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Prevention of accidents in project design in the BIM process: a bibliometric review

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ABSTRACT
In recent decades, urban development has been marked by a growing search for solutions that promote the intelligence and sustainability of cities. In this context, the Prevention through Design (PtD) approach emerges as an important tool to enhance the safety and sustainable development of projects, from conception to deconstruction. This study aims to present a bibliometric analysis of academic productions on PtD that employ BIM, contributing to the advancement of knowledge in this field and the construction of safer, smarter, and more sustainable cities. Using the PRISMA methodology and the PICo approach, 37 articles were analyzed. The results highlight a significant increase in publications, particularly in 2022, led by China, followed by the USA. A probable future research trend is the use of PtD for subway stations. Journals such as Automation in Construction emerge as influential in this field. Co-authorship analysis indicates limited collaborations, while the citation network reveals the influence of journals like Automation in Construction and Safety Science. It is concluded that BIM for PtD represents an expanding research area with international relevance for the construction of safer and more efficient cities.

KEYWORDS: Building Information Modeling. Occupational safety. Sustainable construction.

1 INTRODUCTION

The growing urbanization and the quest for sustainable solutions are redefining the paradigm of modern cities. In this context, the construction sector assumes a crucial role, not only as an economic driver but also as a vector for transforming into smart and sustainable cities (Angelidou *et al*., 2018; Berglund *et al*., 2020). However, it faces significant challenges, especially related to workplace safety, making it one of the industries with the highest incidence of accidents (Alkaissy *et al*., 2023; Famakin; Aigbavboa; Molusiwa, 2023). The impacts of these accidents extend beyond the construction site boundaries, affecting schedules, material resources, and, most importantly, human lives (Rokooei *et al*., 2023).

In line with sustainable development, it is imperative to comprehensively address the challenges faced by the construction industry. Mitigating risks associated with accidents requires a holistic approach that permeates all phases of the project, from conception to deconstruction (Koc; Okudan, 2021; Scopel, 2015). The design phase, in particular, emerges as a crucial stage where strategic decisions can be made to mitigate inherent construction risks (Hsiao; Hsieh, 2023). Notably, about 24% of accidents in the construction industry are attributed to decisions made during this phase (Vasconcelos, 2013).

In this context, the concept of Prevention through Design (PtD) gains prominence as a proactive approach to mitigating risks throughout the lifecycle of a construction project (Chang *et al*., 2023). With technological advancements, a range of digital tools has emerged, notably Building Information Modeling (BIM), which enables the development of detailed three-dimensional models integrating physical aspects and data associated with project elements (Addor *et al*., 2010; Azevedo *et al*., 2023; Azevedo *et al*., 2024; Zheng; Fischer, 2023; Rodrigues; Vasconcelos, 2024). In addition to facilitating collaboration and communication among stakeholders, BIM provides a platform for early identification of safety risks in the design phase (Porwal *et al*., 2023; Santos; Ramos, 2019).

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Although previous studies, such as those by Jin *et al*. (2023), Farghaly *et al*. (2022), and Azevedo and Vasconcelos (2024), have shed light on various facets of the PtD approach, this work seeks to complement the current landscape by conducting a specific bibliometric analysis on the use of BIM technology as a tool to assist PtD. Thus, the objective of this article is to present a bibliometric study of academic productions on PtD that employ BIM, contributing to the advancement of knowledge in this field and to the construction of safer, smarter, and more sustainable cities.

2 METHODOLOGY

This article adopted the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Page *et al*., 2021). A research protocol was developed, presented in Table 1. Additionally, the PICo approach was used to guide the selection of keywords employed in the search (Stern; Jordan; Mcarthur, 2014).

Table 1- Research protocol.

Item	Content
Population	BIM, Building Information Modeling
Interest	Prevention through Design, Safety by Design, Safety through Design, Design for Safety, Safe design, Design for Construction Safety.
Context	Construction.
Database	Compendex, Science Direct, Scopus e Web of Science
Exclusion and quality criteria	(CE1) Articles that do not have the keywords of the research in their title or abstract; (CQ1) Articles that do not focus on the application of BIM for PtD. (CQ2) Articles whose application of BIM integrated with PtD is not conducted in building design projects (architecture, structure, and installations) and infrastructure (structure or installations).
Research questions	* What are the research trends involving BIM and PtD? * Which countries and researchers contribute the most publications on the use of BIM tools for PtD? * What has been the growth in the number of annual publications related to the use of BIM for PtD? * How are keywords used in articles related to BIM for PtD?

Source: Authors.

According to PRISMA guidelines, the study unfolded in three stages: identification, screening, and inclusion. In the identification phase, a search strategy was developed by combining keywords and boolean operators "AND" and "OR" to create the following search string: (BIM OR “building information modeling”) AND ("Prevention through Design" OR "Safety by Design" OR "Safety through Design" OR "Design for Safety" OR “safe design” OR "Design for Construction Safety") AND Construction. This search string was used in the databases to select primary study articles available in Portuguese, English, or Spanish.

Regarding the selection of databases, four internationally relevant databases for the construction field were chosen: Compendex, Science Direct, Scopus, and Web of Science. During

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the search, Microsoft Excel was used to remove duplicates from the sample while identifying articles in each database. Subsequently, in the screening phase, the articles were analyzed based on their titles and abstracts on the online platforms of the databases, and through this analysis, articles not related to the research topic through title, abstract, and keywords were excluded according to exclusion criterion 1 (CE1). After that, the remaining articles were retrieved from the databases for complete reading and analysis according to quality criterion 1 (CQ1), to remove articles that do not focus on the application of BIM for PtD, and quality criterion 2 (CQ2), which aims to remove articles whose application of BIM integrated with PtD is not performed in building design projects (architecture, structure, and installations) and infrastructure (structure or installations). After completing the screening phase, 37 articles were included for bibliometric analysis.

For bibliometric analysis, performance analysis and scientific mapping methodologies were employed (Pereira; Rosa; Cunha, 2023). Performance analysis aims to evaluate the production of authors and countries based on their publication analysis. To do this, some bibliometric performance indicators were used, such as the number of articles published annually, which authors and countries research the theme the most, and the journals with the most publications involving the use of BIM in PtD. The second methodology, scientific mapping, focuses on analyzing the structure and dynamics of knowledge production, generating graphical representations of the interconnections between authors, keywords, and journals (Van Raan, 2004). For developing scientific mapping, VOSviewer software was used, a tool that employs applied mathematics and statistics to create and explore data samples and knowledge maps based on bibliometric network data (Arruda *et al*., 2022; Huang *et al*., 2022).

3 RESULTS AND DISCUSSIONS

The results are presented in two sections. The first addresses the process of identifying, screening, and including studies from the databases. The second encompasses the bibliometric performance analysis and scientific mapping, including indicators such as the number of documents published per year, countries with the highest publications, and the visualization of similarities obtained with VOSviewer support.

3.1 Identification, screening, and inclusion of studies

The systematic review was conducted in October 2023. In the identification phase, a total of 216 results were initially found, as illustrated in Figure 1. Among the results, 16 were found in the Compendex database, 149 in Science Direct, 24 in Scopus, and 27 in Web of Science. Among these, it was identified that 50 were duplicates and were excluded from the count for screening. Next, in the screening phase, exclusion criteria (CE1) were applied based on the reading of the titles and abstracts of the articles, excluding 108 of them. The remaining 166 articles were retrieved from the databases for complete reading and application of quality criteria, where five articles were excluded for not focusing on the application of BIM for PtD,

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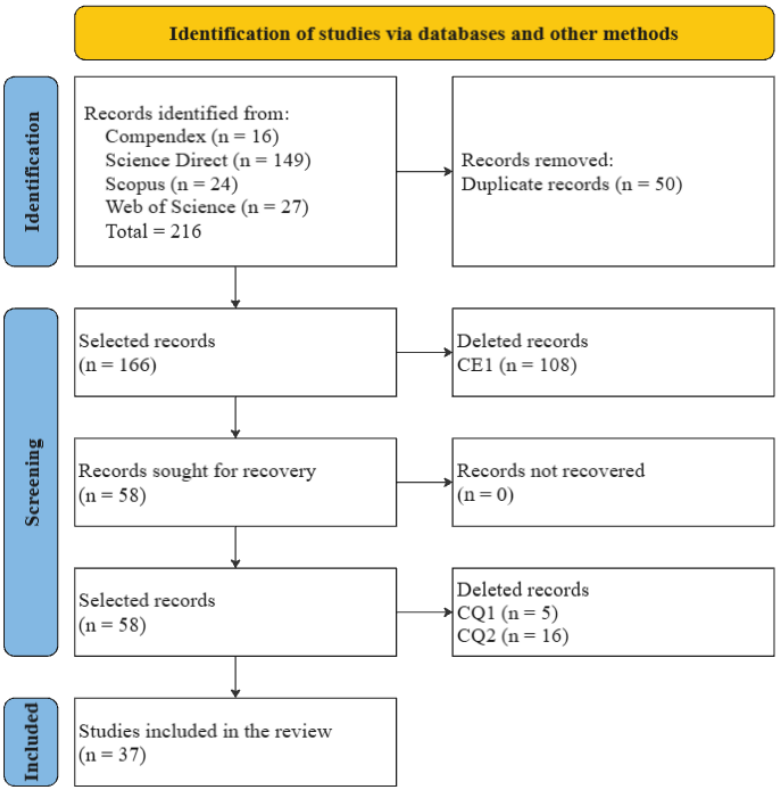
and 16 articles were excluded for not having the application of BIM integrated with PtD in design projects (architecture, structure, and installations) or infrastructure (structure or installations). After the screening phase, 37 articles were included for analysis in the systematic review.

Figure 01 – PRIMA fluxogram



Source: authors

3.2 Bibliometric analysis

The Venn diagram indicated in Figure 02 shows the number of articles included in the systematic review from each of the databases used. Science Direct stands out by presenting the largest number of articles that were not available in any of the other three databases, in addition to registering the highest number of articles included in the research. In contrast, Compendex presented the lowest number of articles included in the systematic review, and all of them were also present in the other databases.

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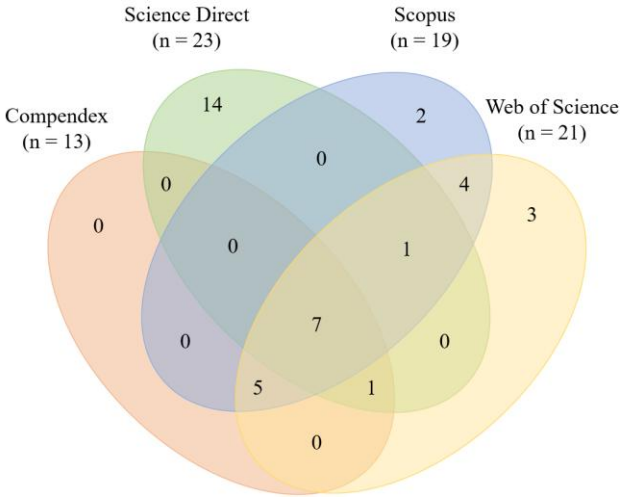
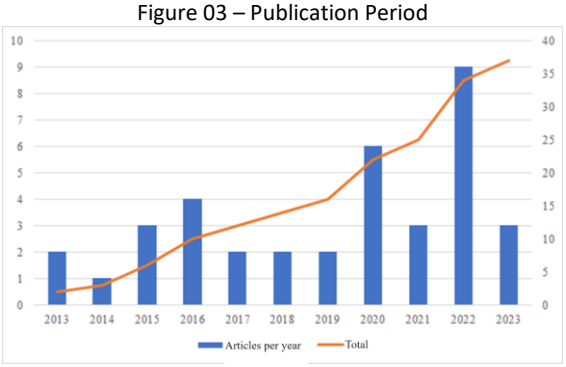
Figure 02 – Venn diagram of article relationships by database.



Source: authors

According to Figure 03, the earliest articles addressing the use of BIM tools for PtD date back to 2013, with no significant increase in annual publications until 2020, with 2022 being the year with the highest number of publications, totaling nine articles published. Although the volume of publications fluctuates over the years, there is a clear increase in interest in developing articles on this topic.

Figure 03 – Publication Period



Source: authors

Among the nationalities of the first authors of the articles, twelve are affiliated with institutions in China, making it the country with the highest number of publications on BIM tools for PtD, followed by the United States (5), the United Kingdom (3), South Korea (2), Singapore (2), and Denmark (2). The other countries that published on the topic have only one publication each, including Germany, Belgium, Canada, Spain, England, Iran, Italy, Malaysia, Portugal, Russia, and Taiwan. Figure 04 illustrates a map highlighting the countries with the highest volume of publications, where the intensity of the blue color indicates the number of publications, with darker shades representing higher numbers and lighter shades representing lower numbers. Countries displayed in gray do not have publications in this area. There is a noticeable concentration of publications in nations located in the northern part of the map, indicating advances in research on BIM tools for PtD in these regions.

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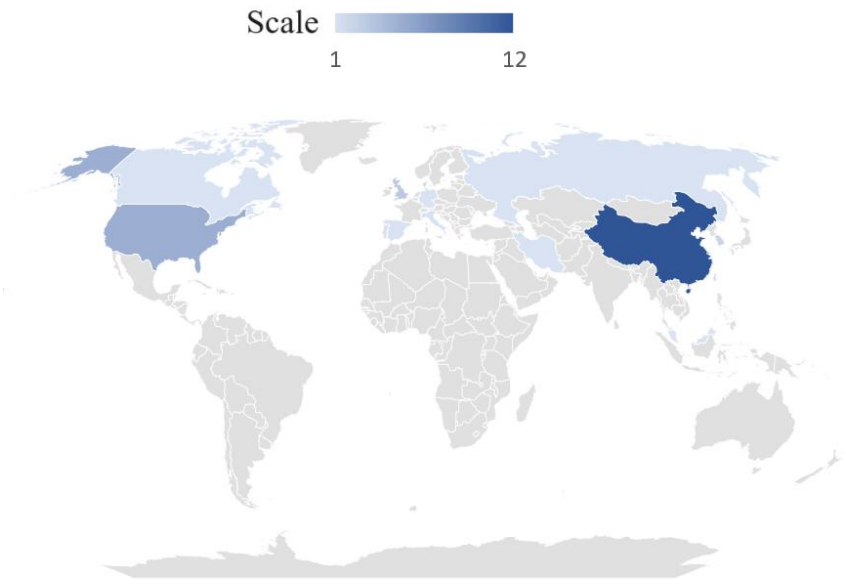
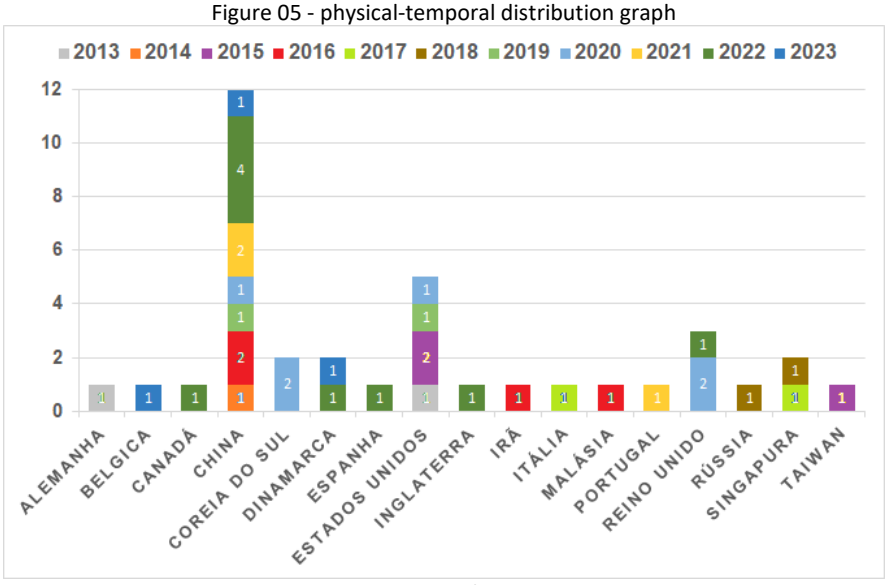
Figure 04 – countries with the highest volume of publications



Source: authors

Figure 05 presents a graph showing the relationship between the year of publication and the country of origin of the research. This visual representation allows observation of the volume of publications across different countries and their corresponding years. Germany and the United States were the first countries to publish on the use of BIM for PtD in 2013. In 2014, the beginning of China's participation in the research is observed, with 2022 being the year with the highest publication volume from a single country, featuring four publications by Chinese authors.

Figure 05 - physical-temporal distribution graph



Fonte: authors

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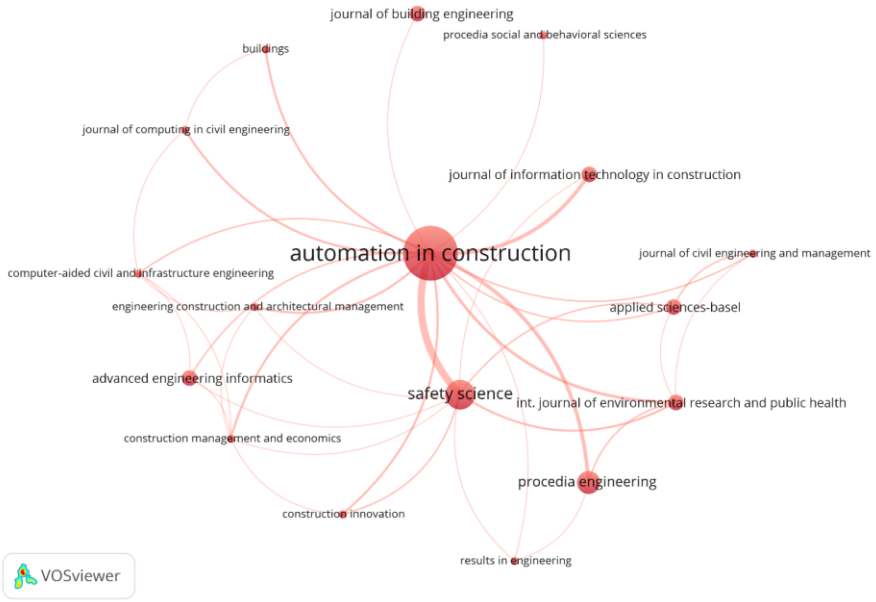
Figure 06 illustrates the bibliometric network of citation analysis among the journals. The arcs connecting the journals indicate that articles from one journal cite articles from another. The width of these arcs is directly related to the frequency of citations received or made by a given journal base concerning another. It is observed that among the analyzed journals, Automation in Construction and Safety Science have the widest arcs, standing out due to the presence of mutual citations between their journal bases. The network consists of a set of 17 journals interconnected, out of 19 journals total, with two journals not included in the network due to a lack of citation relationships with others. The size of the nodes indicates the number of citation relationships that the articles of a journal have with others, highlighting Automation in Construction as the journal with the most cited articles and those citing other journals.

Figure 06 – bibliometric network of journals.



Source: authors

Figure 07 indicates the bibliometric network with the most commonly used keywords in the articles. In this figure, the size of the node represents the number of times the keyword was used in the articles, and the arcs connecting them indicate that the keywords were used concurrently in articles. The thicker the arc, the more common the use of the keywords together. It is noticeable that the most common term is Building Information Modeling, with 32 occurrences, followed by design for safety (13), prevention through design (10), Construction Safety (9), Ontology (6), and the remaining terms occurring from one to three times in articles of the systematic review. The network is divided into sixteen color clusters, indicating keywords that exhibit similarities and interactions among related themes. For example, the dark green cluster indicates the possibility of using automatic risk detection rules for falls from heights. The pink cluster indicates the integration of ontology with the semantic web to perform automatic compliance verification in projects. The cyan cluster indicates the use of knowledge bases for

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developing design for safety plug-ins. The lavender cluster includes works related to fire escape routes. The formation of these clusters provides possibilities for future systematic reviews with these keywords, seeking to research more specific themes.

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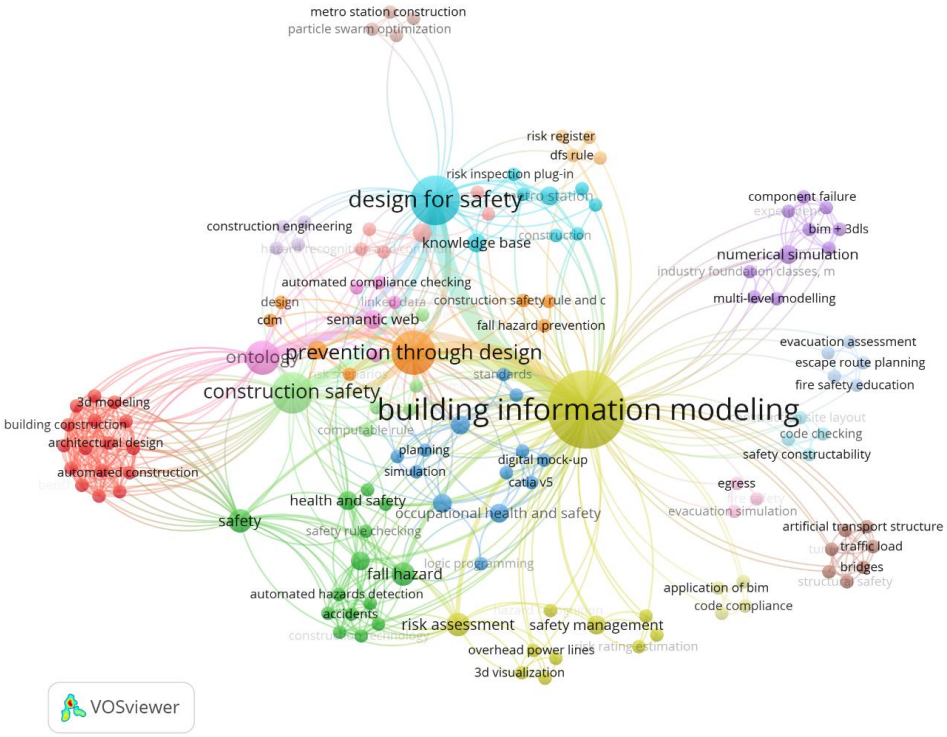
Figure 07 – bibliometric network of Keywords.



Source: authors

Figure 08 indicates the relationship over time of the most frequently used keywords. To do this, the bibliometric network of keywords appearing at least twice in the articles was considered. It is observed that among the more recent terms, subway station is noted, which may indicate a trend for future research involving PtD in subway station projects.

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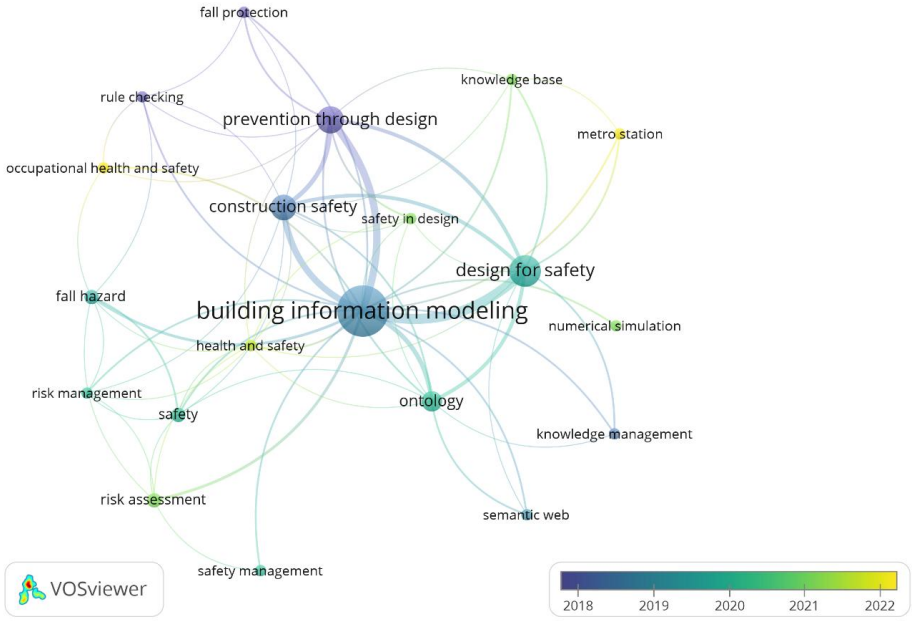
Figure 08 – bibliometric network with keyword periods.



Source: authors

Figure 09 represents the bibliometric network of co-authorship links. The arcs represent co-authorship connections between authors, and the stronger the connection, the larger the node with the author's name. From the image, it is possible to observe the formation of 25 color groups, denoting groups of authors who frequently collaborate in their publications. Most of these groups are dispersed without interconnections, suggesting that research on BIM tools for PtD is conducted with limited collaboration among authors, possibly due to institutional and/or regional restrictions.

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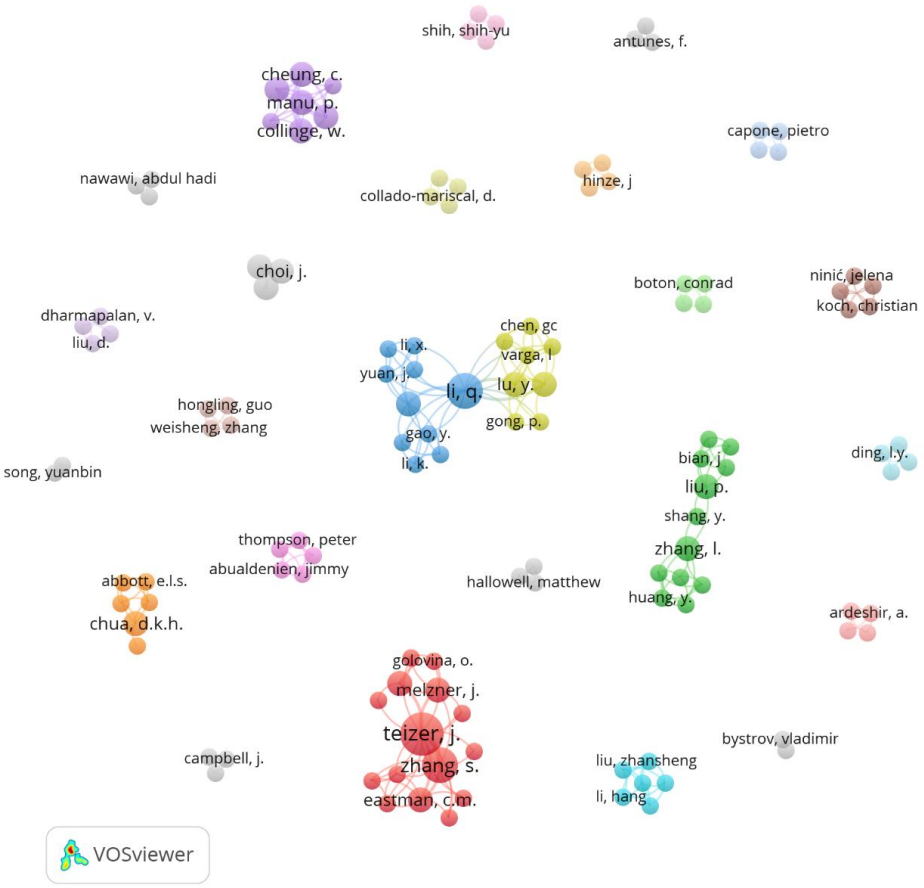
Figure 09 – bibliometric network of co-autorship



Source: authors

4 CONCLUSIONS

The use of BIM for PtD is a research topic with growing interest, and the increase in publications over the years, culminating in a peak in 2022, indicates greater awareness of the benefits of BIM in enhancing safety in construction projects, resulting in safer and more efficient working environments in the construction industry. The analysis of publication trends revealed that the research topic of PtD for subway station projects is a likely future trend. Furthermore, the global dissemination of this topic has been notable, with significant contributions from authors and institutions from various countries. China's prominence as a leader in this field underscores the international relevance of the BIM approach for PtD.

As limitations of this study, the restriction to analyzing articles in Portuguese, English, and Spanish, as well as the use of only four specific databases, may have limited the scope of the results. Additionally, bibliometric analysis, while providing insights into research trends, does not directly address the practical implementation of BIM for PtD in the construction industry.

Therefore, future research may focus on filling this gap by evaluating the real implementation and impact of these practices in the workplace. Questions about how BIM can be effectively applied for PtD, its impact on safety, and its limitations should be explored further.

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Moreover, broadening the scope to include a wider variety of languages and data sources could provide a more comprehensive understanding of BIM practices for PtD on a global scale. Investigating how these practices are implemented in the industry and their real impact on the safety and efficiency of projects is also essential to advance this research area and promote the development of safer and more sustainable cities.

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