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CURRENT RESEARCH, TRENDS, AND CHALLENGES IN BUILDING EMERGENCY MANAGEMENT

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Abstract

Digital technology has been showing promising outcomes in all phases of construction in pre, current, and post-construction, including facility management. Emergency management is a topic within facility management that also could be improved using digital technologies, particularly for buildings and related asset information models and digital twin. Research in this field is just starting. This paper presents current research, trends, and challenges of building emergency management assisted by digital construction technologies. The outcome of this analysis shows that new technologies and areas of focus are not fully integrated into the deep articulation of facility management sub-fields. The most studied topics include evacuation in case of emergency, damage reports, and repair plans. Eventually, this work leads to identifying the research gaps in the use of BIM and digital technology in the field of emergency management and the challenges required to fill in those gaps.

Keywords: BIM, Facility Management, Emergency Management, Digital Twin, AIM.

Introduction

Facility management is a broad topic where the boundaries of many subfields are not defined entirely. It is a discipline that has been practiced in the post-construction phase of the buildings to optimize their lifespan (Cotts, Roper and Payant, 2010).

Emergency management is one of many topics that are subcategorized under facility management. Emergency management is defined as the coordination of unexpected events in an unplanned manner. In a simplified term “a definition that deals with risk and risk avoidance” (George D. Haddow, 2020).

Research has revealed that BIM can contribute to emergency management optimization. This is made possible by the implementation of digital monitoring systems. It was shown how such systems that are linked with BIM inhibited many emergencies.

In order to achieve a well-organized and structured literature review, in this paper, a four-stage review method has been adopted. These four stages include (1) creating an initial literature mind-map that puts together 117 research papers, categorized into three categories and subcategorized based on the area of focus of every paper; (2) identifying common challenges and gaps indicated in the papers which included a deep analysis of 7 state of the art review papers; (3) creating a secondary literature categorization analysis that consists of 17 papers categorized into two categories and subcategories based on their specific fields of research, while their focus was always emergency management in BIM; (4) defining research gaps in emergency management concerning BIM with proposed potential future research work that might contribute to the construction industry.

The rest of the paper is organized into three sections. After the introduction (section 2); section 3 explains the primary analysis of categorization, indicated gaps, and challenges that were extracted from the 7 deeply analyzed review papers. Section 4 explains the secondary categorization focusing on emergency management, and section 5 concludes and presents potential future research.

BIM and Digital Solutions for Facility Management

The broader literature survey concerns facility management in a BIM-based development environment which was aimed to establish the current trends and to find out gaps in the field. Some insights into the most strategic categories will be provided, too. A detailed analysis of the opportunities and implications determined by the application of facility management will be reported later on in this section.

The preliminary stage started by collecting papers from international search engines such as Elsevier, IEEE, and Engineering Village to name the most relevant ones. The keywords used to search for papers were related to the topic from a general point of view. The most used keywords were Facility Management, Building Information Modeling (BIM), Digital Twin, and Asset Information Modeling (AIM). After gathering papers that

were related to the envisioned field of contribution, they have been archived in an excel sheet where they were identified and distributed into categories.

The final archive consists of 117 papers that cover the target topic. After the second round of recategorization, it was shown that nearly all papers can be categorized into three main categories namely; (1) Digital Twin (mainly focused on the potential digitization of different tasks done by the engineer); (2) Facility Management (that is the set of topics that discuss generally on the available tools that can be enhanced); (3) Heritage BIM which is a category that falls outside the scope and interest of this paper. All the papers gathered are summarized in Table 1. Not all papers were referenced due to limitations required on the length of this paper. The difference between the number of papers in the archive and the references ones can be worked out from columns no.3 and no.4 in Table 1, respectively.

Table 1: First categorization with reference

Category	Subcategory	Total Papers	Referenced Papers	Selected Referenced Papers
Digital Twin (59 papers)	Acoustics	1	1	(Philipp, 2013)
	Construction	1	1	(Darko *et al.*, 2020)
	Data	13	2	(Matarneh *et al.*, 2019; Ozturk, 2020)
	Design	2	1	(Lan, 2016)
	Digitization	20	4	(Yalcinkaya and Singh, 2014; Araszkiewicz, 2017; Edirisinghe *et al.*, 2017; Firdaus Razali *et al.*, 2019)
	Energy	4	1	(Francisco *et al.*, 2018)
	Government-concerned	5	1	(Glema, 2017)
	Handing Over	3	1	(Zhu, Shan and Xu, 2019)
	Project Management	8	1	(Zhang, 2020)
	Structure	2	1	(Wu and Lepech, 2020)
Facility Management (53 papers)	Asset Management (AM)	3	1	(Marzouk and Ahmed, 2019)
	Augmented Reality (AR)	5	1	(Baek, Ha and Kim, 2019)
	Emergency Management	10	10	(Atyabi, Kiavarz Moghaddam and Rajabifard, 2019; Cui, Wen and Zhang, 2019; Bayat *et al.*, 2020; Fu and Liu, 2020; Ma and Wu, 2020; Peijun *et al.*, 2020; Sergi *et al.*, 2020; Diao and Guo, 2021; Feng *et al.*, 2021; Hosseini and Maghrebi, 2021)
	Event Management	1	1	(Krämer and Besenyői, 2018)
	Geographic Information System (GIS)	3	1	(Trisyanti *et al.*, 2019)
	Life Cycle Assessment (LCA)	2	1	(Pan and Su, 2015)
	Mechanical, Electrical, and Plumbing (MEP)	3	1	(Hu *et al.*, 2018)
	Operation and Maintenance	12	1	(Pärn, Edwards and Sing, 2017)
	Plugin	7	1	(Ferguson and Law, 2019)
	Safety Management	4	4	(Wetzel and Thabet, 2015; Tang *et al.*, 2019; Afzal, Shafiq and Jassmi, 2021; Wu *et al.*, 2021)
	Space Management	2	2	(Solla *et al.*, 2020; Xiang-yan and Kun-Fa, 2020)
	Transparency	1	1	(Guo, Yu and Fang, 2019)
Heritage BIM (5 papers)	Documentation and Support	3	1	(Bruno, De Fino and Fatiguso, 2018)
	Scanning	2	1	(Usmani *et al.*, 2020)

Digital twin focused contributions include 59 journal papers categorized into 10 subcategories, which were defined based on the core topic of the papers. The most important ones are Data, Digitization, Government-concerned, and Project Management.

Data category focused papers emphasize the importance of data flow in BIM modeling, where if data is not defined it will cause huge consequences regardless of the purpose. Such matters may generate errors and clashes in the model and the system. Digitization focuses on the potential benefits of transforming traditional style tasks into digitalized systems thanks to the support of BIM which led to maximum optimization of accuracy and costs.

Government-concerned focused papers show the potential integration trials of governments' implementation of BIM and standardizing the regulation into the policies. Such matters include comparisons and successful projects that fulfilled the requirements set by government bodies of specific countries and regions. Project Management covers all possible tasks that project managers face before, during, and after the project is done. These tasks can take advantage of the digital model.

The second main category facility management focused papers consist of 53 journal papers that we sub-categorized into 12 subcategories. The majority of them focused on integrating technology with facility management tasks for accurate and quick results. The most important sub-categories are Emergency Management, Operation and Maintenance, Safety Management, and Space Management.

Emergency Management focused papers emphasized the potential benefits of connecting cloud models to monitoring and detection. They were proposing potential strategies that can lead to the quick evacuation of a premise in case of an emergency.

Operation and Maintenance focused papers showed available technologies that helped facility managers in the building operation, for instance, the CMMS ticketing system that showed positive outcomes for the building performance.

Safety Management focused papers were focusing on all the precautious measures and applying them in action to avoid bigger consequences that can affect the building's performance.

Space Management focused papers address the managing of spaces in the managerial theoretical matter. The trials of implementing proposed strategies and present concluded remarks for future contributions.

As a further step, papers were sorted into three main sections depending on the level of technology reliance and core topic. They were distributed based on reliance on three types of technology, hence they were divided into BIM, AIM, and Digital Twin. Whereas core topics were divided into Design, Construction, and Facility Management. Finally, based on a deeper analysis, another category level was generated under the title of Emergency Management and split into Maintenance, Evacuation, Space, and Digitization. Statistics regarding the three higher-level categories are depicted in Figure 1.

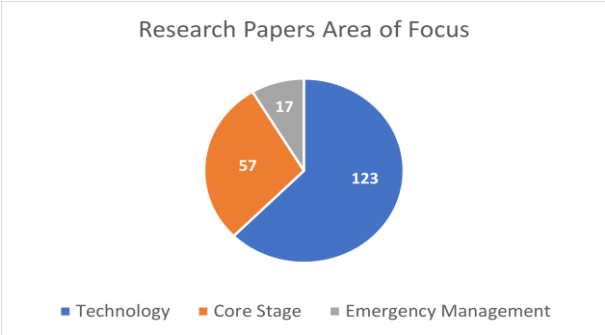

Figure 1: Research Papers Area of Focus

The chart in Figure 1 presents how technology dominates the focus of papers. Papers focusing on technology almost double those focusing on emergency management and core topics combined. Emergency Management as an independent category is even smaller compared to core topics. This comparison proves the potential research in this specific field of management.

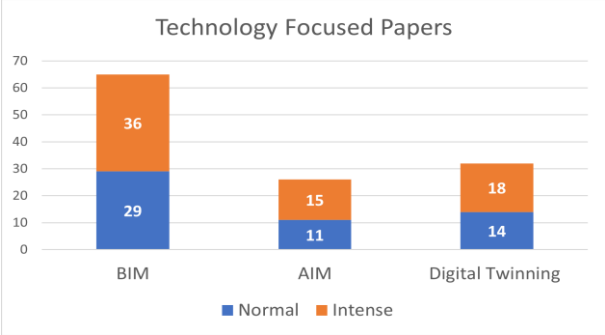

Figure 2: Technology Focused Papers

In figure 2 it was shown that papers can provide different insights of focus per category, thus a normal and an intense level were defined per each type of technology. Literature papers showed an impressive focus on BIM regardless of if it was intense or not. Research papers presented current challenges of the topic field and digital merge. Thus, a huge contribution to future researchers to build on.

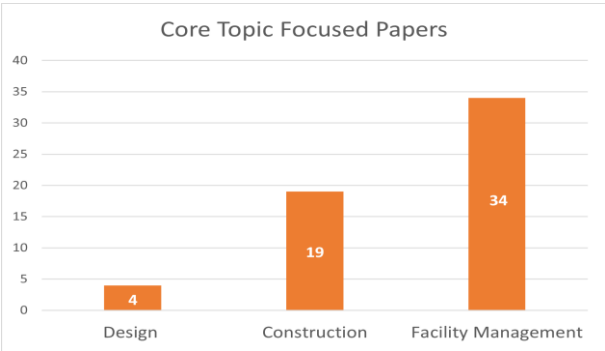

Figure 3: Core Topic Focused Papers

Figure 3 distributes papers according to the core topic, and the bar chart shows a huge focus on facility management. A deeper investigation showed that the technology industry field already digitalized the design phase of the building and now is mainly focusing on the post-design phases of the project. Papers also investigate the huge financial and time waste generated in the post-construction phase. The construction industry is gradually shifting its focus to guarantee the full optimization of the full building life cycle.

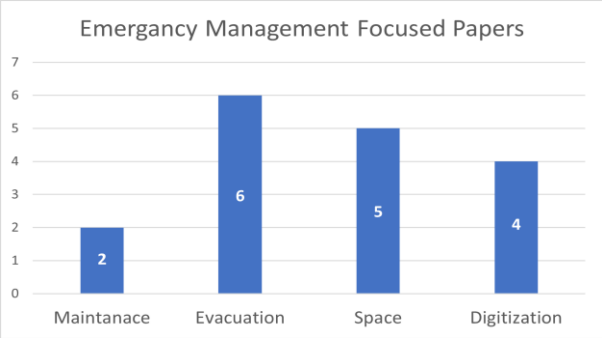

Figure 4: Emergency Management Focused Papers

Figure 4 compares emergency management-focused papers that were distributed into four main sub-categories. Papers under the category of evacuation talked about the proposed theories that are linked to algorithmic formulas. One example is finding the fastest route for the users in case of urgently required evacuation from the building. However, post-emergency management looks not well focused on, when compared to other factors. It was shown theoretically that it is vital to link evacuation and maintenance to minimize damages. Papers in respect to both categories are not linked within the process flow.

Research challenges regarding Building Emergency Management

As a result of the preliminary analysis followed by topic categorization, it was clear that several challenges were not been deeply investigated, yet. Emergency management was the broader scope that was taken as a core target that led to a secondary categorization analysis to gather research challenges that can be supported by building information modeling. This section will present the research paper's analysis that leads to emergency management secondary categorization to gather future research gaps.

Emergency Management is a broad topic that can be divided into three general areas, that is precautious planning, action, and post-emergency. Facility Managers (FM) should prepare a strategy in case any emergency occurs in the building facility. The FM should guarantee the safety of the users by evacuating the premises, as well as minimizing the damage to the building. Finally, repairing the collateral damages by reporting the situation and learning for future matters. Fire monitoring plays a vital role in building fire emergency management and can help the facility manager grasp the fire situation in real-time (Ma and Wu, 2020).

It is argued that much research deals with integrating BIM systems in new buildings, at the same time some studies were dedicated to show issues faced when BIM was applied. Therefore, the construction industry suffers from integrating BIM systems (such as evacuation plans) into existing buildings due to the challenging transformation to a smart cloud model (Edirisinghe et al., 2017).

The efficiency of the communication and information flow is one of the vital prerequisites for the fulfillment of strategic objectives of facility management to process emergency systems within the building scope. The goal of emergency facility management is to reduce building occupants from time-consuming tasks that are not directly related to the core business. Therefore, efficiency can be obtained by linking the quality of available building features with active digitalized systems for a successful optimized emergency management plan under facility management as a whole (Araszkiewicz, 2017).

A common matter mentioned in the gathered literature is the early integration of the facility management process into emergency management. It is proven that early engagement of emergency facility management could reduce major maintenance and alterations that will affect the building performance before, during, and after an emergency appears. Facility managers mainly have to identify the components' location and get access to the attributes and data relevant documents and emergency information of the components (Yalcinkaya and Singh, 2014).

Table 2: Second Categorization

Category	Subcategory	Total Papers
Safety (8 Papers)	Maintenance	2 Papers
	Evacuation	6 Papers
Management (9 Papers)	Space	5 Papers
	Digitization	4 Papers

Based on the primary categorization and deeper analysis, it was concluded that a secondary categorization analysis that focuses on emergency management should be established. Therefore, a total of 17 papers were analyzed and categorized to the second degree as shown in Table 2 above. 2 main categories were established which are safety and management. Safety consists of 6 papers which are divided into 2 sections, maintenance, and evacuation. This category emphasizes the present and future process of emergency in the building. Management consists of 9 papers that focus on the prevention and optimization of emergency management strategies and systems.

Research has indicated that in facility management, safety-related information is fragmented among multiple resources. They are generated throughout the lifecycle of a project, creating inefficiencies in the procurement of information. The facility manager will need to address all the safety concerns that apply to the maintenance process

of that equipment. To achieve that goal, it is required to reference multiple documents to obtain a comprehensive understanding of the task. The inconvenience of obtaining comprehensive safety information scattered through multiple documents can result in exacerbate the likelihood of work-related fatality injury (Wetzel and Thabet, 2015).

In regard to building evacuation, georeferencing BIM models can help identify the location of each entity, making it possible to establish a spatial analysis for different applications. BIM also offers more intelligence and interpretability compared to traditional styles regarding the optimization of any evacuation strategy process (Bayat et al., 2020). BIM can be used to provide detailed assessments of emergency management and evacuation. This can be supported by the integration of several algorithms such as Ant Colony and Dijkstra algorithms (Atyabi, Kiavarz Moghaddam and Rajabifard, 2019).

The management of space is vital in emergency case scenarios. Users' behavior will lead to chaos if not directed properly to evacuation gather points in an organized matter. The literature review indicates that building a smart integrated system requires the convergence of multiple technologies which include WSNs, big data, AIM, and BIM. However, it should be noted that the building fire emergency management has emphasized the innovation of technology and methods if trapped people fail to implement the precautious plans set due to rapid reaction behavior (Ma and Wu, 2020). Thus, understanding the psychological user's reaction would present a successful integration application.

New BIM technology has many advantages in resolving common problems in emergencies. Digitization actions for that matter start with the installation of multi-data sensors and video surveillance for 3D visualization in BIM models for intelligent optimized intelligent monitoring. The BIM model can be easily used to detect the exact location of the fire points online if additional hardware support has previously been spotted in the right locations all over the building. Therefore, the actions of the trapped and rescued groups can also be guided by the AIM route instructions (Ma and Wu, 2020). This is conditioned upon the application of suitable algorithms for the model.

Based on observed literature, many research gaps exist. For instance, finding a quick alternative to importing data into the digital model of the building to get a quick and accurate response on important safety management plans set by the facility manager. Optimization of data transformation would help with the immediate action response. With evacuation, the literature review also suggested the urgent need for accurate testing of algorithms that need to be tested when applied in the digital cloud model and system. Since there are several algorithms proposed to be integrated into the digital prototype system, they should be further tested and compared. Many contributions were dedicated to applying and presenting research outputs in this field. A minor dedication was reserved to compare outputs and to see if there is a different evacuation route or the same route, as well as the time, taken to establish the calculations for the system to be processed.

It was also implied that logistical aspects can affect the intentional purpose of the system to work successfully. From a building user's psychological perspective, the facility manager would use the general predicted reaction of the users and apply the emergency evacuation plan in their favor. However, the facility manager would not be able to customize evacuation plans that suit everyone. Therefore, research conclusions suggest setting a strategy that the facility manager can use to tailor evacuation plans on the digital model based on prior scenarios observed. Finally, it was shown that a huge key aspect of a successful implementation of the digital system is to determine the type, quantity, and location of sensors that should be installed and linked in the building project. A full understanding is vital for a beneficial system.

Conclusion

All in all, the literature review indicated many challenges regarding testing and implementation. The overall investigation showed potential research gaps that will contribute to the modern construction industry, and the secondary analysis also presented the direction in which emergency management with BIM is heading.

Based on experience and final analysis, research gaps that need to be addressed concern the application of different algorithms and testing their suitability for various scenarios. Another important field is the effective management of information flow in a BIM environment. These outputs will guide future research performed by authors in building emergency management.

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