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Exploring the Role of BIM in Knowledge Management in Construction Projects

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ABSTRACT
The non-serialized nature of the construction industry, the dynamic environment of construction sites, and the high turnover of workers are conditions that hinder the application of knowledge management (KM) in the sector. Given this, several studies highlight the use of BIM as a platform capable of optimizing KM. The main objective of this study was to investigate the potential of BIM for KM in construction. To this end, a systematic literature review was conducted, revealing a variety of practical applications of BIM in KM in areas such as occupational safety, project management, and sustainability in facilities management. However, studies are still in the early stages, with limited activities and risks included in the analyses. Moreover, ontology is widely used to structure knowledge in conjunction with a BIM model, followed by case-based reasoning (CBR). Although BIM can optimize KM, its application needs to be scaled up. Future studies should explore the use of machine learning to accelerate the knowledge modeling process.

KEYWORDS: Design for safety, Project Management, Facilities Management.

1 INTRODUCTION

Since the introduction of knowledge management (KM) technologies in the late 1980s, this area of study has become increasingly popular. However, KM initiatives remain ambiguous as there are various perspectives on what KM truly represents (Cheng et al. 2014). Santiago (2002) differentiates between the concepts of data, information, and knowledge, where data is considered a sequence of numbers and words without any specific context. However, if data is organized within a context, it becomes information, and knowledge is viewed as information structured with an understanding of its meaning. Quigley and Debons (1999) argue that information is essential to answer questions about who, where, when, and what, while knowledge addresses the reasons and means—i.e., the why and how.

Despite construction being considered an industry, the built environment presents peculiar characteristics. Unlike manufacturing industries, the production structure is relocated to the specific site of the project and dismantled at the end of the work to deliver the product to the end user (Fabrício 2002). Due to this migratory nature of construction and the complexity of construction sites, obtaining and coordinating information becomes a complex challenge (Yang et al. 2022). Furthermore, the construction sector experiences a high turnover rate of employees, complicating the transformation of tacit knowledge—individual know-how based on personal experiences and held in the minds of workers—into explicit knowledge, which is embodied in documents and transferable in formal and systematic language (Medeiros 2012).

Given this scenario, Building Information Modeling (BIM) was developed to assist in the information management process and, consequently, in knowledge management. Succar (2009) defines BIM as a set of technologies, processes, and policies that allow stakeholders in a project to collaboratively design, build, and operate a building in a virtual space. According to Lee, Yu, and Jeong (2015), BIM enables coordinated, consistent, and computable information management throughout the design, construction, maintenance, and operation cycle of a project. Alhusban (2021) states that despite various definitions of BIM in the literature, the main characteristic across definitions is the management of construction information.

ISSN 2318-8472, v. 12, n. 86, 2024

Building Information Modeling (BIM) allows for improvements in design productivity, sustainable design, waste reduction, and environmental impact (Olawumi; Chan 2019). Furthermore, enhanced accessibility to information, how knowledge is exchanged, and transparency in this process are significant contributions of digitalization to the built environment, especially in the field of sustainability (Santos et al. 2019).

However, BIM should be combined with methods such as ontology, case-based reasoning (CBR), or rule-based reasoning (RBR) for information to be captured and transformed into knowledge and subsequently shared. Zhang, Boukamp, and Teizer (2015) describe ontology as the definition of concepts and their relationships within a particular domain that characterize semantics. Ontologies are typically expressed in formal languages such as the Ontology Web Language (OWL) or Resource Description Framework (RDF), making them machine-readable and suitable for automated processing.

2 OBJECTIVES

Given that the construction environment requires improvements in knowledge management processes and that BIM has been highlighted in research as a sustainable methodology and a technology capable of transforming this scenario, this study aims to conduct a systematic literature review (SLR) on the application of BIM in construction concerning knowledge management, to understand how KM is practically applied and to discuss the benefits and challenges when utilized.

3 METHODOLOGY

The systematic literature review was conducted using the “Preferred Reporting Items for Systematic Reviews and Meta-Analyses” (PRISMA) methodology. The review was structured into four stages: identification, selection, eligibility, and inclusion. The databases chosen for the SLR were Engineering Village, Scopus, and Web of Science, as they are relevant international databases in the field of Civil Engineering, offering relevance, breadth, and specificity on the topic.

In the identification phase, to assist in defining the keywords used in the search, the PICo strategy was employed (JIDONG et al. 2021). The PICo strategy defined the population as construction, the interest as building information modeling, and the context as knowledge management. Therefore, the keywords combined with the boolean operators “AND” and “OR” formed the search string: ((Construction OR “Construction Management”) AND (BIM OR "Building Information Modeling" OR “Building Information Modelling” OR “Building Information Model”) AND ("Knowledge Management" OR Knowledge). It is important to note that this string was applied to search for terms only in the titles, abstracts, and keywords of the articles.

In the selection stage, only journal articles were initially selected, as they undergo peer review and thus meet higher scientific rigor before being accepted and published. Next, only articles published in English were considered, and finally, duplicate articles detected in more

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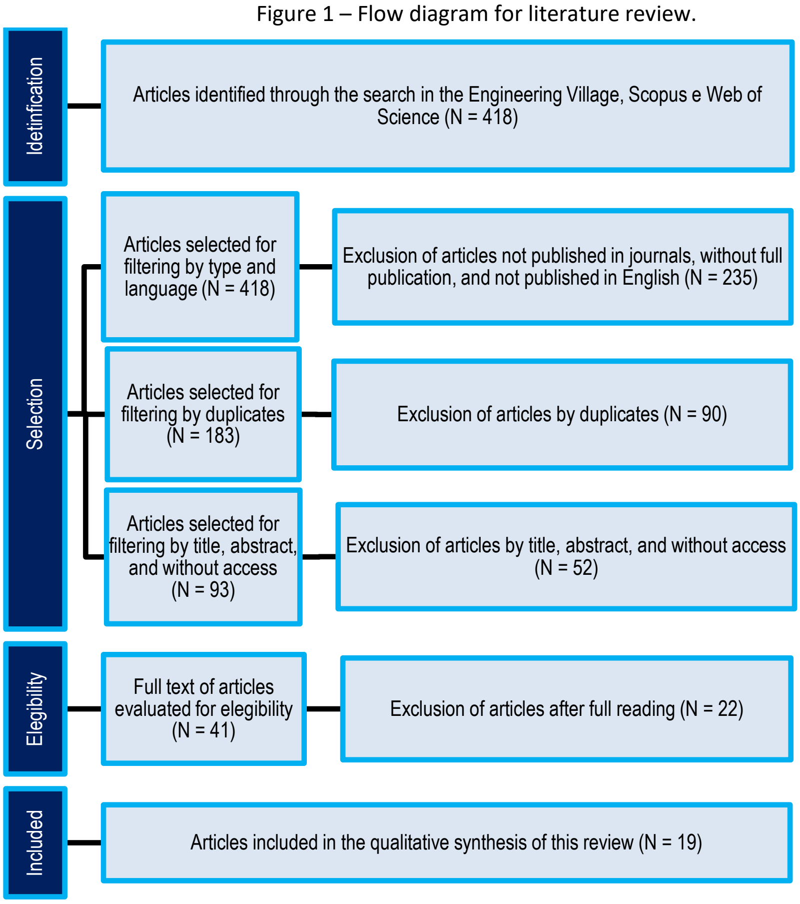
than one database were removed. Subsequently, by reading the titles and abstracts, literature review articles and those without practical applications of KM in construction projects—such as opinion surveys—were discarded.

In the eligibility phase, full readings of the articles were conducted to ensure that the inclusion and exclusion criteria were respected and to evaluate the quality of the methodology employed in the studies. Later, the remaining articles were included for quantitative and qualitative analysis of this review. In the quantitative analysis, data such as the year and country of publication of the articles were collected, while in the qualitative analysis, the application areas of KM were identified, as well as the benefits and limitations.

4 RESULTS AND DISCUSSIONS

Initially, 418 articles were identified as illustrated in Figure 1. Next, filtering was performed considering only journal articles published in full in English, resulting in 183 articles. However, 90 articles were found in more than one database, leaving 93 articles for evaluation through titles and abstracts. After this stage, 41 articles were read in full for eligibility evaluation, and finally, 19 articles were included in this literature review.

Figure 1 – Flow diagram for literature review.



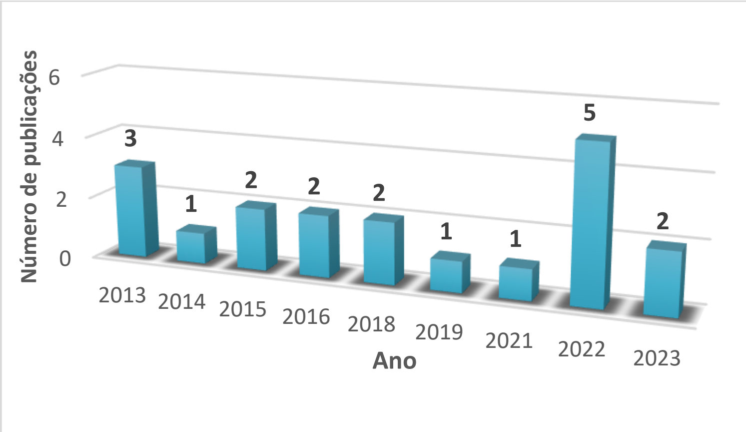
Source: Authors.

ISSN 2318-8472, v. 12, n. 86, 2024

After selecting the articles, it was possible to quantitatively analyze three parameters of the studies: the number of articles published per year, the countries responsible for the publications based on the institutional affiliation of the first author, and the frequency of keywords used.

Initially, the inclusion criteria considered articles published between 2018 and 2023; however, due to the topic of KM supported by BIM still being underexplored in the literature, this criterion was disregarded. Analyzing Figure 2, it can be seen that the first studies found on this topic date back to 2013, corroborating the idea of it being a recent topic. It is also worth noting that 2022 saw the highest publication on the topic, with five articles found.

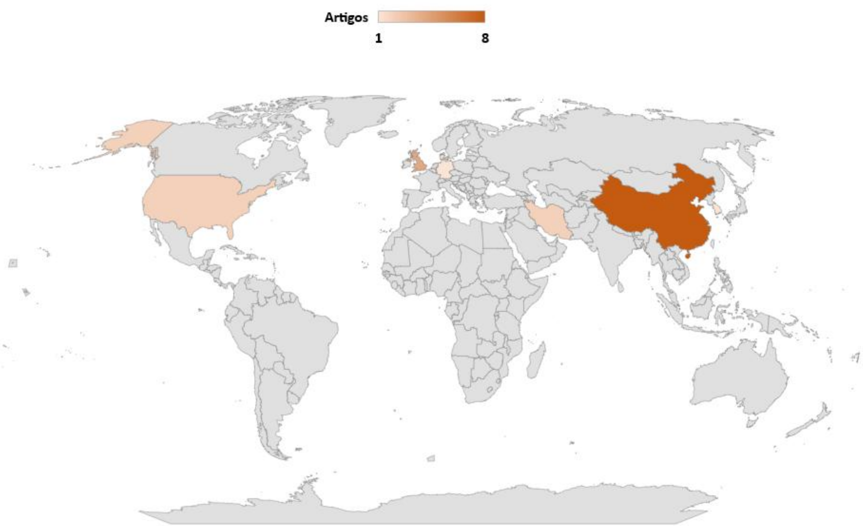
Figure 2 – Number of publications by year.



Source: Authors.

Figure 3 indicates the number of publications by country, taking into account the country of the first author. China stands out with a total of 8 published articles, followed by the United Kingdom and the United States with 4 and 2 publications, respectively.

Figure 3 – Número de publicações por países.



Source: Authors.

GC Revista Nacional de Gerenciamento de Cidades
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Figure 4 presents a word cloud of keywords found in the articles of this review. The most frequently observed terms are: BIM (11), Building Information Modelling (6), Ontology (6), Building Information Modeling (5), and Knowledge Management (4). This word cloud can aid future research regarding the use of more precise keywords on the studied topic.

Figure 4 – Word cloud of keywords.

Source: Authors.

After a comprehensive reading of all the articles, three uses of BIM in KM were identified. The first use was in occupational safety through safety design, the second use was in project management with a strong focus on schedule management, and lastly, KM was utilized in facilities management.

4.1 Design for safety

Throughout the lifecycle of a project, knowledge is acquired through experiences, and when structured and passed on to future projects, it can significantly contribute to better outcomes in occupational safety. Safety design, also known as design for safety (DFS), shares the philosophy with BIM of eliminating or mitigating risks during the planning and design phase (Rodrigues; Vasconcelos 2024).

In this context, Xiahou et al. (2022) identified potential risks in the deep foundations of subway construction through an analysis of regulatory standards, literature, and accident cases. They then used trajectory crossing theory and accident causation theory to understand the relationship between design processes and workplace accidents, subsequently quantifying

ISSN 2318-8472, v. 12, n. 86, 2024

the risks using the FEC method (frequency, exposure, and criticality) to alert managers through the BIM model if risks exceeded pre-established safety limits.

Dadashi, Haji, and Behnam (2023) structured a knowledge base based on leading safety indicators such as equipment-related accidents and falls from heights using the opinions of experts and documentation from similar projects already completed in water transfer stations. They then created an interface with Navisworks software to connect the 4D BIM model with the knowledge base. This allows the construction manager to visualize daily which activities have the most significant impact on worker safety through a heatmap.

In a study conducted by Wang Meng and Zhu (2022), case-based reasoning (CBR) and natural language processing (NLP) were utilized to retrieve knowledge from a database of construction projects. CBR retrieves knowledge by comparing attributes between similar cases; however, it is not suitable for long texts, making it necessary to use NLP to ensure project context (Wang Meng and Zhu 2022). This knowledge storage system was combined with BIM using shared parameters to store health and safety knowledge acquired during user queries.

Knowledge-based systems allow for risk assessment and incorporation into the model from the design phase. This enables architects and design engineers to choose design solutions that reduce risks during construction (Lu et al. 2021). The enhancement of safety design is notable when integrated with knowledge systems, as architects and design engineers, who are usually not safety specialists, are guided through these techniques and tools to select solutions that minimize risk probabilities.

4.2 Project Management

According to the PMI (2017), a project is a temporary endeavor undertaken to create a unique product, service, or result. The temporary nature of a project indicates a well-defined start and end date; in this sense, a real estate project is considered a project in the construction industry.

As per the Project Management Body of Knowledge (PMBOK) guide, lessons learned refer to knowledge gained during project execution (PMI 2017). Whether stemming from failures or successes, these learnings need to be adequately validated and documented to benefit future projects. These records require continuous updating and must be easily accessible through conventional information retrieval methods, which largely depend on ongoing improvements in information technology applications.

In a study developed by Oti, Tah, and Abanda (2018), lessons learned data were stored in a NoSQL unstructured query system like MongoDB, connected via the .NET Framework interface to a BIM project management tool, Navisworks Manage. The system was tested with a federated model of a school project, which improved the product through knowledge reuse. This was executed by going beyond a conventional text-based query, linking lessons learned to model items associated with the appropriate tasks in the project schedule. This way, lessons

ISSN 2318-8472, v. 12, n. 86, 2024

learned became more beneficial for those responsible for their respective assignments in the project.

Another crucial aspect of project management in construction is site planning. Improper selection of construction equipment or their locations can impact the project's schedule, increase costs, and even raise safety risks. Currently, this activity is mainly performed manually due to a lack of computational support, resulting in a slow and error-prone process. Thus, Jahr and Borrmann (2022) created a semi-automated selection of construction equipment based on a knowledge-based inference and rule system. In the case study, the living areas, concrete pumps, and cranes on the site were calculated and visualized in the BIM model based on input parameters such as the land area, total constructed area, and construction methods.

Still within the scope of schedule management, Tavakolan, Mohammadi, and Zahraie (2021) developed a framework through the creation of an ontology and semantic reasoning techniques for short-term planning on-site, encompassing planned activities and necessary resources. Using a BIM model, it was possible to visualize the plans created by the system and existing constraints; however, it is essential to note that the developed framework did not consider spatial limitations and congestion on the construction site.

4.3 Facilities Management and Sustainability

Considering that the time spent on constructing a project is relatively short compared to the operational and maintenance cycle of buildings, several studies are being developed to utilize a BIM model in facilities management (FM).

In this scenario, with the aim of evolving from the BIM concept to Building Knowledge Modeling (BKM), Motawa and Almarshad (2014) used case-based reasoning (CBR) and a BIM model to capture knowledge of maintenance activities. Knowledge was structured based on studies of similar cases and interviews with professionals in the field, identifying critical knowledge for building maintenance and which model elements were affected by these cases.

In addition to assisting in the management of modern building facilities, BIM is also efficiently utilized in the conservation of historic buildings, known as Historic BIM or HBIM. From this perspective, to increase the effectiveness of sustainable management in historic buildings, Lee et al. (2019) developed a maintenance platform based on BIM and ontology that relates building components to potential pathologies and maintenance methods. With the support of experts in the area, pathological manifestations were identified in a case study, and based on the combination of Failure Mode and Effects Analysis (FMEA) techniques with a cloud-based model, they were prioritized according to frequency, severity, and detectability.

Rapid changes in the built environment and stakeholder requirements have raised growing concerns about the importance of achieving environmental sustainability. Facilities management (FM) plays a vital role in sustainable development by prioritizing energy and water management, maintenance management, and waste management (Jayasena; Mallawaarachchi; de Silva 2019).

GC Revista Nacional de Gerenciamento de Cidades
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ISSN 2318-8472, v. 12, n. 86, 2024

4.4 Limitations of Using BIM in Knowledge Management

Despite the benefits BIM can bring to knowledge management, it is necessary to highlight the existing limitations found in studies, as incorporating knowledge into the BIM model remains a complex and time-consuming task.

The application of knowledge management through BIM in occupational safety is still in its early stages. Most studies focused on a specific scenario within a particular construction typology, meaning there was only a small amount of activities and risks included in the analyses. Consequently, the greatest challenge is to expand safety management to different risks involved (Shen et al. 2022). Similarly, in project management, studies demonstrated common difficulties. In addition to the spatial constraints mentioned in the work of Tavakolan, Mohammadi, and Zahraie (2021), the framework developed for short-term planning only considered the concrete structure of the work, leaving all other activities out of the analysis.

Another limiting factor identified across all application fields was the influence of the human factor in the knowledge management process. In summary, the complete automation of knowledge into a BIM model is not feasible, as many decisions involving safety engineering and site layout require a broad understanding of the context based on human experience, which cannot be entirely formalized (Jahr and Borrmann 2022).

5 CONCLUSIONS

The dynamic nature of the construction industry, the complexity of construction sites, and the high turnover of employees are factors that hinder the application of knowledge management in the construction industry. Therefore, it was possible to observe an advancement in the practical applications of BIM in the Architecture, Engineering, and Construction (AEC) sector aimed at enhancing knowledge management.

From the literature review, ontology was identified as a widely used method for structuring knowledge alongside a BIM model, followed by case-based reasoning (CBR). Additionally, it is noted that BIM allows knowledge to be structured and visualized more clearly and centrally, facilitating dissemination to all stakeholders involved in projects across various areas of construction, such as in occupational safety management, schedule management, and facilities management.

It is evident that the use of BIM in knowledge management enables a reduction in safety risks during the planning and design phase, optimization of schedules and site layouts during construction, and finally, in the operation phase of the building, it aids stakeholders in developing a sustainable environment encompassing the entire lifecycle of a project. However, despite the increasing use of BIM in knowledge management, this SLR highlighted that several restrictions still exist in the studies conducted.

ISSN 2318-8472, v. 12, n. 86, 2024

Regarding the limitations of this analysis, it is important to note that the impact of the journals responsible for the studies analyzed was not considered. This is because such a criterion could have reduced the sample size and hindered the inclusion of more recent journals. However, it is worth emphasizing that the research opted to include only articles published in journals to ensure greater quality in the selected publications.

The utilization of BIM in knowledge management is still a process that requires significant effort to be developed, as professionals need to be trained, and various workflows must still be automated and improved. In this scenario, the use of enabling technologies in future studies is recommended, such as laser scanning or machine learning, to gain more speed in the knowledge modeling process.

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