction (see **Error! Reference source not found.**).

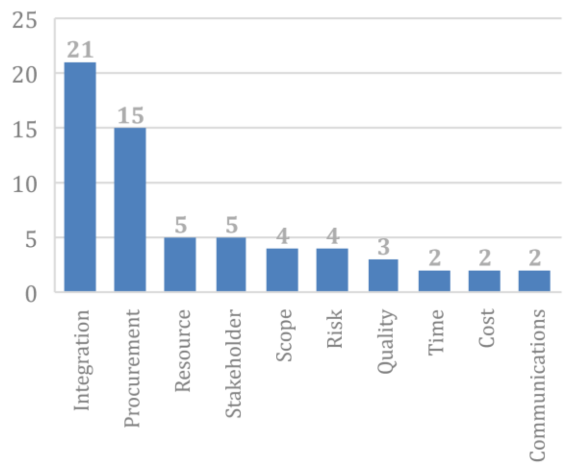

Figure 5: Number of references related to project management knowledge areas

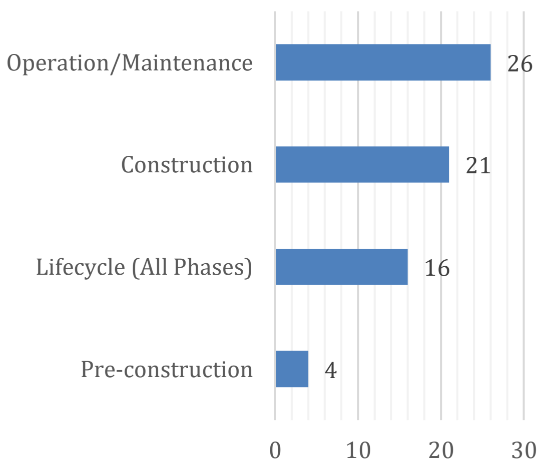

Figure 6: Analysing the number of references based on relation to construction phases

The distribution of articles across different phases of the project lifecycle (see Figure 6) reveals a comprehensive exploration of the synergies between Building Information Modeling (BIM) and the Internet of Things (IoT). The emphasis on the Operation/Maintenance phase, with the most articles, underscores a keen interest in leveraging BIM and IoT for sustained facility performance and efficiency. This phase represents a recognition of the long-term transformative impact of these technologies in ensuring optimal operational conditions and streamlined maintenance practices.

CONCLUSION

The examination of literature across various categories and subcategories within the scope of this research sheds light on key areas where the integration of BIM and IoT has been extensively explored. Notably, the utilization of “RFID and LoRa” for procurement tracking and construction logistics emerges as a well-explored area with a total of six references. These articles delve into the integration of BIM and IoT for real-time tracking and procurement, emphasizing its potential to enhance procurement and inventory tracking processes. Conversely, the “Emergency Evacuation” subcategory stands out as the least explored, with only one reference addressing the simulation of disaster response. This gap highlights a potential need for more research into innovative strategies leveraging BIM and IoT to improve emergency evacuation plans, ensuring the safety of users and equipment during unforeseen catastrophic events. Additionally, the “Distributed Construction” subcategory, within novel construction techniques, is also among the topics with few references highlighting the need for further exploration. Future researchers are encouraged to delve into these less-explored domains to contribute nuanced insights and innovative solutions, fostering a more comprehensive understanding of the challenges and opportunities in the integration of BIM and IoT in the construction and logistics industry.

The distribution of articles within project management knowledge areas suggests a substantial interest in understanding and enhancing project integration, with emphasis on Procurement, Stakeholder, and Resource aspects. The prevalence of articles in these subcategories indicates a recognition of their critical role in the successful implementation of BIM and IOT. Future research in this field could further explore innovative integration strategies, while paying more attention to less-represented areas such as Time, Cost, Communications, and Risk. Additionally, exploring the interplay between different knowledge areas while considering the effects of BIM and IoT integration would be valuable for advancing project management practices in the construction industry.

Additionally, the substantial focus on the Operation/Maintenance phase highlights the long-term benefits of BIM and IoT integration in the entire lifecycle efficiency of construction projects. While the Pre-construction phase features the least number of articles, its inclusion underscores the acknowledgment of early-stage planning and conceptualization as foundational to successful BIM and IoT integration. This holistic approach reinforces the transformative potential of BIM and IoT throughout every stage of construction, from project inception to ongoing facility management.

LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

It is necessary to consider that the lack of research on BIM and IoT integration within any of the mentioned research areas in the conclusion section might be affected by other factors such as lack of potential for improvements or technical barriers however these factors are not examined and are excluded from the scope of this research.

Another limitation of this research originates from the limitations of scope. Although the provided categorization may be subject to updates and improvement in future studies, the intention here is to create a foundation for future reviews to build upon.

The aim of this study is merely to reflect and compare the literature within the context of proposed categories that are coming from open coding and exploration of the main focus for each reference to identify and suggest the potential gaps based on the provided results.

Considering the limitations of the number of articles included in this review, changing the initial search keywords and concepts might result in a more generalized categorization. Additionally, future researchers can include other factors such as research methodology and sample and demography information along with limitations suggestions, and implementations of each reference during the initial data collection phase to improve the generalizability of the results.

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