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Review

Building Information Modeling Applications in Civil Infrastructure: A Bibliometric Analysis from 2020 to 2024

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Abstract: Building Information Modeling (BIM) has emerged as a transformative technology in the Architecture, Engineering, and Construction (AEC) industry, with increasing application in civil infrastructure projects. This study comprehensively reviews the research landscape of BIM applications in civil infrastructure through bibliometric analysis. Based on data from the Web of Science database, 646 relevant papers published between 2020 and 2024 were collected, and 416 papers were selected for in-depth analysis after screening. Using bibliometric methods, the analysis reveals the evolution of research trends, identifies key contributors and influential publications, and maps the knowledge structure of the field. Our study shows a significant increase in research output over the past five years, particularly in studies focusing on the integration of BIM with emerging technologies such as Digital Twins, the Internet of Things (IoT), and Machine Learning. The results indicate that the United States, China, and the United Kingdom lead in terms of research output and citation impact. Additionally, based on clustering results and representative keywords, several key research clusters were identified, including BIM in infrastructure lifecycle management, BIM collaboration in large-scale projects, and BIM for sustainable infrastructure design.

Keywords: BIM; civil infrastructure; bibliometric analysis; research trends; construction technology

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1. Introduction

BIM is a process based on three-dimensional digital technology, enabling the creation and management of digital models that cover all stages of a project's lifecycle. BIM not only includes geometric information about the building but also integrates non-geometric information related to cost, materials, and construction processes. It is designed to facilitate collaboration among various stakeholders, enhance design and construction efficiency, and reduce waste and cost overruns. In the civil infrastructure domain, BIM is widely applied across multiple subfields, including transportation, bridges, tunnels, water resources, and energy [1].

In recent years, BIM has evolved by incorporating cutting-edge technologies such as Big Data, Artificial Intelligence (AI), the Internet of Things (IoT), drone technology, and Geographic Information Systems (GIS), deepening its application in civil infrastructure [2]. For example, Oreto et al. combined Lifecycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) to improve the sustainability of road pavement management [3]. Liu et al. explored how to use point cloud data and deep learning techniques to convert on-site bridge scan data into BIM models, which enhanced collaboration efficiency in large bridge projects, particularly in managing interdisciplinary teams and sharing detailed engineering data.

Additionally, with the integration of BIM, IoT sensors, and Artificial Neural Networks, BIM is playing an increasingly important role in infrastructure health monitoring and intelligent management [4,5].

Despite the growing demand for BIM in the construction industry, there are still some limitations and challenges in its application. While collaboration in large projects is one of BIM's strengths, it also presents challenges. Designers from different disciplines (such as architecture, structural engineering, and mechanical–electrical engineering) may use different software or standards, leading to difficulties in model integration and information exchange. Currently, there are multiple BIM software platforms on the market (such as Revit and ArchiCAD), but they often suffer from poor compatibility, particularly when collaborating across companies or disciplines, leading to issues in data import/export and model conversion. Some researchers have sought to address these issues. For instance, Girardet et al. explored the application of parametric BIM in bridge design, aiming to improve design efficiency through a parametric file capable of generating all types of bridges [6]. Furthermore, while BIM adoption is gradually becoming widespread, the levels of standardization across countries and regions vary, causing inconsistencies in cross-national or cross-regional projects. These disparities in standards can lead to challenges in data format compatibility and model sharing, ultimately affecting collaboration efficiency [7].

Researchers have reviewed recent advancements in BIM technology within the construction industry. A preliminary search of relevant keywords reveals that most prior reviews focused on the traditional application frameworks of BIM, primarily centered on how BIM improves efficiency and reduces costs in civil infrastructure projects [8,9]. Other reviews have emphasized how BIM enhances the accuracy of cost estimation, facilitates collaborative decision-making, and optimizes resource utilization [10,11]. These qualitative review papers summarize various BIM applications from a technical perspective, often supported by specific case studies. However, they lack a multidisciplinary examination of the knowledge, theories, applications, and trends within the field.

This paper aims to fill this research gap by conducting a comprehensive bibliometric analysis, highlighting key research foci, and constructing a knowledge framework for BIM applications in civil infrastructure. The structure of this review is as follows: Section 2 presents a literature review on the application of Building Information Modeling (BIM) in civil infrastructure; Section 3 identifies the search keywords related to BIM technology and construction management in the industry, collecting and refining target papers; Section 4 identifies major research trends through bibliometric analysis; Section 5 provides a detailed analysis and discussion of the data results; and Section 6 concludes the paper by analyzing the limitations of current research and summarizing the contributions of this study.

2. Literature Background

2.1. Review of BIM Implementation Across Different Countries and Time Periods

Saka et al. employed scientometric analysis and meta-synthesis methods to specifically examine the use of BIM in the AEC industry within Africa, a region that is relatively underrepresented in existing BIM research [12]. Their study primarily focuses on the adoption and implementation of BIM in Africa's AEC sector, highlighting the challenges and barriers encountered in promoting BIM across different regions. Salah et al., through various case studies, demonstrated the application of Historic Building Information Modeling (HBIM) in historic transportation infrastructure, providing detailed insights into architectural design, structural characteristics, and material usage [13]. Bradley et al. utilized a mixed-methods approach, integrating both quantitative and qualitative analyses to categorize and review literature on the application of BIM in infrastructure projects [14]. Their comprehensive review, conducted from a contractor's perspective, offers a thorough evaluation of current research and industry developments. Shishehgarkhaneh et al. identified several potential areas for future research, such as circular economy, risk management, smart villages, and infrastructure construction projects, providing a clear direction for researchers in the field [15]. Their work also explored the applications of emerging technologies like blockchain in supply chain management, smart contracts, BIM, IoT, and sustainability. Despite the broad geographical scope of these studies, the application of BIM technology in the construction industry remains predominantly concentrated in a few countries, particularly China and the United States [16]. Significant disparities exist in the adoption and standardization of BIM across different nations, with limited research focused on other regions, which may restrict the global applicability of the conclusions drawn from these studies.

Liu et al. conducted a scientometric analysis of global BIM research, utilizing a substantial dataset comprising 1455 academic publications to uncover key research trends and emerging topics within the field [17]. Although their study provides a comprehensive overview of the developments in BIM research from 2004 to 2019, it does not include recent advancements, potentially overlooking the latest research trends and technological innovations. Similarly, Zhao's research primarily focuses on BIM-related literature published between 2005 and 2016, lacking coverage of more recent studies (from 2017 onwards), which may limit its ability to reflect the current trends and directions in BIM research [18].

2.2. Literature on the Integration of BIM with Other Technologies

Castañeda et al. conducted a systematic review covering 39 distinct applications of BIM in road infrastructure projects, categorizing these into 9 major groups and identifying 26 technologies used in combination with BIM, such as GIS and laser scanning [19]. Liu et al. systematically analyzed the integration methods of BIM and GIS at the data, process, and application levels, examining various standards and technologies like CityGML, IFC, IndoorGML, and InfraGML to evaluate their effectiveness across different application scenarios [20]. In the context of BIM and GIS integration, Cao et al. proposed a Quantitative Risk Assessment (QRA) method based on BIM and GIS technologies, using case studies of bridges, tunnels, and embankments to illustrate multi-hazard risk propagation and the vulnerability of railway systems [21]. Xia et al. provided a comprehensive review of the current state of GIS and BIM integration within digital twin technology, focusing on its application in the sustainable design of smart cities [22]. In studies examining the joint application of BIM and IoT, Ruiz-Zafra et al. introduced a framework called IFC+ for integrating IoT technologies during the early stages of building design [23]. Their research detailed the data requirements for IoT across different phases of the building lifecycle, particularly emphasizing real-time monitoring needs during design and construction stages, thus laying a foundation for intelligent BIM applications. Both Huang et al. [24] and Altohami et al. [25] also explored the fusion of BIM with IoT, analyzing its implications for smarter construction practices. Ślusarczyk et al. reviewed the application of various machine learning techniques within BIM, including neural networks, support vector machines (SVM), decision trees, and Bayesian networks, highlighting the potential of these methods to enhance BIM capabilities [26]. Rachmawati et al. delved into the integration of Unmanned Aerial Vehicles (UAV) with other digital technologies, identifying key trends like automated progress monitoring, UAV inspection planning, real-time video streaming, and the development of parametric models for heritage buildings [27]. Hakimi et al. discussed the combined application of BIM with multiple digital technologies such as DT, AI, and IoT [28]. Radzi et al. examined the use of DT and BIM across various stages of the construction lifecycle, including planning, design, construction, operation, and decommissioning [29]. Although these studies extensively explore the integration of emerging technologies like DT, AI, ML, and IoT in BIM, they highlight a significant gap in the effective integration of these technologies to achieve true intelligent management in construction projects.

2.3. Literature on the Application of BIM in Various Architectural Scenarios

Shou et al. conducted a comprehensive review utilizing over 40 academic studies and 24 industrial case studies, focusing on the implementation of Building Information Modeling (BIM) across various stages of the project lifecycle, including design, construction, and operations [30]. Their work places particular emphasis on a comparative analysis between building projects and infrastructure systems. Similarly, Costin et al. explored the integration of BIM with other domains such as Bridge Information Modeling (BrIM) and Civil Information Modeling (CIM), highlighting the potential for BIM to enhance multi-disciplinary approaches in civil infrastructure projects [31]. Satyanaga et al. delved into advanced methodologies for integrating geotechnical engineering data within BIM frameworks, demonstrating its practical application through case studies like the integration of I-BIM with Plaxis 3D [32]. Their findings underscore BIM's potential to address complex geological structures and soil information effectively. Although these studies provide detailed insights into the use of BIM in areas such as bridges, highways, and geotechnical engineering, they primarily focus on a limited number of application scenarios. There remains a noticeable gap in research on BIM's integration within other transportation infrastructure sectors, such as ports, airports, and tunnels, and a lack of comprehensive studies addressing BIM's application across various scenarios in the construction industry.

Kivits et al. conducted an in-depth study on the application of BIM throughout the stages of design, construction, operation, facilities management, and decommissioning, offering a comprehensive perspective on asset lifecycle management [33]. Their research utilized extensive academic literature and case studies, including examples like the Sydney Opera House, the Construction-Operations Building Information Exchange (COBie) project, and the U.S. General Services Administration (GSA), to illustrate BIM's role in facilities management. Jrade et al. explored the integration potential of BrIM with LCA and Life Cycle Costing (LCC) tools, especially within the context of Construction 4.0 [34]. This integration aims to enhance the precision of environmental impact and cost analyses in bridge design and construction. Xue et al. provided a systematic review of image-based 3D reconstruction technologies for monitoring construction progress, summarizing current technological approaches, and developing a research map through literature analysis [35]. They examined image acquisition devices, point cloud generation methods, and semantic recognition techniques, evaluating their applicability in various construction scenarios. Collao et al. reviewed the application of visual programming (VP) tools like Dynamo, Grasshopper, and Python in infrastructure projects, analyzing multiple case studies to assess their effectiveness in automating processes across different types of infrastructure projects, such as bridges, tunnels, and roads [36]. Volk et al. addressed various aspects of BIM's implementation in existing buildings, covering functional, informational, technical, organizational, and legal challenges, thus providing a holistic view of BIM's role in building lifecycle management [37]. Bouhmoud et al. employed a combined approach of scientometric analysis and scoping review to deeply explore the use of BIM in LCCA [38]. This hybrid methodology revealed key concepts and trends linking BIM with carbon emission studies. Ciotta et al. focused on the application of BIM in structural engineering, detailing its use in design, analysis, construction, and maintenance phases [39]. Their study compared different BIM tools, such as Revit and Tekla, highlighting their strengths and limitations, as well as their integration capabilities with other structural analysis software like SAP2000 and ETABS. Despite these studies' focus on BIM's role in complete asset lifecycle management, there remains a broader scope for its application within civil infrastructure. The current research often limits itself to specific aspects of BIM, which falls short of encompassing its full potential within the construction industry.

Therefore, this study aims to bridge this gap by employing bibliometric methods to analyze the use of BIM in civil infrastructure projects and to categorize these applications systematically.

3. Methods and Materials

3.1. Research Framework

Compared to traditional systematic reviews and other literature review methods, bibliometric analysis offers significant advantages when studying the application of BIM in civil infrastructure. Traditional reviews often lack systematic and quantitative analysis, whereas bibliometrics uses a data-driven, objective approach to comprehensively cover a large volume of literature, revealing research trends, identifying key contributors, and highlighting research hotspots. With the application of tools like Bibliometrix, researchers can accurately filter and visualize literature data, overcoming the limitations of traditional reviews in handling interdisciplinary research and large datasets, thus providing clearer guidance for future research directions.

The bibliometric analysis framework of this study is illustrated in Figure 1. First, the basic information of relevant literature was extracted, including publication year, source of publication (journals, countries, and institutions), authors, citations, and keywords, providing foundational data for subsequent analysis.

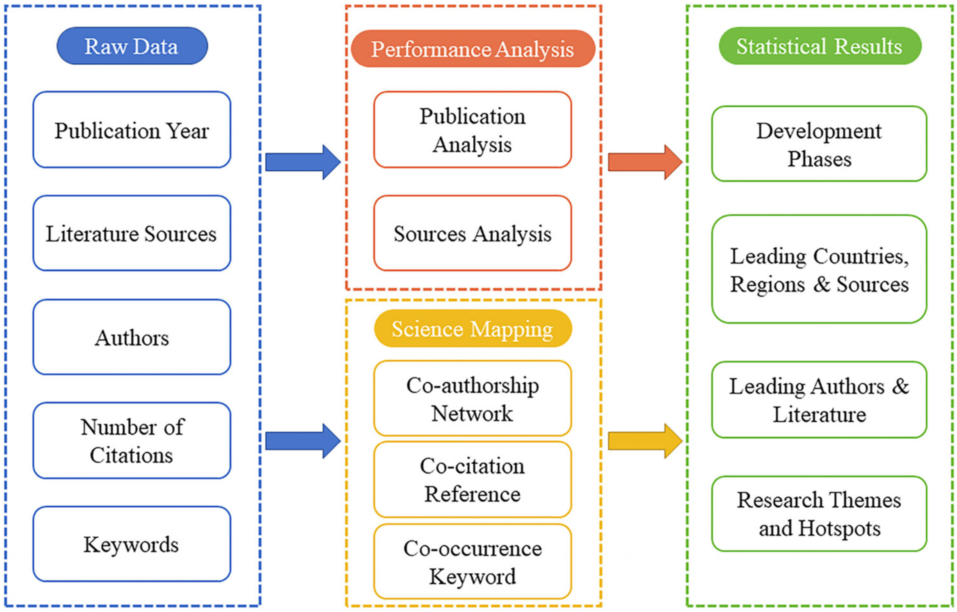

Figure 1. Research framework.

Two bibliometric techniques were applied in this study: performance analysis and scientific mapping [40]. Performance analysis is a commonly used method in bibliometrics, primarily employed to quantify and evaluate research output and impact within a specific field, author, institution, country, or journal [41]. It measures productivity and impact through indicators such as the number of publications, citation counts, and the H-index, offering insights into the productivity and influence of countries or regions, sources, and authors [42]. This technique was used to analyze the publication years and sources in this study.

Scientific mapping, on the other hand, visualizes the relationships between different research entities (e.g., authors, institutions, countries) through networks, enabling researchers to gain a more intuitive understanding of the knowledge structure and developmental dynamics of a particular field. The core techniques include co-authorship networks, co-citation reference analysis, and keyword co-occurrence analysis. In this study, scientific mapping was employed to explore the knowledge structure and evolving dynamics of BIM-related knowledge in the construction industry.

Finally, based on performance analysis and scientific mapping, a comprehensive quantitative analysis was conducted on the development stages of the research field, key countries or regions, institutions and major journals, influential authors and literature, as well as research themes and emerging hotspots.

3.2. Data Extraction and Collection

To ensure a reliable research process, this study strictly adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [43,44]. The PRISMA framework, as illustrated in Figure 2, consists of three key stages: (i) the retrieval process, (ii) screening—comprising both the first and second screening stages, and (iii) final selection. This structured approach ensures a comprehensive and meticulous review process, enhancing the rigor and transparency of the study.

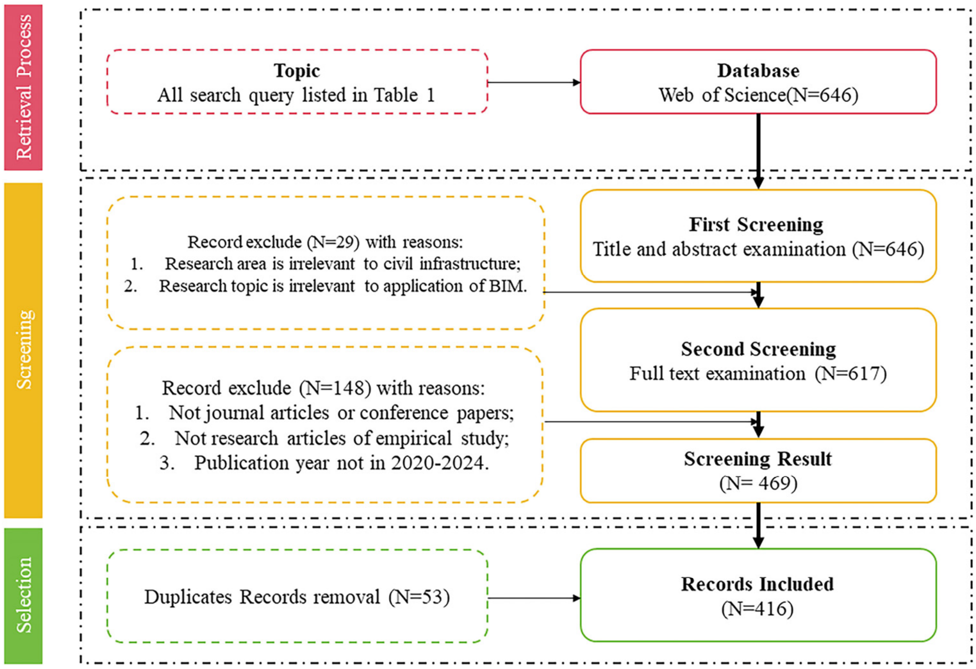

Figure 2. PRISMA Flow Diagram.

3.2.1. Databases Accessed

In the retrieval process, a systematic search strategy was implemented. First, the Web of Science (WoS) online database was selected as the primary data source. Web of Science is widely used by researchers in engineering and management due to its extensive coverage of journals across various disciplines, making it well-suited for interdisciplinary research. It also includes the latest cutting-edge results on BIM in the construction industry [45]. The integration of this online database provided essential support for conducting a comprehensive search of relevant literature in the fields of engineering management and construction science.

3.2.2. Query Strategy

This study explores the application of BIM in civil infrastructure during the period from 2020 to 2024. The literature search for this study was conducted up until 9 September 2024, using a combination of search queries inspired by previous research, as shown in Table 1, to ensure the retrieval of the most relevant and comprehensive studies. The retrieval process was further optimized by using advanced search categories in combination with Boolean operators, enhancing the precision of the search results.

Table 1. Search Query.

Database	Search Query
Web of Science (n = 646)	TS = ("BIM" OR "Building Information Model *") AND TS = ("civil infrastructure" OR "infrastructure" OR "civil engineering") AND TS = ("building *" OR "bridge *" OR "road *" OR "tunnel *" OR "dam *" OR "highway *" OR "railway *" OR "airport *" OR "port *" OR "pipeline *" OR "water supply" OR "sewerage" OR "power grid" OR "telecommunication")

3.2.3. Include and Exclude Criteria

To ensure a comprehensive exploration of the literature on the application of BIM technology in the construction industry, we implemented a rigorous inclusion and exclusion protocol, as illustrated in Figure 2. The screening process was divided into three stages to refine the initial pool of 646 articles extracted from the database.

- Stage 1: The first screening aimed to ensure relevance. Only articles focused on BIM and explicitly addressing its applications in engineering were retained. In this initial screening, 29 articles were deemed irrelevant and discarded, leaving 617 articles for the second screening.
- Stage 2: The second screening focused on ensuring the quality and specificity of the selected literature. Only empirical studies published between 2020 and 2024, including journal articles or conference papers, were chosen. This step eliminated 148 articles, reducing the pool to 469 articles.
- Stage 3: In addition to the primary search mechanism, we manually reviewed the reference lists of selected articles, tracked citations of key papers, and consulted field experts to verify the relevance and importance of the selected literature. To avoid redundancy, 53 duplicate articles were removed. Finally, 416 articles were considered suitable for this study.

The literature review utilized Bibliometrix [46] and VOSviewer [47] to conduct bibliometric analysis and generate networks, which were divided into several key sections. It is essential to explain the meaning behind the parameters used to generate these graphs, as each parameter reflects a different evaluation aspect.

For example, basic statistical functions in Bibliometrix assess fundamental characteristics of the literature, such as the number of publications, citation counts, and H-index, which help quantify research productivity and impact. Through time-series analysis, Bibliometrix can track changes in keywords and research themes over time, allowing for an assessment of the field's dynamic development.

VOSviewer is a specialized tool for constructing and visualizing scientific knowledge networks, widely used in bibliometric studies. In network graphs, the size of nodes typically represents the output or impact (e.g., citation count) of the literature, authors, institutions, or keywords. The density of lines between nodes indicates the frequency of collaboration or citation, with denser connections representing closer academic ties. VOSviewer also clusters the network using color to categorize different research groups or themes. The number and composition of clusters help evaluate the various research directions and points of interest within the field.

It is important to highlight that in this study, all keyword analyses were conducted using Author Keywords rather than Keyword Plus, as Author Keywords more accurately capture the core content, emerging trends, and research hotspots within the field [48]. While Keyword Plus may offer a broader range of related terms, it does not necessarily reflect the central themes of the articles with the same precision. In the analysis of research trends, focal areas, and the knowledge structure of the field, the use of Author Keywords ensures a higher degree of accuracy and relevance.

4. Results

4.1. Publication Outputs and Trends

According to the bibliometric analysis of literature from 2020 to 2024, research on BIM in the civil infrastructure domain has shown a steady growth trend, with a total of 416 papers addressing this topic, reflecting an annual growth rate of 2.27%. Figure 3 clearly illustrates the key information from these papers. As of September 2024, a total of 1352 authors have contributed to these publications. The rate of international collaboration stands at 28.61%, with an average of 3.97 co-authors per paper, indicating that research in this field is highly collaborative on a global scale and multidisciplinary in nature. The research papers have been cited an average of 14.52 times, highlighting the significant impact of BIM research on civil infrastructure. The average age of the cited literature is 1.93 years, demonstrating that the research in this field is at the forefront of current developments. The substantial number of references (20,002) and keywords (1310) further underscores the wide and deep application of BIM in civil infrastructure, covering a broad range of topics from technology to management.

Figure 3. Overview of publications.

Figure 4 presents a Three-field plot, illustrating the relationships between countries (AU_CO), authors (AU), and author keywords (DE). This visual representation highlights the international collaboration in BIM research within civil infrastructure, the key contributing authors, and the associated research keywords.

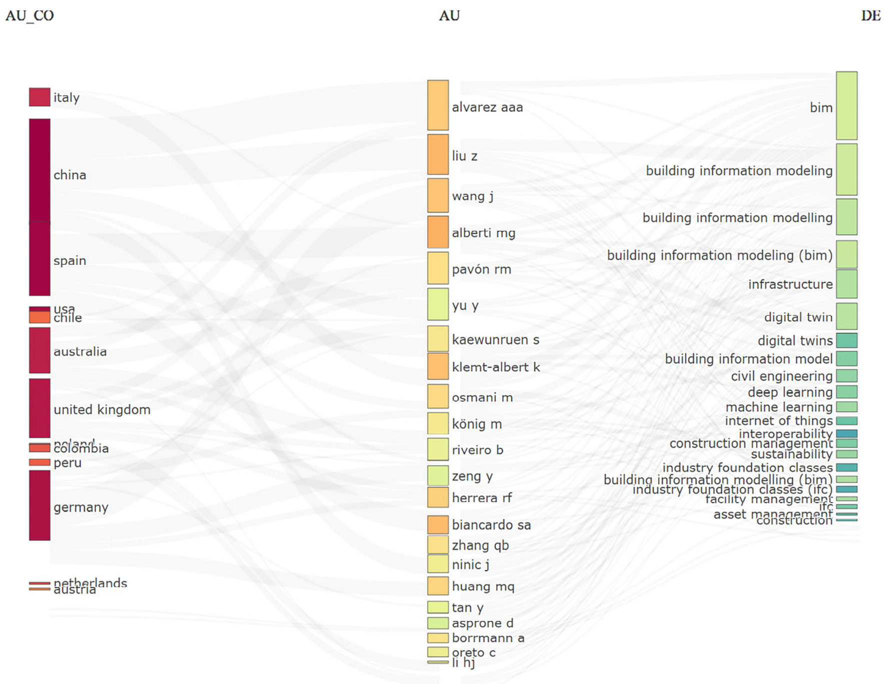

Figure 4. Three-field plot of AU_CO, AU, and DE.

According to the bibliometric analysis, researchers from countries such as Italy, China, and Spain dominate the BIM research landscape, demonstrating the global influence of BIM studies. Prominent authors include Alvarez AAA, Liu Z, and Wang P, whose research keywords are concentrated in areas such as "Building Information Modeling", "Digital Twin", and "Infrastructure". This reflects the close connection between BIM technology and emerging topics like digital twins, infrastructure development, and sustainability.

Figure 5 displays a statistical chart regarding the countries of corresponding authors in the field of BIM research. China leads in terms of the number of publications, followed by Germany, Spain, and the United States, which are major contributors to BIM research. The chart categorizes publications into single-country publications (SCP) and multi-country collaborations (MCP), with blue representing SCP and red representing MCP.

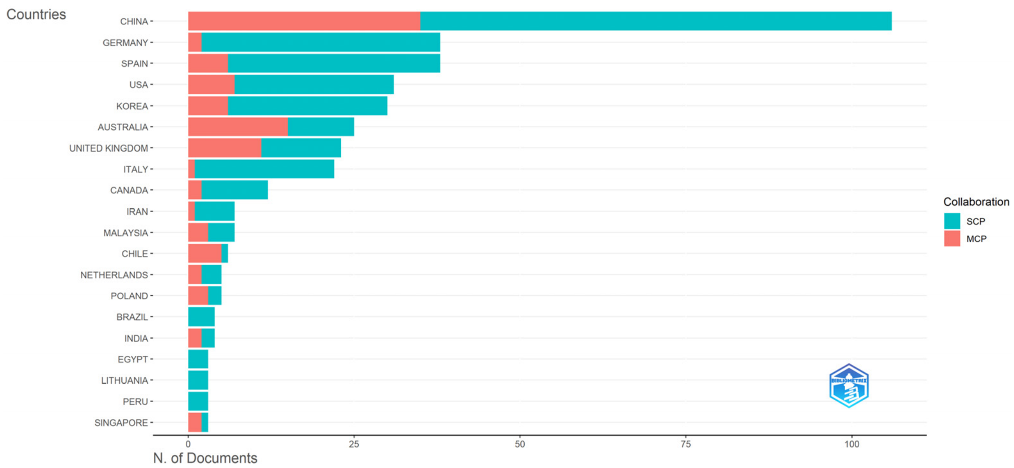

Figure 5. Corresponding author's countries.

- SCP: Number of articles published in a single country. This refers to the number of papers with authors from that country only.
- MCP: Number of articles published by multiple countries. This refers to the number of publications with authors from more than one country.

The results indicate that countries like China, Germany, and Spain primarily conduct single-country research, while countries such as the United Kingdom, the United States, and Australia have a higher proportion of multi-country collaborative research. This suggests that researchers from these nations are more inclined to collaborate with other countries, collectively advancing BIM technology in civil infrastructure. The findings highlight the globalized nature of BIM research and the significance of international cooperation in this field.

Figure 6 is a visualization of the research output by country, showcasing the number of publications related to BIM research. Different colors are used on the map to represent the scientific output of each country, with the intensity of the color being proportional to the volume of output. Specifically:

- Dark blue represents countries with a scientific output of 100 or more publications, primarily concentrated in China, indicating a significant research output in this field;
- Light blue (including two gradients: 51–100 and 1–50 publications) is distributed across North America, Europe, and parts of Asia and South America, indicating moderate research output in these regions;
- Gray represents countries with no scientific output or regions where data are unavailable.

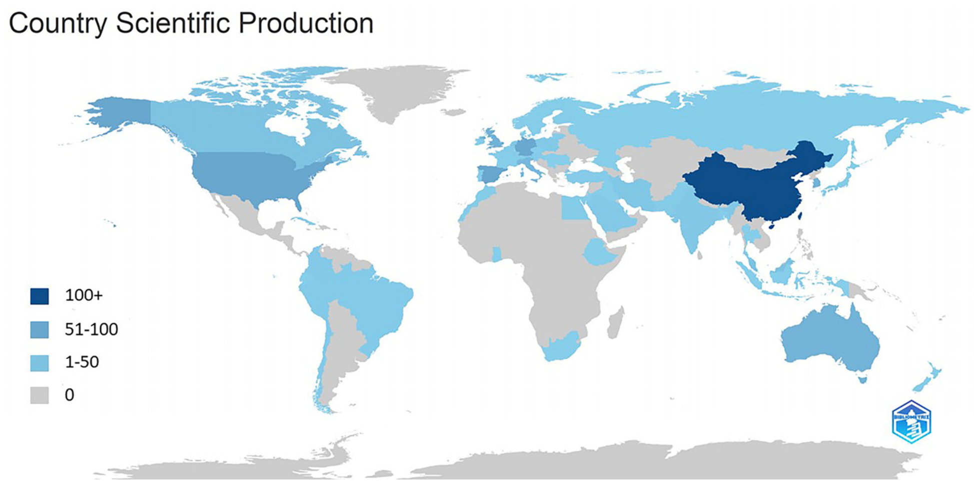

Figure 6. Countries' Scientific Production.

This indicates that these countries hold significant shares in BIM-related research, with China emerging as one of the global leaders in BIM research within the civil infrastructure field. The chart further supports the internationalization of BIM research and highlights the scientific influence of various countries in this domain.

Table 2 presents the ranking of countries based on the number of citations in BIM research. China ranks first with 1552 citations, significantly ahead of other countries, indicating that China's research in the BIM field has the greatest scholarly impact. Australia, the United Kingdom, and Spain follow with 764, 727, and 495 citations, respectively, demonstrating their substantial influence in BIM research as well.

Table 2. Most cited countries.

Country	TC	Average Article Citations
China	1552	14.60
Australia	764	30.60
United Kingdom	727	31.60
Spain	495	13.00
USA	413	13.30
Korea	350	11.70
Italy	347	15.80
Germany	178	4.70
Canada	152	12.70
Netherlands	123	24.60

Additionally, the United States, South Korea, and Italy also have high citation counts, with 413, 350, and 347 citations, respectively. This suggests that these countries not only excel in terms of research output but that their findings have been widely cited and recognized, highlighting their important contributions to the development of BIM. Overall, this table reflects the global distribution of influence in BIM research, with China clearly dominating the field.

The comparison of Figure 6 and Table 2 reveals a significant consistency between the rankings in Table 2 and the color intensity in Figure 6. The countries with the highest citation counts also tend to produce the largest volume of BIM research, indicating a positive correlation between these two variables. This demonstrates that China not only produces the most BIM-related publications but also receives the highest number of citations, further reinforcing its dominant role and substantial contributions to the field of BIM research.

4.2. Analysis of Institutional Output

Table 3 ranks the top 10 research institutions contributing to BIM research. The most prominent institutions include Shenzhen University (19 articles), Southeast University (China) (19 articles), Polytechnic University of Madrid (17 articles), and Tongji University (14 articles). These universities and research institutions have a high publication output in BIM-related studies, indicating their significant influence in the field.

Additionally, notable institutions from other countries, such as the University of Naples Federico II in Italy (12 articles), RWTH Aachen University in Germany (11 articles), and Monash University in Australia (10 articles), have also made important contributions to BIM research. Overall, the contributions to BIM research show a wide geographic distribution, with Chinese universities leading the field. This highlights the diversity of global research efforts and the potential for international collaboration in the development of BIM.

Table 3. Most influential institutes.

Affiliation	Articles
Shenzhen University (China)	19
Southeast University (China)	19
Universidad Politecnica DE Madrid (Spain)	17
Tongji University (China)	14
University of Naples Federico II (Italy)	12
RWTH Aachen University (Germany)	11
Monash University (Australia)	10
Universitat Politecnica DE Valencia (Spain)	10
University of Hong Kong (China)	10
Chinese Academy of Sciences (China)	9

4.3. Analysis of Influential Authors

Table 4 ranks the top 10 most influential authors in the field of BIM research, based on the number of publications. Alberti MG and Liu Z are the leading authors, each having published eight articles in this field. Close behind are Biancardo SA, Klemt-Albert K, and Wang J, with six publications each.

Table 4. Most active authors.

Authors	Articles	Articles Fractionalized
Alberti MG	8	1.96
Liu Z	8	2.23
Biancardo SA	6	1.17
Klemt-Albert K	6	1.56
Wang J	6	1.19
Alvarez AAA	5	1.26
Herrera RF	5	1.15
Huang MQ	5	1.37
Osmani M	5	1.28
Pavón R M	5	1.37

Additionally, other active researchers, such as Alvarez AAA, Herrera RF, Huang MQ, Osmani M, and Pavón RM, have each contributed five articles. This table highlights the significant contributions of these scholars to BIM research, showcasing their influence and active participation in advancing the field.

Table 5 ranks the top 10 most locally cited authors in the field of BIM research. Alberti MG leads with 37 local citations, making them the most cited scholar in this domain. Following closely are Ninić J (24 citations), Kaewunruen S (23 citations), and Huang MQ (21 citations), who also have significant influence in BIM-related research. Other highly active and locally cited scholars include Ma T, Zhang QB, and Biancardo SA, each with around 20 citations. The high local citation counts of these scholars indicate that their research has garnered substantial attention and recognition within the academic community, highlighting the importance and impact of their contributions in advancing BIM technology within the civil infrastructure field.

Table 6 illustrates the variation in academic output over time for different authors in the field of BIM research. The table lists each author's number of publications per year (freq), and total citations (TC). For example, Alberti MG published 3 articles in 2020, receiving 73 citations, with an average of 14.6 citations per year, indicating his significant contributions to the field. Similarly, Alvarez AAA published multiple papers in 2021 and 2022, with a particularly high average yearly citation rate of 11.75 in 2022, reflecting the substantial impact of his recent work. This table helps to track the academic productivity and citation impact of specific authors over time, highlighting their contributions and influence in different years within the BIM research domain.

Table 5. Most cited authors.

Author	Local Citations
Alberti MG	37
Ninic J	24
Kaewunruen S	23
Huang MQ	21
Ma T	21
Zhang QB	21
Biancardo SA	20
Sresakoolchai J	20
Tang FL	19
Bazán AM	18

Table 6. Authors' production over time.

Author	Year	Freq	TC
Alberti MG	2020	3	73
Alberti MG	2021	2	28
Alberti MG	2022	1	2
Alberti MG	2023	2	15
Alvarez AAA	2020	2	44
Alvarez AAA	2021	2	28
Alvarez AAA	2022	1	2
Biancardo SA	2021	1	47
Biancardo SA	2022	2	11
Biancardo SA	2023	3	23

4.4. Most Active Journals

Table 7 highlights the most influential journals and publications in the field of BIM research. *Automation in Construction* is the leading journal, publishing 51 articles on BIM, significantly surpassing other sources. This indicates the journal's critical role in BIM technology and automation in construction. *Sustainability* (40 articles) and *Applied Sciences-Basel* (36 articles) follow closely, suggesting that BIM research extends beyond technical aspects and is also linked to sustainability and interdisciplinary applications. These journals collectively cover a broad spectrum of BIM-related studies, ranging from construction and civil engineering to information management, underscoring the diversity and interdisciplinary nature of BIM research across different fields.

Table 7. Most relevant sources.

Sources	Articles
Automation in Construction	51
Sustainability	40
Applied Sciences-Basel	36
Buildings	36
Bautechnik	20
Advanced Engineering Informatics	14
Engineering Construction and Architectural Management	14
Tunnelling and Underground Space Technology	13
Journal of Construction Engineering and Management	12
Advances in Civil Engineering	9

Table 8 presents the journals and publications with the highest local citation counts in the field of BIM research. *Automation in Construction* leads with 3004 local citations, showcasing its dominant position in BIM-related studies and its significant influence in the fields of construction automation and BIM. *Advanced Engineering Informatics* and *Sustainability-Basel* follow with 495 and 488 citations, respectively, highlighting their importance in engineering informatics and sustainability research. Other frequently cited sources, such as *Journal of Computing in Civil Engineering* and *Applied Sciences-Basel*, further demonstrate their critical roles in civil engineering and applied sciences within the context of BIM. These journals and publications provide extensive references and support for research in BIM technology, construction, civil engineering, and sustainability, reflecting their broad influence in the academic community.

Table 8. Most cited sources.

Sources	Articles
Automat Constr	3004
Adv Eng Inform	499
Sustainability-Basel	488
J Comput Civil Eng	381
Appl SCI-Basel	334
J Clean Prod	331
J Constr Eng M	300
Procedia Engineer	235
J Build Eng	229
Buildings-Basel	226

Figure 7 illustrates the trend in academic output from different journals in the BIM field over time. It shows the cumulative number of articles published between 2020 and 2024 by five major sources. *Automation in Construction* has consistently been the top journal for BIM research throughout this period, with its cumulative output steadily increasing and reaching its peak in 2024. This demonstrates the journal's leadership and ongoing contributions to BIM research. Similarly, *Sustainability* has seen significant growth in cumulative publications, reflecting the increasing volume of BIM-related research focused on sustainability. Its article count has risen steadily since 2020 and shows a marked upward trend through 2024. *Applied Sciences-Basel*, *Bautechnik*, and *Buildings* also exhibit continuous growth in their BIM research output. Although their publication counts are slightly lower than the top two, these journals remain important contributors to BIM-related studies. Overall, the cumulative output from all journals has increased over the 2020 to 2024 period, highlighting the sustained attention and growing research interest in BIM across multiple fields.

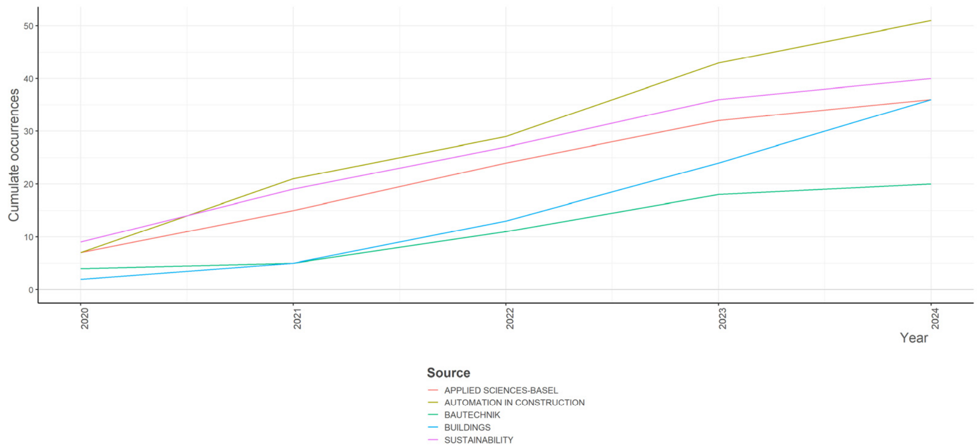

Figure 7. Source's production over time.

4.5. Co-Cited References

Table 9 ranks the most globally cited publications in the field of BIM research, highlighting their academic impact and significance. Jiang F, 2021, *Automation in Construction* [49] is the most cited paper, with 168 citations, indicating its substantial influence in the field of automation and construction. Following closely, Huang MQ, 2021, *Tunneling and Underground Space Technology* [50] has 165 citations, reflecting the critical role of BIM in tunneling and underground space applications. Rahimian FP, 2020, *Automation in Construction* [51] garnered 159 citations, further emphasizing the sustained focus on BIM in automated construction processes. Other highly cited papers include Sepasgozar SME, 2021, *Buildings-Basel* [52] with 141 citations and Li X, 2022, *Journal of Construction Engineering and Management* [53] with 112 citations, showcasing their broad impact in architecture and construction management. The high citation counts of these publications underscore the wide application and profound impact of BIM technology across various fields, including automated construction, underground engineering, and construction information management.

Table 9. Most Global Cited Documents.

Paper	Total Citations	TC per Year	Normalized TC
Jiang F, 2021, *Automat Constr* [49]	168	42.00	6.36
Huang M Q, 2021, *Tunn Undergr SP Tech* [50]	165	41.25	6.24
Rahimian F P, 2020, *Automat Constr* [51]	159	31.80	6.43
Sepasgozar SME, 2021, *Buildings-Basel* [52]	141	35.25	5.34
Li X, 2022, *J Constr Eng M* [53]	112	37.33	7.16
Xia H S, 2022, *Sustain Cities Soc* [22]	103	34.33	6.58
Shahzad M, 2022, *Buildings-Basel* [54]	100	33.33	6.39
Pan Y, 2023, *Arch Comput Method* E [55]	86	43.00	13.68
Tang F L, 2020, *Automat Constr* [56]	84	16.80	3.40
Argyroudis S A, 2022, *Clim Risk Manag* [57]	76	25.33	4.86

Figure 8 illustrates the citation relationships between documents in the field of BIM research, where different colors represent distinct research themes or clusters. The red node cluster primarily focuses on BIM and construction automation, indicating a concentration of research on construction technology and information management. The green node cluster is closely related to themes like infrastructure management and lifecycle management, highlighting the significance of these areas in data integration and facility optimization. The blue nodes concentrate on the integration of BIM with CAD technologies, pointing to research directions in technological innovation.

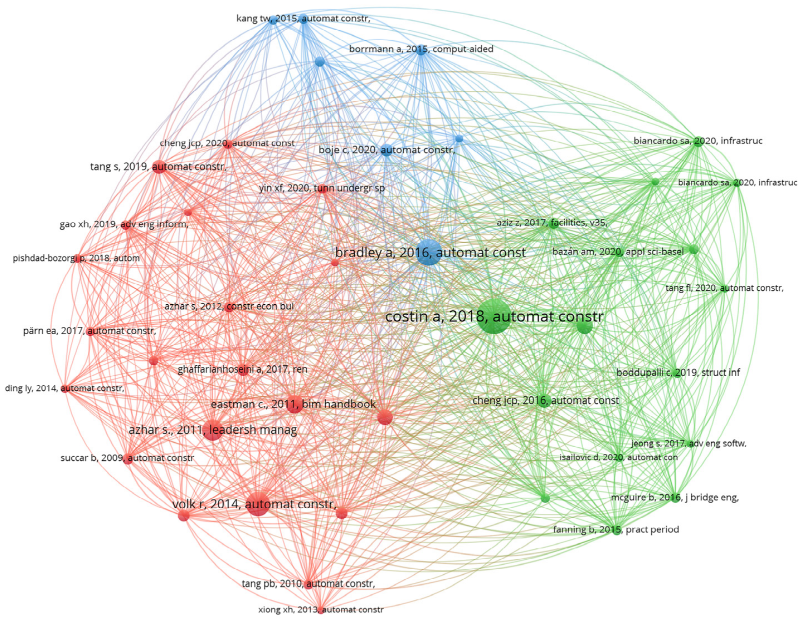

Figure 8. Co-citation network.

The diameter of each node indicates the frequency with which a paper is cited, with larger nodes, such as those representing Bradley A. [14] and Costin A. [31], signifying key reference points in the research field. The thickness of the links reflects the strength of co-citation between documents; thicker links suggest that these papers are frequently cited together in other studies, revealing their close association in academic discussions. This network structure aids in understanding the dissemination of knowledge and the mutual influence between different research directions in the BIM field.

4.6. Analysis of Co-Occurring Keywords

Figure 9 presents the core themes and keywords in the field of BIM research. Core keywords such as "BIM" and "Digital Twin" demonstrate their widespread application in infrastructure and facility management. Additionally, the figure highlights emerging technologies like "Machine Learning", "IoT", and "Augmented Reality", indicating a deep integration of BIM with intelligent systems, data integration, and visualization. These terms collectively suggest that BIM technology plays a crucial role in driving digitalization and sustainable development in the construction sector.

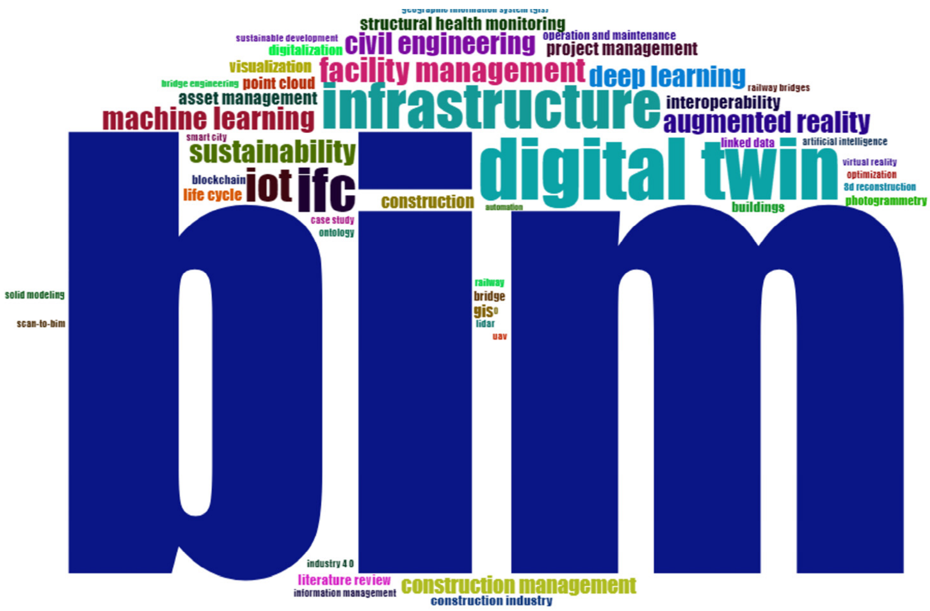

Figure 9. Word clouds of topics.

Figure 10 shows a co-occurrence network based on author keywords, where different colors indicate various research themes related to Building Information Modeling (BIM) in the field of civil infrastructure. The red node cluster is centered around "BIM", encompassing topics such as sustainability, facility management, GIS, and civil engineering. The green nodes focus on emerging technologies like "Machine Learning" and "Deep Learning". Meanwhile, the yellow nodes are closely associated with concepts like "Digital Twin", "IoT", and smart cities. The blue nodes primarily relate to topics like infrastructure management and asset management, reflecting their application in data integration and lifecycle management.

The diameter of each node typically represents the frequency of keyword occurrence, meaning that larger nodes indicate more frequently mentioned keywords in the literature, signifying their importance and impact on academic research. The thickness of the links reflects the co-occurrence strength between keywords; thicker links suggest that these keywords frequently appear together within the same study, highlighting their close association in academic discourse. This network visualization helps to understand the interrelationships among research themes in the BIM field and their development trends.

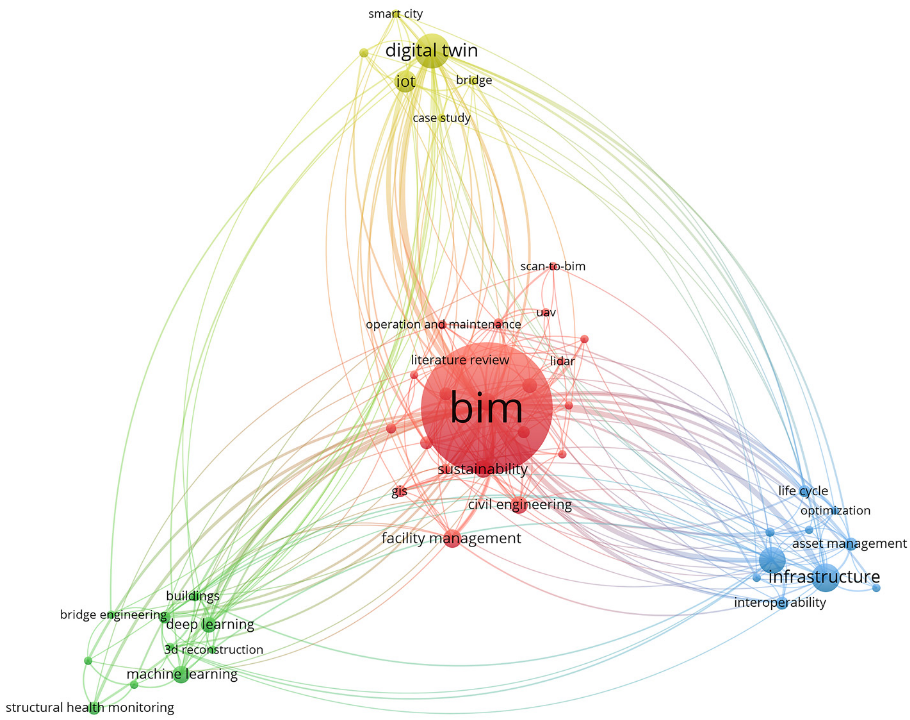

Figure 10. Co-occurrence Author Keywords Network.

5. Discussion

With the advancement of information technology, the application of BIM in civil infrastructure has become increasingly widespread. The core of BIM lies in its capabilities for data integration, 3D visualization, and information management. To systematically integrate the observations from all articles, this study conducts a further analysis of the author keywords represented by the four colors in Figure 10. As a result, the application of BIM technology in the field of civil infrastructure is categorized into three modules: BIM for infrastructure lifecycle management, BIM collaboration in large-scale projects, and BIM for sustainable infrastructure design. The specific analytical framework is illustrated in Figure 11.

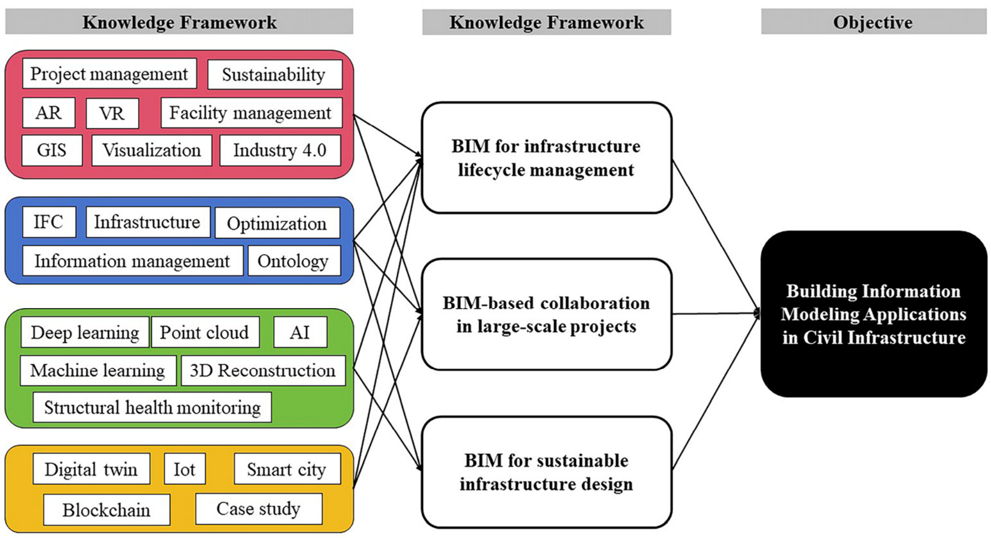

Figure 11. The relationship between keyword co-occurrence and the application of BIM in civil infrastructure.

Although all three applications rely on BIM technology, their focal points differ significantly. Lifecycle management emphasizes the long-term operation and maintenance of infrastructure. The rich data provided by BIM support equipment management, risk prediction, and the development of maintenance plans during the operational phase, ultimately extending the infrastructure's lifespan. In contrast, collaboration focuses on enhancing cross-team coordination efficiency in large-scale projects. During construction, BIM assists in managing complex construction schedules, resource allocation, and risk forecasting, ensuring both efficiency and safety. Sustainable design, on the other hand, aims to minimize the environmental impact of projects. BIM is used to optimize design through 3D visualization, clash detection, and structural simulation, improving both design accuracy and sustainability.

The following sections will provide a more detailed description of the various applications of BIM in civil infrastructure. Based on the three modules derived from the analysis, this study will classify the applications of BIM technology in civil infrastructure, summarizing its diverse application scenarios, methods of integration with other emerging technologies, and its overall impact. A comprehensive summary of BIM's various applications in civil infrastructure is presented in Table 10.

Table 10. Summary of BIM application in civil infrastructure.

Category	Application Scenario	Method	Function
BIM in Infrastructure Lifecycle Management	Resolving contract disputes, payment transparency, information security	Blockchain Technology (BCT)	Reduces information asymmetry and the risk of human tampering
BIM in Infrastructure Lifecycle Management	Bridges, tunnels, roads, and airports	Digital Twin	Reduces capital expenditure and operating costs, enhances operational efficiency and asset management
BIM in Infrastructure Lifecycle Management	Full-process quality assessment of asphalt pavement construction	GIS	Enables real-time monitoring and full-process quality assessment of road construction, addressing inefficiencies and delays in traditional quality assessment methods
BIM in Infrastructure Lifecycle Management	Smart city development	BP Neural Network	Integrates information on urban buildings and infrastructure
BIM in Infrastructure Lifecycle Management	Bridge quality inspection	Artificial Neural Network (ANN) Model	Detects anomalies in bridges under complex load conditions
BIM Collaboration in Large-scale Projects	Monitoring construction progress on-site	Image Detection and Deep Learning	Tracks construction progress
BIM Collaboration in Large-scale Projects	Transportation infrastructure projects	Supply Chain Management	Enhances coordination among project stakeholders, helps identify and mitigate potential risks
BIM Collaboration in Large-scale Projects	Environmental monitoring during construction	Pre-construction BIM-based GHG Assessment	Records energy consumption at construction sites
BIM Collaboration in Large-scale Projects	Restoration of cultural heritage buildings	VR/AR	Enhances the interactivity and immersion of models
BIM Collaboration in Large-scale Projects	Understanding civil infrastructure scenarios	Deep Learning	Suitable for object recognition and segmentation in infrastructure scenarios like buildings and bridges
BIM for Sustainable Infrastructure Design	Bridge engineering	BIM and GIS integration, Relational Database (RDB)	Facilitates digital bridge management
BIM for Sustainable Infrastructure Design	Large-scale city modeling	Integration of Point Cloud, BIM, and GIS	Generates high-quality 3D models
BIM for Sustainable Infrastructure Design	Road engineering	Point Cloud	Enables semi-automated road alignment model generation
BIM for Sustainable Infrastructure Design	Interoperability of different building software	IFC Instance Data Deconstruction	Enhances interoperability and flexibility of BIM data, simplifying data manipulation and analysis

5.1. BIM in Infrastructure Lifecycle Management

Infrastructure lifecycle management encompasses all stages from planning, design, and construction to operation and maintenance, with the goal of optimizing resource utilization and reducing LCC while ensuring facility performance [58]. BIM provides an integrated platform for the entire lifecycle of infrastructure projects, enabling all stakeholders to share information and collaborate on a unified model. The focus of BIM in lifecycle management is on data management and maintenance across the entire lifecycle of infrastructure—from planning, design, construction, and operation to demolition—with the aim of optimizing long-term benefits and performance through the continuous flow and use of information.

In infrastructure lifecycle management, BIM integrates with construction management systems to enable project progress tracking, cost control, and refined management of construction processes. For example, Oreto et al. proposed a method combining LCA and LCCA to evaluate the sustainability of road pavement materials and designs from both environmental and economic perspectives [59]. Nsimbe et al. highlighted improvements in cost control and project delivery through enhanced project transparency, resource utilization, and collaboration efficiency [10]. BIM, through accurate 3D modeling and simulation tools, optimizes the design process and reduces potential design errors and conflicts. For instance, Liu et al. demonstrated the use of high-precision "as-built" BIM models to support the full lifecycle management of bridges, including structural health monitoring and asset management, especially in the decision-making processes during the maintenance phase [3]. Furthermore, Sara et al. introduced an ontology model called IFCInfra4OM, designed to integrate operation and maintenance (O&M) information into highway information models [60].

In recent years, BIM has advanced rapidly through integration with low-cost augmented reality (AR), optimizing decision-making during facility operation and maintenance by enhancing visualization and data integration capabilities [61]. GIS have also been combined with BIM to enable the real-time, full-process evaluation of asphalt pavement construction quality, enhancing both visualization and data management in construction processes [62]. When combined with IoT and sensor technology, BIM supports asset management and facility maintenance, improving the ability to monitor and manage the entire lifecycle of infrastructure. Pavón et al. showed how the integration of BIM models with IoT technology enhances data integration and real-time information synchronization in infrastructure management [63]. Salzano et al. proposed a method that integrates BIM with facility management (FM) to optimize maintenance for existing assets. By combining BIM with Building Condition Assessment (BCA) and data collection tools (such as mobile devices, sensors, and Excel databases), maintenance processes can be improved, and costs reduced [64]. Additionally, emerging technologies such as blockchain [65], smart cities [66], digital twins [67], and even artificial neural networks [4] have been integrated with BIM in recent years, as demonstrated by various case studies. These innovations provide new possibilities for civil infrastructure and lay the foundation for more precise and efficient engineering management methods.

5.2. BIM Collaboration in Large-Scale Projects

BIM collaboration is particularly critical in large-scale projects, as it involves the coordination of multiple stakeholders and cross-disciplinary teams. BIM provides a shared information platform that enables participants to design, discuss, and optimize within the same digital environment, fostering transparent and efficient communication [68]. In large projects, BIM collaboration emphasizes the coordination between multiple stakeholders and professional teams, utilizing a shared BIM platform to facilitate information exchange, design coordination, and decision support. The primary focus is on how to collaborate efficiently and reduce misunderstandings during project implementation.

By using BIM models, various disciplines such as architecture, civil engineering, and mechanical, electrical, and plumbing (MEP) can work together, minimizing information silos and misunderstandings, thereby improving design and construction coordination. For instance, Castaneda et al. proposed a collaboration framework in BIM that integrates different disciplines (such as civil engineering and traffic planning), combining traffic simulation with real-time data integration to enhance decision-making in large urban infrastructure projects [69]. In managing large construction projects, traditional manual data collection often falls short of requirements, and conventional methods such as point clouds also present significant limitations. Xue et al. discussed the use of 3D reconstruction technology for monitoring construction progress [70]. They highlighted that BIM, through automated progress tracking combined with computer vision and deep learning, provides real-time feedback, thus improving collaboration efficiency.

In complex infrastructure projects, BIM facilitates multi-party collaboration and real-time data sharing by integrating 3D models from various sources, enhancing communication and management efficiency. Zhou et al. demonstrated how BIM models guide construction, using a BIM + GIS management platform to reduce communication and collaboration challenges, thereby improving management efficiency [2]. In large projects, the collaboration between digital twin technology and BIM supports real-time data sharing, helping to address uncertainties and risks in complex engineering projects [71]. Ibragimov et al. showed how BIM optimizes data collaboration among different project teams in large construction projects by generating synthetic data, which also provides high-quality training data for automated systems, improving project management and operational efficiency [72]. Liu et al. introduced the use of BIM models with automated point cloud classification and 3D object detection, which enhances the accuracy of bridge structure modeling [3]. This method not only assists in recognizing complex geometries but also improves collaboration efficiency in bridge infrastructure projects, particularly in decision support for resource allocation and asset management. Fabrizio et al. proposed integrating BIM with virtual reality (VR) and AR platforms to enhance data interactivity and shareability in cultural heritage management. They also emphasized the use of visual programming languages (VPL) to enhance user interaction with digital heritage models [73].

Furthermore, the integration of BIM with IoT, big data [74], and machine learning [75] facilitates more efficient cross-departmental collaboration and information sharing in large industrial projects. This combination enhances data reliability and collaboration efficiency in project management, which is especially beneficial for improving collaboration in transportation infrastructure projects.

5.3. BIM for Sustainable Infrastructure Design

In sustainable infrastructure design, BIM focuses on reducing the environmental impact of projects by optimizing design, material usage, and energy efficiency management. BIM supports comprehensive sustainability assessments of projects, including energy conservation, carbon emissions, and resource recycling [76]. The emphasis in sustainable infrastructure design with BIM is on environmental impact, utilizing BIM tools for energy efficiency optimization, material management, and lifecycle assessment to support the goals of green building and sustainable development. Key objectives include minimizing carbon emissions and reducing resource waste.

BIM has wide applications in sustainable construction, such as reducing carbon emissions, lowering resource consumption, and improving energy efficiency. In road infrastructure design, BIM combined with GIS enhances information management, facilitating the development of eco-friendly infrastructure [77]. For instance, Mohammad et al. integrated the quantity takeoff (QTO) capabilities of BIM models with material GHG intensity data from databases to assess greenhouse gas emissions in bridge construction [78]. Xie et al. noted that in China's sustainable building practices, BIM, when combined with other lifecycle technologies, optimizes energy management and material usage, and supports the design and construction of green buildings [79]. When combined with IoT, BIM provides real-time monitoring, environmental data collection, and intelligent decision support, helping optimize building energy efficiency and resource utilization while supporting sustainable design and smart city development [80]. BIM is used to mitigate unforeseen on-site conditions and improve resource efficiency, optimizing design to reduce air and noise pollution, thus enhancing the safety and sustainability of road infrastructure [81,82]. Additionally, BIM helps conserve construction materials, optimize resource use, and achieve building energy-saving goals through better design tools. Its visualization and simulation capabilities streamline the evaluation process of green buildings, making it easier to record and track green building performance metrics [83].

In supply chain management, BIM plays a critical role by optimizing transportation routes, reducing delays, and improving overall project efficiency. In large-scale projects, BIM promotes collaboration among stakeholders and the integration of environmental responsibility, significantly enhancing project sustainability [84].

6. Conclusions

BIM is a digital, 3D-model-based technology utilized in the AEC industries for design, construction, and operational management. In recent years, BIM has garnered significant attention in the fields of civil engineering and infrastructure projects, and its robust performance and potential have been proven through its expanding application. This paper provides a comprehensive review of the advancements in BIM technology within civil engineering projects, specifically focusing on civil infrastructure from 2020 to 2024, based on both quantitative and qualitative analyses. A quantitative bibliometric analysis of 416 papers reveals that the integration of BIM with technologies such as IoT, cloud computing, VR, and AI has enhanced its application potential in smart buildings and smart cities. The bibliometric analysis indicates a notable increase in BIM's use in civil infrastructure projects, a trend driven by technological advancements and global collaboration. The study highlights the prominent roles of the United States, China, and the United Kingdom in BIM-related research. Key findings include the growing integration of BIM with IoT, digital twins, and machine learning, technologies that have strengthened real-time monitoring, data management, and predictive maintenance in infrastructure projects.

The qualitative review of this study presents BIM's applications in civil infrastructure, categorizing its use into three areas: BIM for lifecycle management of infrastructure, BIM collaboration in large-scale projects, and BIM for sustainable infrastructure design. The results demonstrate that BIM plays a crucial role in sustainable design, particularly in optimizing building design and construction processes, improving energy efficiency, reducing material waste, conserving resources, and enhancing both indoor and outdoor environments. Through parametric design, energy efficiency analysis, and dynamic simulations, BIM supports the full lifecycle management of green buildings while streamlining green building evaluation processes, thus improving collaboration efficiency and sustainability.

Despite offering a comprehensive exploration of BIM's latest applications in civil infrastructure over recent years, the study acknowledges several limitations. The literature review focuses only on publications from 2020 to 2024, which may overlook some foundational or historical studies on BIM technology. Additionally, while the descriptive analysis, co-citation, and co-occurrence analyses provide valuable insights, they may not fully capture emerging trends or complex dynamics in the literature. Future research should consider a broader search scope, review the entire history of BIM development, and apply advanced bibliometric methods to address these gaps. These improvements could yield deeper and more comprehensive insights, ensuring a better understanding of the field.

In summary, the contributions of this paper include (1) a comprehensive mapping of BIM research in civil infrastructure through bibliometric analysis; and (2) a summary of the multi-scale practical use cases of BIM technology in civil infrastructure. This review serves as a BIM technology guide for practitioners in the construction engineering field and provides theoretical references for researchers to highlight mainstream trends and inspire new use cases for BIM technology.

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