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Digitalization of the Construction Industry Driven by AI and BIM: A Bibliometric Study Using CiteSpace and VOSviewer

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Abstract

The article which is a review of relevant literature from 2020 to 2024, explores the integrated application of Artificial Intelligence (AI) and Building Information Modeling (BIM) in a construction industry and its future development. Research indicates that AI can learn and apply big data through complex algorithms, thereby enhancing production efficiency and accuracy. BIM, on the other hand, manages the total life cycle of architectural design, construction or process through digital technology. Based on CiteSpace and VOSviewer tools, this paper answers the following key questions: 1) What is the current status of AI-BIM integration and what is its future development trend? 2) How is AI-BIM applied in the actual management of the construction industry? 3) What are the latest advancements in the research on AI-BIM integration? 4) What are the future application trends of purpose AI and BIM in the construction industry? This article provides a reference for understanding the current plan status about AI-BIM integration via a totally perfect bibliometric study and looks forward to the future of research directions.

Keywords

AI, BIM, Smart Construction, Construction Industry, Digitalization

1. Introduction

Industry 5.0, a totally fresh concept of industrial revolution proposed by the European Commission in 2020, is also known as the "Fifth Industrial Revolution" and has attracted much attention. The most important aspect of industry 5.0 is the emphasis on cooperation and symbiosis between man and machine. By combining human intelligence and creativity with machine efficiency and precision, higher levels of efficiency and production quality can be achieved. Thus, industry

5.0 facilitates the integration of man and machine, allowing machines to provide better tools, services and support to man through intelligent and automated technologies, rather than simply replacing human labor. As shown in Figure 1, the core concept of industry 5.0 is human-centric, sustainable and resilient. This means that man and machine work together and collaborate to achieve more efficient production operations and innovative discoveries.

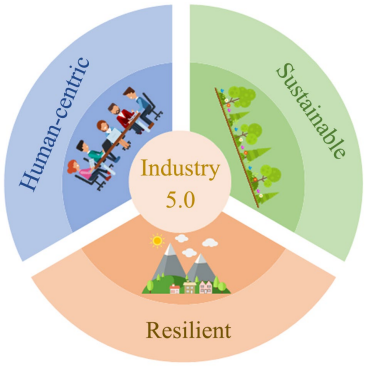

Figure 1. The core concept of Industry 5.0.

Figure 2 is to conduct a more comprehensive and scientific review of relevant literature on application of AI and BIM in the construction industry from 2020 to 2024. More specifically, AI-BIM integration can be understood as a flexible application of various AI technologies in BIM-based projects, ultimately making significant contributions to innovation in the construction industry in terms of improving efficiency, ensuring the safety of construction personnel, and intelligent construction [1]. Therefore, from a perspective of scientific value, it is helpful to grasp a current situation about the integrated development of AI and BIM and clarify a future research direction about a integration of AI and BIM [2]. As for reference value, our review can enhance knowledge about researchers and decision-makers in a construction field, and then guide them to implement far more AI-driven applications than machine learning algorithms in a wide range of applications about BIM projects.

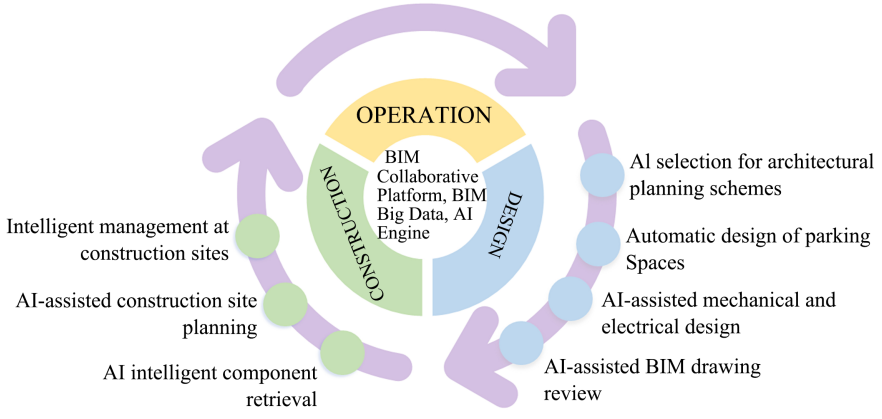

Figure 2. The combination of BIM and AI.

During a process about literature collation, we also identified four urgent issues that need to be addressed: 1) What is the current status of AI-BIM integration and how will it develop over time? 2) Whether this application about AI-BIM integration in actual construction management has been implemented. 3) What is the most advanced research on AI-BIM integration? 4) What are a future application trends about AI and BIM in a construction industry? To seek answers to these questions, we plan to conduct a comprehensive review based on bibliometric analysis and information analysis with the help of two literature analysis tools, CiteSpace and VOSviewer, to study an existing research work on an application about AI-BIM integration in a construction industry [3]. On the one hand, bibliometric research, as a statistical assessment, is able to serve an exact purpose in converting text into quantitative data. Charts and visual cluster analysis can not only measure the impact of articles and workers in various countries and fields but also capture a development process for target keywords. Meanwhile, information analysis focuses on elaborately explaining a content of representative papers, thereby enabling summaries and inferences to ensure in-depth investigations in certain key areas [4].

Therefore, by studying the literature from 2020 to 2024, it can be found that researchers have been conducting research on how to apply AI and BIM concepts to construction problems. This will bring many benefits, such as simplifying complex work processes, saving time and financial costs, reducing construction risks, and creating a safe working environment for staff.

However, the lack of research on actual project cases has made a connection between some theoretical discoveries and practice somewhat weak. There is a limitation of research depth. These papers fail to deeply explore their specific implementation and technical details in different specific scenarios.

So, a necessity of this literature review lies in highlighting these limitations of the application of AI and BIM integration in a construction industry, helping researchers to better break through these limitations in a future. Then, researchers should delve into some analysis methods, combine more empirical studies or case analyses, and explore a specific application and technical implementation of AI-BIM integration at actual projects.

2. Methodology

To better present a research process and screening approach about this paper, **Figure 3** visualizes a general framework based on a PRISMA flowchart for an exact purpose of critically screening literature related to AI, BIM and construction industry. That framework can best utilize quantitative and qualitative methods to eliminate biased conclusions [5]. It can be seen that a screening process begins with searching for an exact purpose of relevant articles in a web of science database for paper retrieval. When selecting literature, only sources from the Web of Science database were utilized, without conducting parallel searches across multiple databases. As a result, no duplicate literature entries were identified. Subsequently, a CiteSpace and VOSviewer software packages were used to generate in-

formation-rich conceptualizations that could systematically map and discover a structural and logical aspects of a prepared literature dataset [6]. Finally, information analysis of knowledge discovery is conducted from three perspectives to draw conclusions, with the purpose of having a deeper understanding of a development potential of AI in developing new BIM-related topics.

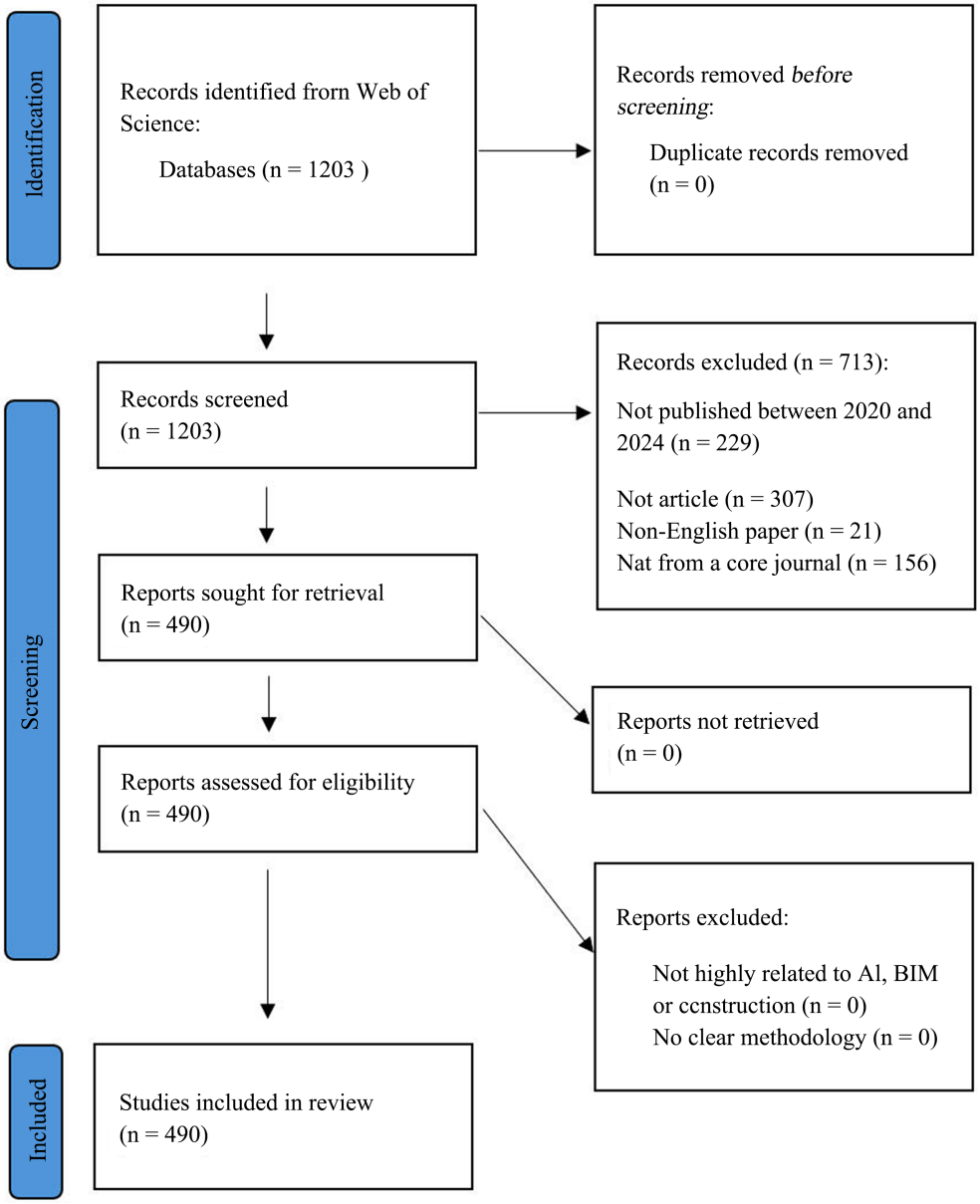

Figure 3. PRISMA flow diagram for the Systematic Literature Review (SLR).

Therefore, by observing **Figure 4**, it can be objectively found that the literature related to the application of AI-BIM integration in the construction industry is also increasing year by year [7]. This can also assist the researchers in quickly obtaining the current situation, determining typical research objectives, and tracking future goals.

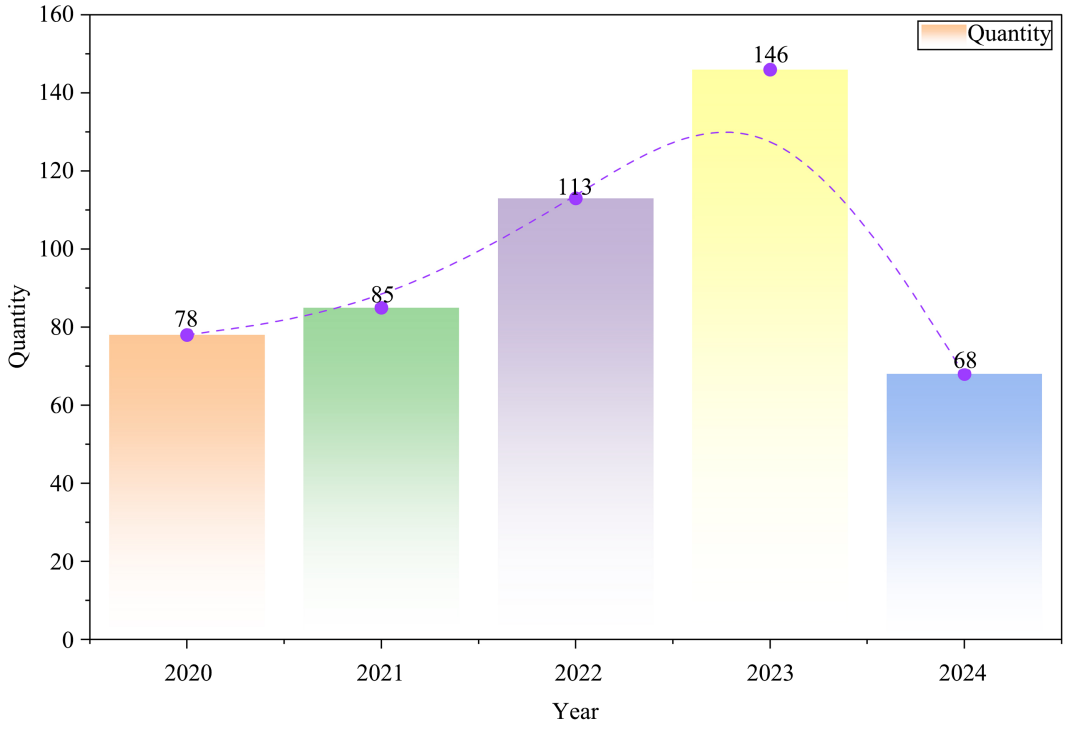

Figure 4. Yearly distribution of the used literature.

Bibliometry is a quantitative analysis method that uses several external characteristics about the scientific literature as the subject of research [8]. It uses mathematical and statistical ways to describe, assess and predict the current state and trends about science and technology development, and is characterized primarily by the production of quantitative information content [9].

There are many software technologies for accurate bibliometric analysis, and each tool has its own advantages or disadvantages. For example, VOSviewer is easy to use and has a quick convergence analysis or visualization process. It also gives a quick overview of the relevance of the literature [10]. Despite this, its main drawback is the lack of complex grouping or temporal analysis capabilities, and its processing capacity for the precise needs of big bibliographic databases is relatively limited.

CiteSpace visualization software can handle large-scale databases, address complex bibliometric analysis requirements, offer rich functions such as cluster analysis, keyword evolution, and co-citation networks, and make the results more persuasive and replicable [11]. In spite of that, it also has some shortcomings, such as a high reliance on data quality and accuracy, as well as potential computational efficiency issues when dealing with big data.

Therefore, I adopted the method of using CiteSpace and VOSviewer together and cross-mapping to conduct a bibliometric visual analysis of the literature on the development of the construction industry driven by AI and BIM, in order to depict the dynamic evolution of the research field [12]. Our goal is to identify the characteristics and representative details of the development of the construction

industry driven by AI and BIM from the perspectives of the current publishing situation, partnerships, research evolution and potential hotspots, helping researchers gain a deeper understanding of this field [13]. And the reason why I chose Web of Science as the database is that Web of Science is a highly comprehensive database that encompasses a vast number of scholarly publications dating back to 1896, spanning nearly all disciplines of scientific research. In comparison, while Scopus is also a large-scale academic database, the quality of its early records and coverage of non-English publications are somewhat inferior to those of Web of Science. IEEE Xplore and Engineering Village are specialized resources focused primarily on engineering and technological fields. Although they serve as valuable tools for in-depth disciplinary research, their applicability is more limited in interdisciplinary or broad-spectrum scientific inquiries.

Using CiteSpace and VOSviewer, we obtained the results and visualized the network through the following steps.

1) Data files of 490 articles compatible with a topic of a scientific network were searched, a process of deduplication was carried out and a final data was obtained from 2020 to 2024. Input "Artificial Intelligence" or "AI" or "BIM" (Topic) and "digitalization" or "digital transformation" or "smart construction" or "policy development" (Topic) and "construction industry" or "building industry" or "civil engineering" (Topic) on the WOS. 2) Select a period from January 2020 to December 2024. Define a source of a context processing terms, such as title, abstract, and author's keywords; Put selection criteria in the top 50. Using the top 50 citations as a screening criterion can effectively exclude irrelevant or low-quality studies, thereby enhancing the rigor of the selection process. This approach also helps avoid the analysis of excessively complex citation networks, ensuring that the resulting analysis remains both interpretable and methodologically stable. A data processing time for rational or special cases, too long for certain types of nodes of exact purpose, we define options, selecting a size and a blazer, a cut of elegant networks and a fusion of elegant networks to improve the processing efficiency and the legibility of a graph [14]. 3) A type of node selected by an author, respectively institutional and national, and obtaining a collaborative visualization of a network that explains some respective collaborative relationships between each node helps us to identify the most influential actors in the development of BIM and AI driven by the construction industry over the last 20 years. 4) A type of reference node, a cited writer and a cited journal were selected separately to obtain a common reference status for this area of study. 5) Selecting a type of key byte points to obtain a concurrency network of keywords can help researchers understand the evolution of research, current research points and possible tipping points. 6) An analysis of each part has allowed me to understand and study in depth a construction of AI that drives industrial development and a BIM knowledge framework, allowing us to establish a research line or priorities based on research results and predict future research lines [15]. A selection of conditions and requirements for some specific purposes of a entire document collection are detailed in **Figure 5**.

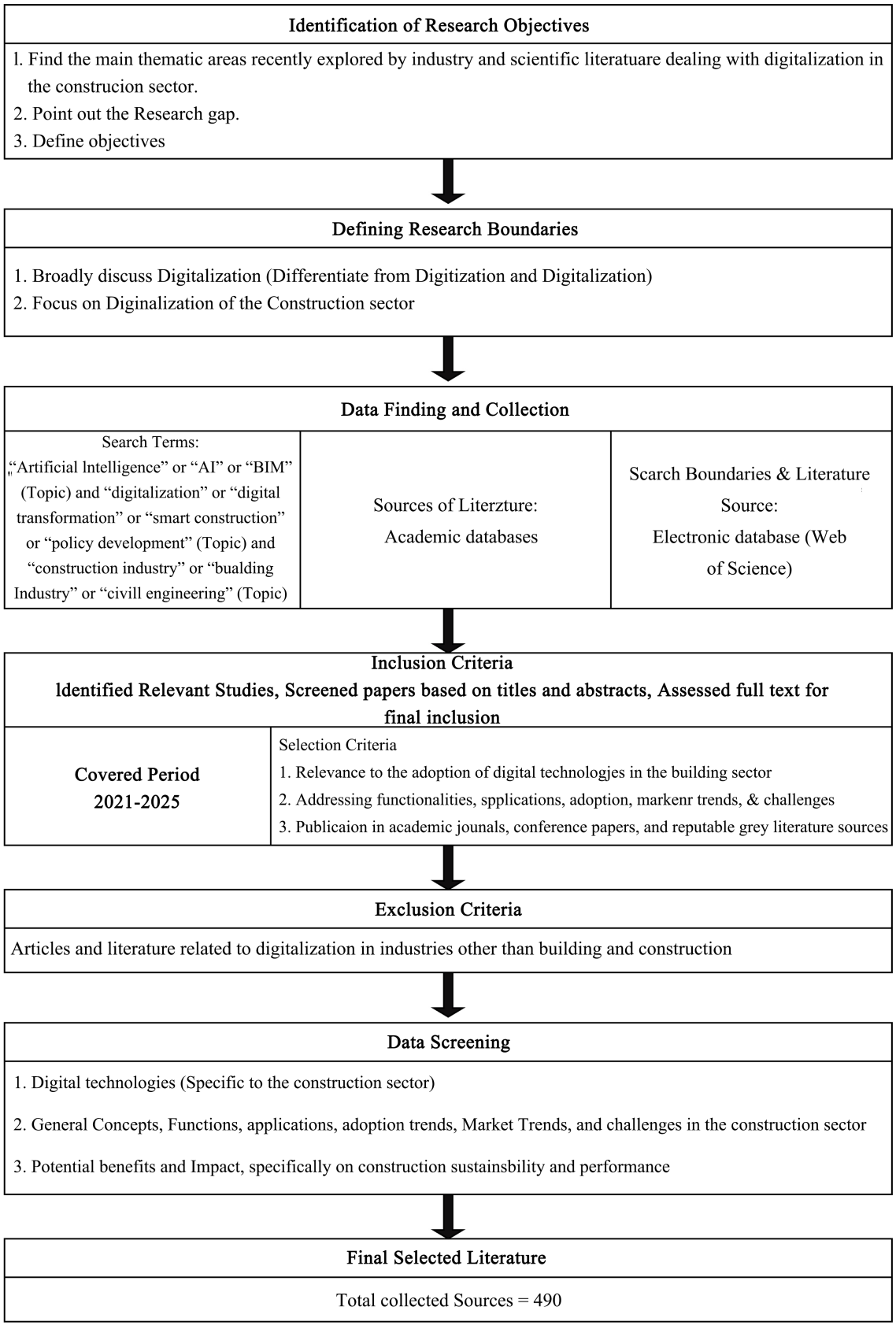

Figure 5. Overview of the literature review process methodology.

3. Review Results

3.1. Co-Authoring

Collaboration between academics from various countries and academic schools is important for advancing research disciplines. I used the "coauthor" function of the CiteSpace software and the "institution" as the basis of analysis [16]. To ensure the quality and readability of the built network, through a series of tests and errors, the value of the parameter "minimum number of source documents" is set to 13. Figure 6 and Figure 7 clearly show that China, the UK and Australia lead the research about digital AI for buildings in the construction sector. However, the relatively low number of citations of work by us, German and Italian researchers, as well as the overall intensity of interconnections, indicates a relatively low level of cooperation between researchers in the three countries.

To establish a research network of co-authors with CiteSpace, we set the "minimum number of published articles" at 3. Of the 421 researchers analyzed, only 40 reached this threshold. Figure 8 shows the most active researchers. Co-authors' contributions and collaboration models are an important part of research exploring the impact of AI on digital transformation in the construction sector. Through the analysis of the different areas of collaboration, it is possible to reveal the practical use of AI techniques in the digitization of buildings or their role as a catalyst in the development of the sector.

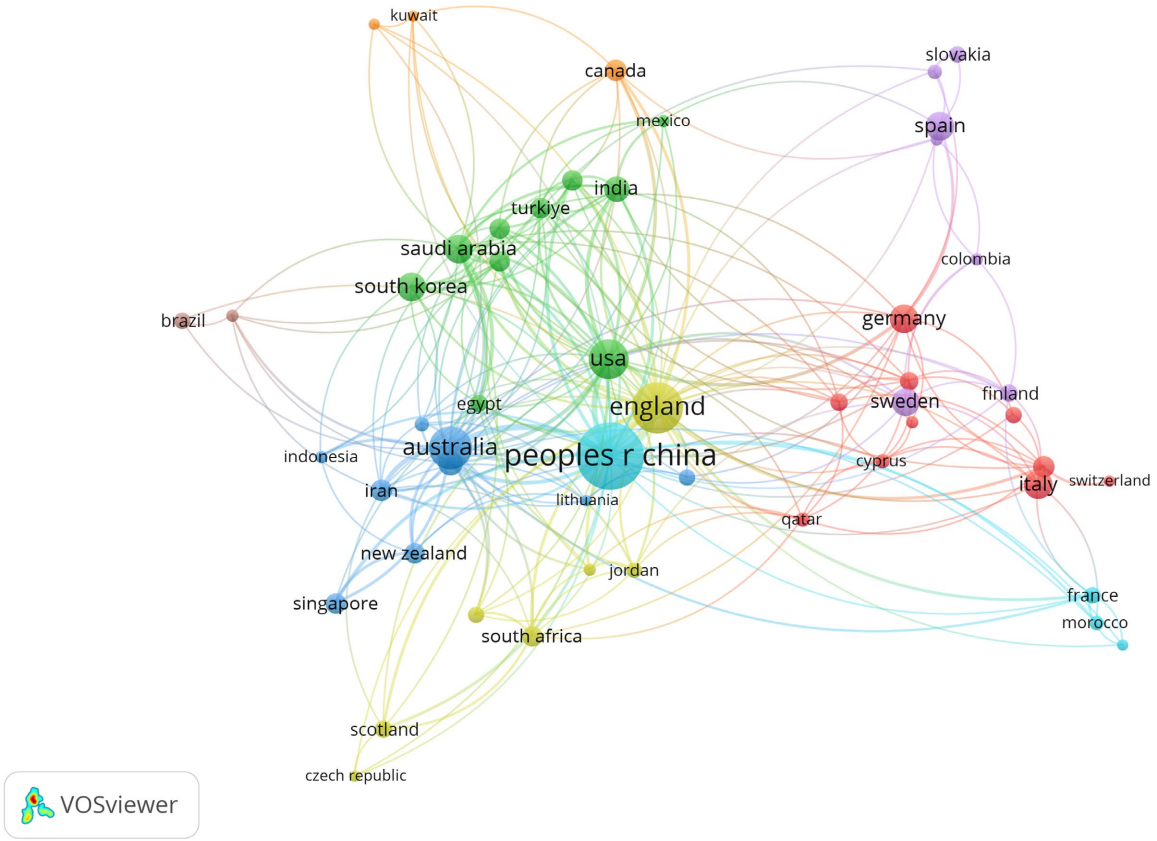

Figure 6. Co-authorship network based on the country/region.

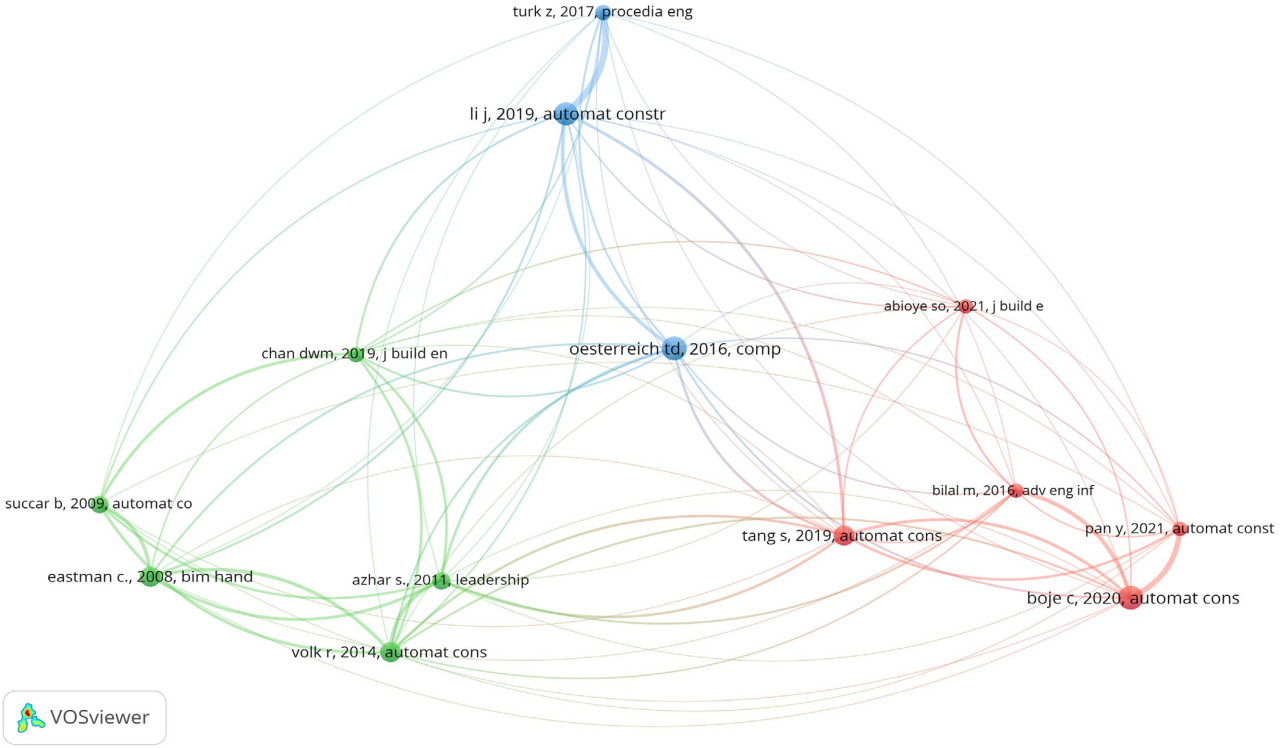

Figure 7. Co-authorship network based on the institution.

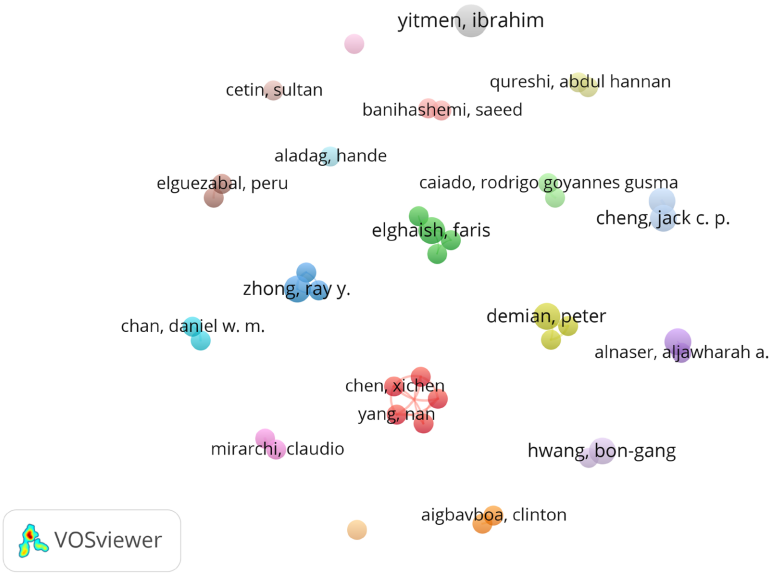

Figure 8. Co-authorship network based on the authors.

An analysis of the contributions of co-authors reveals that in a process of AI promoting a digitalization of the construction industry, experts from different fields have worked in collaboration and division of labor, jointly driving technological progress and industry innovation. This synergy based on co-authors not only accelerates the practical application of a technology but also makes a powerful foundation for an exact purpose in future development of architecture.

3.2. Co-Currence

Keywords co-occurrence networks are used to uncover key themes in a specific research area. To finish this goal, a co-occurrence analysis is performed about keywords extracted from all relevant literature and a relationship between a research subject and a method is explored. A parameter "minimum frequency of occurrence of keywords" is set to 5, and common keywords such as "AI", "big data" and "technology" are excluded. This selection process produced a network containing 73 keywords. In Figure 9, each node is a keyword, and its size is a frequency of occurrence in the title, summary and keywords of an article included. The thickness of a curve linking two key words indicates the frequency of their co-occurrence [17].

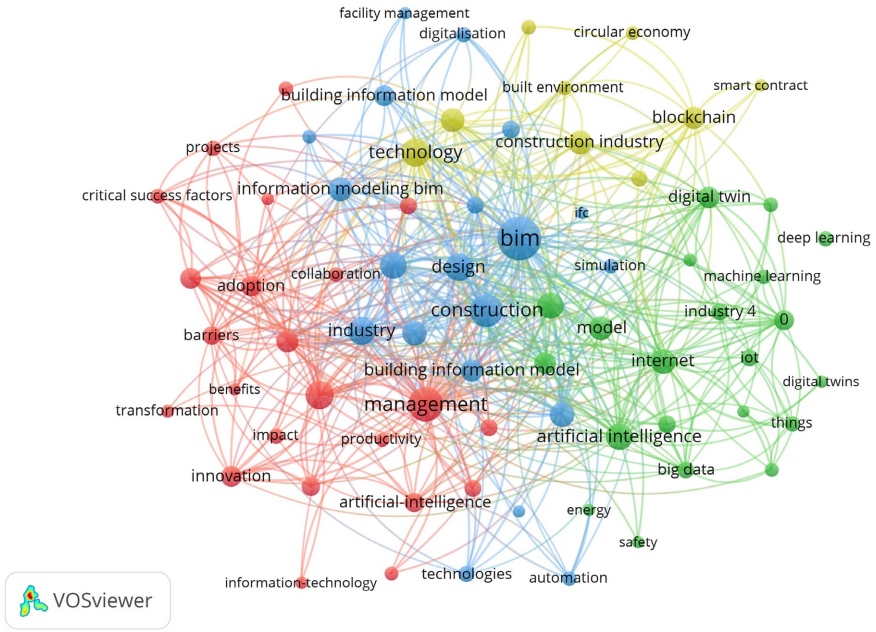

Figure 9. Keyword co-occurrence network.

These 73 keywords can be divided into two groups: "application" and "method". This review mainly analyses the keywords of a category "method". An examination of these keywords shows that they are mainly structured around four central themes: industry, smart construction, BIM and construction management. It should be noted that a total strengths of keywords related to industry, smart construction, BIM and construction management are of type 4.03, 3.15, 1.97 and 1.97. Therefore, in one field of AI at digital construction of a construction industry, the attention of academic community is mainly on digital transformation, closely followed by BIM models. On the other hand, subjects related to BIM or construction work received less attention. Figure 10 shows the top 15 research clusters. An interrelationship between blue, yellow, red and green clusters indicates that there is a strong and active network of collaboration between these areas.

Figure 10. Keyword co-occurrence cluster.

3.3. Co-Citation

Today, one method employed in this article is to accurately describe hotspots and trends by introducing Von information data into Science VOS. In the statistical model, a total of 11,426 keywords were examined from the selected files covering all aspects of the research. This might unnecessarily increase the complexity of the network. It should be pointed out that such a network is useful in intuitively revealing the knowledge structure behind the target scientific goals. A node corresponds to a specific keyword, and its size is proportional to the frequency of the keyword. A node represents a combination of two keywords. The thickness of the line indicates the distance between two nodes. What we do, what we do, what we do. For precise use, Table 1 combines a keyword list and similar concepts, where total links measure the sum of links of one node to other nodes [18]. We have noticed that the most common keywords are related to industry and BIM. Apart from these two terms, the term "construction management" is also often understood, which indicates that a person specializes in construction. Meanwhile, there is one strong correlation between architectural design and BIM, so they can be regarded as one of the most important applications about integrating BIM.

Table 1. Top keywords with the most frequent occurrence.

Top	Keyword	Cluster	Year
1	Industry 4	5	2022
2	Construction management	14	2022
3	Smart manufacturing	11	2022
4	Building information model	2	2022
5	Internet of things	7	2023
6	Smart construction	1	2022
7	Integration	9	2022
8	Visualization	10	2022
9	Construction 4	3	2023
10	Models	6	2023

Another network is from the perspective of the evolution of keywords over time, as shown on. One keyword was color-coded according to the average publication year in which they were studied in the paper. That is to say, the nodes with blue tones represent the hot keywords that have been paid attention to and discussed earlier, while the nodes with yellow tones represent the hot keywords that have only attracted great interest from researchers in recent years. Therefore, **Figure 11** can visually present an evolution trend of research hotspots. Based on the clustering outcomes, this provides a reference for the subsequent in-depth exploration of advanced research on a deep integration of BIM and AI. Silhou-ette assigned a value greater than 0.86 to each cluster, indicating that these extracted clusters have a high degree of homogeneity and intrinsic connection.

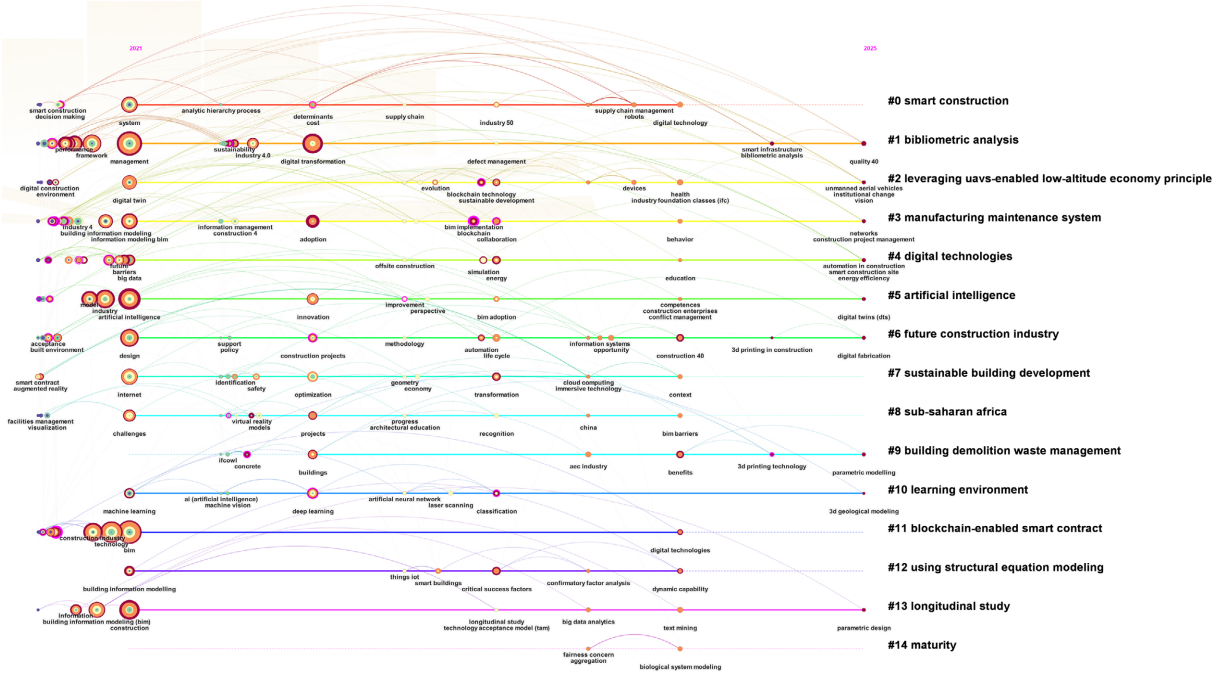

Figure 11. Keywords with the strongest occurrence bursts (Timeline).

The table combines a keyword list and similar concepts, where total links measure the sum of links of one node to other nodes. We have noticed that the most common keywords are related to industry and BIM. Apart from these two terms, the term "construction management" is also often understood, which indicates that a person specializes in construction. Meanwhile, there is a strong correlation between architectural design and BIM, so they can be regarded as one of the most important applications of integrating BIM.

Another network is from the perspective of the evolution of keywords over time, as shown on the left. First, through cluster analysis, cluster modules are generated. Then, the keywords in the clusters are sorted in chronological order by the year of their first appearance, thereby forming such a cluster timeline graph.

The sequence is from 0 to 14. The smaller the number, the more keywords are contained in the cluster. Each cluster is composed of multiple closely related words. Then, a value is given to each keyword. The one with the largest value in the same cluster is selected as the representative of that category and labeled.

4. Discussion

4.1. AI Based-Model Application

Faris Elghaish *et al.* Adopted one conceptual framework construction method, based on results of literature analysis, integrated one interrelationship of different Industry 4.0 technologies, and established a conceptual framework to promote the implementation of a circular economy in the construction industry. A conceptual framework integrating IoT, blockchain, AI and other technologies has been constructed. This framework can support the tracking and management of the entire life cycle of building assets (such as component performance monitoring, salvage value optimization, reuse/recycle timing judgment, etc.), and emphasizes the importance of circular supply chain management for both new and existing buildings. It has been made clear that the existing research pays insufficient attention to the circular economy transformation of existing cities and infrastructure, and there are relatively few practical explorations on the integrated application of technologies. It is proposed to enhance the application research of multi-technology integration, develop digital tools suitable for actual scenarios, promote the circular economy transformation of the construction industry from theory to practice, and provide support for the sustainable development of smart cities [19].

However, J. Kodikara *et al.* Employed the technology integration analysis method to analyze the compatibility of key technologies in the post-digital era (such as sensor monitoring, numerical simulation, big data analysis, digital construction management, etc.) with each link of non-adhesive pavement, and constructed a multi-link integration framework. It has been verified that this framework can enhance the accuracy and efficiency of each link: for instance, digital testing can obtain material performance data more accurately and optimize design schemes; Real-time monitoring of the construction process can reduce compaction defects. Performance prediction models can identify potential degradation risks in ad-

vance. It has been proven that the integrated model can reduce the full life cycle cost of non-bonded roads, enhance the durability of road surfaces, and provide a practical path for the innovation of road engineering technology in the post-digital era [20].

4.2. BIM Based-Model Application

One research methods adopted by R. Zimmermann *et al.* include qualitative in-depth interview method and prototype development method. Eight qualitative in-depth interviews were conducted with medium and large-sized architectural design, engineering and contractor companies in Denmark, covering most areas of the Danish AEC industry, to understand industry practices and demands of BIM-LCA. Subsequently, a prototype using IFC and 3D views was developed for the Danish context to verify whether these requirements could be met. It was found that the 3D view of the developed prototype met some requirements. In spite of that, due to the different workflows of each company, the feedback on the use of IFC varies. In the future, the development of BIM-LCA should solve the problem of model quality and support different workflows.

Maciej Wardach *et al.* Developed a parametric BIM model by using the numerical modeling method and demonstrated the application of this model in the entire life cycle stages such as design, construction, operation and maintenance (such as defect tracking, maintenance plan formulation, etc.) through case studies. The limitations of BIM technology in practical application (such as high cost and data interoperability issues, etc.) have been clarified, and the value of the combination of point cloud and BIM technology in the digital management of large-scale slab buildings has been verified, providing a technical reference for engineering practice [21]. As shown in **Figure 12**, this is the entire process of BIM application in the modeling of teaching buildings.

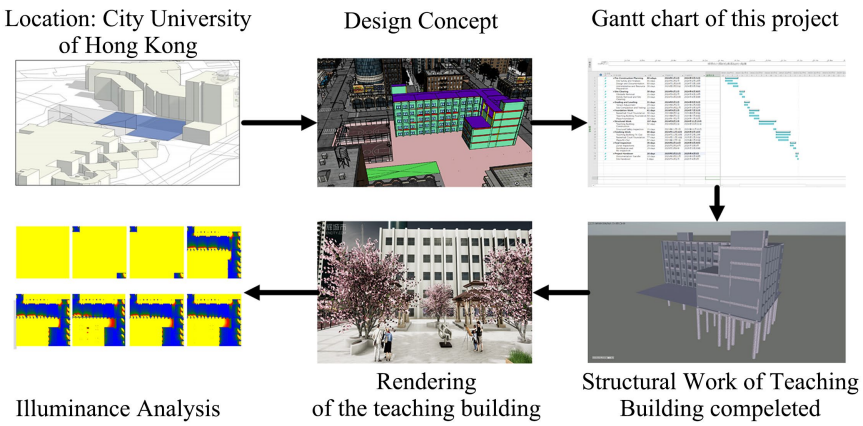

Figure 12. The application process of BIM.

Based on the analysis of the above literature, it is not difficult for us to obtain the answers to the four questions raised at the beginning of the article. At present, Building Information Modeling (BIM) has been developed into a digital backbone

of the architecture, engineering, and construction industry. Also, recent decades have witnessed the fast development of various AI techniques in reliably tackling a huge amount of data under complex and uncertain environments; Application about AI-BIM integration in actual construction management has been implemented; According to keyword clusters derived from the research, we determine six advanced research interests and discuss the state-of-the-art research, including automated design and rule checking, 3D as-built reconstruction, event log mining, building performance analysis, virtual and augmented reality, and digital twin; AI and BIM will be more comprehensively and systematically integrated in the construction industry, promoting its faster and better development.

5. Conclusions

Overall, the research objective of this paper is to conduct a systematic study and analysis of research papers on the application of AI and BIM in the construction industry over the past five years. Finally, a literature review will be compiled and a systematic visual analysis will be carried out using CiteSpace and VOSviewer, which is conducive to researchers obtaining research results more intuitively [22]. AI and BIM are intelligent machines and computer systems science that can learn and solve problems in a construction industry. It plays a significant role in Industry 5.0 in a digital age, driving a digital transformation of many industries, including a construction industry [23]. In a construction industry, AI and BIM offer advantages in handling a wide range of difficult and complex engineering and management issues that run counter to traditional computation-based solutions [24]. Therefore, by studying the literature from 2020 to 2024, it can be found that researchers have been conducting research on how to apply AI and BIM concepts to construction problems.

At present, BIM has been developed into a digital backbone of the architecture, engineering, and construction industry. Also, recent decades have witnessed the rapid development of various AI techniques that reliably tackle a huge amount of data in complex and uncertain environments. Applications about AI-BIM integration in actual construction management have been implemented. According to keyword clusters derived from research, we determine six advanced research interests and discuss state-of-the-art research, including automated design and rule checking, 3D as-built reconstruction, event log mining, building performance analysis, virtual and augmented reality, and digital twin. AI and BIM will be more comprehensively and systematically integrated in a construction industry, promoting its faster and better development.

The most important limitations of this study are as follows: Firstly, there is one limitation in the scope of this research. As a study is mainly focused on literature reviews or bibliometric analyses from 2020 to 2024, it is impossible to comprehensively cover some research achievements in earlier related fields. In addition, due to a selection of research tools (such as Citespace and Vosviewer), which limit the coverage of publication types and languages, there is a high possibility of missing some important research progress, resulting in an insufficient scope of litera-

ture research. Secondly, there is a limitation of data sources. Since this study only relies on results about bibliometric data analysis and citation analysis tools, in fact, there is likely to be a large amount of data in the literature that has not been included in an analysis. Meanwhile, due to resource limitations, literature information from certain regions or fields may not be fully presented, which will lead to a certain degree of deviation in research results. Then, there is a limitation in the research depth. This study mainly focuses on the current application status, research hotspots and future trends about AI-BIM integration, but fails to deeply explore its specific implementation and technical details in different specific scenarios.

Therefore, to overcome the above-mentioned research limitations, future research can consider following directions: Firstly, in terms of expanding the research scope, more literature analysis tools or methods should be actively introduced to more comprehensively cover research results over a longer period of time and in a wider range of fields. Secondly, it is necessary to have a wide range of rich data sources and collect and analyze as many original documents as possible, especially English ones, to make up for deviations caused by language and resource limitations. Finally, it is very important to conduct systematic research. For those problems existing in this current research (such as technical costs, privacy protection, etc.), systematic empirical research should be carried out to verify a scientific and feasibility of a conclusion. These articles, as a literature review, scientifically summarize a relevant literature on the application of BIM and AI in a construction industry over the past five years. It is believed that through the above measures, we will surely be able to reveal the current research status and future development direction of AI-BIM points more comprehensively.

So, a necessity of this literature review lies in highlighting these limitations of the application of AI and BIM integration in a construction industry, helping researchers to better break through these limitations in a future. Then, researchers should delve into some analysis methods, combine more empirical studies or case analyses, and explore a specific application and technical implementation of AI-BIM integration at actual projects.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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