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Article

BIM in Construction: A Bibliometric Analysis About BIM and Digital Twin

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Abstract: Even though the integration of BIM and digital twin technologies is still relatively new, it has rapidly become a key research focus due to the urgent need for a technologically advanced and sustainable built environment. This research paper presents a comprehensive bibliometric literature analysis of Building Information Modeling (BIM) and Digital Twins in the construction sector. By exploring a global dataset of 239 publications, the study dives into co-citation, co-authorship, and keyword patterns to pinpoint influential authors, emerging research clusters, and key trends. The findings show a rapid surge in BIM research, peaking in 2023, with international collaborations driven by countries like the United Kingdom, China, and Australia. The thematic clusters emphasize sustainability, Industry 4.0, construction 4.0, and smart city development, highlighting how artificial intelligence, blockchain, and automation are changing construction management. This analysis paper shines a light on future opportunities for seamlessly integrating BIM and Digital Twins into construction and smart infrastructure projects, serving as a strategic roadmap for researchers and practitioners to understand the evolving BIM and Digital Twin research area.

Keywords: BIM; digital twin; industry 4.0; industry 5.0; AEC industry; bibliometric review

1. Introduction

The Architecture, Engineering, and Construction (AEC) industry is undergoing rapid digital transformation, with Building Information Modelling (BIM) and Digital Twin technologies playing a central role in improving efficiency, sustainability, and lifecycle management. BIM supports integrated design and construction processes, while Digital Twins extend these capabilities through real-time data and operational analysis.

Although research on BIM and Digital Twins has grown significantly, recent studies have attempted to map the development of these technologies using bibliometric approaches. For instance, (Shishehgarkhaneh et al. 2022) provided a comprehensive review of the integration between IoT, BIM, and Digital Twins, highlighting the growing importance of data-driven construction processes. Similarly, (Ametepey et al. 2024) conducted a bibliometric analysis of construction digitalization research, emphasizing trends related to BIM, automation, and blockchain technologies. However, these studies primarily focus on broader digitalization themes or earlier phases of technological development and do not fully capture the most recent evolution of BIM and Digital Twin integration in the construction sector.

There remains a limited number of recent bibliometric studies that capture the transition from Industry 4.0 toward emerging Industry 5.0 paradigms, where artificial intelligence, human centric design, and sustainability are increasingly integrated. Additionally, existing reviews often overlook the latest developments from 2023 to 2024, during which BIM and Digital Twin integration has expanded into intelligent systems and lifecycle-based applications.

To address these gaps, this study provides a more recent and focused bibliometric analysis examining research developments from 2019 to 2024 and highlighting the transition toward Industry 5.0. By mapping publication trends, collaboration networks, and thematic evolution, the study offers an updated overview and a clearer research direction for the AEC industry.

1.1. Building Information Modelling (BIM)

BIM is a modern approach in the technical communication of the AEC industry, involving the use of computers to create a simulated building representation. It treats the structure as an object within a digital environment, providing a more detailed, interactive, and collaborative way to visualize and plan construction projects (Abbasnejad and Moud, 2013). From the reviewed literature, although BIM doesn't have a precise definition yet, it is commonly perceived as a process that employs tools and software to foster collaboration across departments in building processes within the AEC sector. Using BIM minimizes clashes between building components through continuous collaboration and updates of shared models. The National BIM Standard-United States Project Committee (NBIMS-US) organization provides one of the oldest yet still relevant definitions, stating that "BIM is a digital representation of the physical and functional characteristics of an object. As such, it serves as a common knowledge resource for information about an object, forming a reliable basis for decision-making throughout its life cycle, from inception" (National BIM Standard, n.d.; Borkowski, 2023).

The evolution of BIM began with 3D modeling, focusing on the physical and functional aspects of buildings. This concept expanded to 4D BIM, which integrates construction timelines and scheduling for a dynamic view of project progress. Further development led to 5D BIM, which incorporates cost estimation for real-time financial management throughout the project's lifecycle. 6D BIM brought sustainability into the fold by assessing environmental impact and energy efficiency. The 7D BIM model emphasized facilities management, aiding in building maintenance and operations post-construction. Finally, the concept of nD BIM represents an adaptable model with unlimited dimensions, including safety and asset management, to meet the comprehensive needs of the construction industry (Mohanta and Das, 2017).

1.2. Digital Twin

NASA's technology roadmap draft, published in 2010, presented a comprehensive vision for the Digital Twin concept. It defined a Digital Twin as "an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, and the ability to use the digital twin in aerospace applications. Models, sensor updates, fleet history, etc., to mirror the life of its flying twin." This early definition emphasized the potential of Digital Twins in aerospace applications, allowing the digital counterpart to reflect the lifespan of its physical counterpart using real-time data and predictive modeling (Ji et al., 2022).

Although Digital Twin first emerged in 2002, it did not attract significant research attention until 2011, when technological advancements and increasing interest in predictive maintenance and data-driven decision-making brought it to the forefront of research and industry conversations. Since then, Digital Twins have evolved to encompass various sectors beyond aerospace, with their applications expanding to manufacturing such as smart manufacturing, construction and AEC sector, and urban planning (Malik et al., 2018; Ji et al., 2022).

In (Ji et al. 2022) Bibliometric analysis's study on Digital Twins revealed that the primary areas in digital twins research currently focus on smart manufacturing and AEC sector such as shop floor systems, cyber-physical systems, product lifecycle management, and product design in manufacturing while digital and virtual design and smart construction in the AEC sector. These fields illustrate the current emphasis on using Digital Twins to optimize production processes, enhance product quality, and streamline operations by creating real-time digital replicas that inform and improve their physical counterparts.

As technology continues to advance, the future applications of digital twins appear increasingly diverse. Researchers have envisioned the digital twin concept extending far beyond smart manufacturing and construction, encompassing sectors such as healthcare and transportation. This is due to digital twin's facilitation of predictive maintenance, efficient resource management, and enhanced decision-making through sophisticated simulations and real-time data analysis (Malik et al., 2018; Ji et al., 2022).

BIM is primarily utilized during the design and construction stages of a project, whereas digital twins leverage real-time and operational data. As projects transition from construction to operation, BIM models evolve into digital twins. This evolution significantly extends the utility of digital twins, as they can be scaled up to create urban-level digital twins. These larger-scale models are invaluable tools for conducting urban analysis and enhancing disaster resilience (Karmakar and Delhi, 2021).

Digital twins simulate, analyze, and understand complex systems by serving as virtual replicas of physical environments, whether their sites, districts, cities, or entire regions. These sophisticated models enable informed decision-making by predicting and mitigating potential issues before they arise. Through digital twins, stakeholders can test recommendations, evaluate different scenarios, and continuously monitor data and performance, making them invaluable in planning, development, and operational processes (Shafei et al., 2022). In addition, the urban digital twin concept can aid smart cities in achieving sustainability (Malik et al., 2018).

1.3. Integration of BIM in the Construction Industry

BIM can be utilized throughout all phases of a construction project, starting from the initial concept to the end of the structure (Sun et al., 2015).

- Visualization: Simple generation of 3D views, renderings, and walk-throughs;
- Change Management: Automatic coordination of any modifications made to one section of a building with all other parts;
- Code Checking: Municipal building firms can utilize building information models to assess and approve building projects;
- Clash Detection: Visually checks for time-space conflicts among significant systems, such as piping, plumbing, construction equipment, and sheet metal ducting, in the preconstruction phase of building information model creation;
- Fabrication: The production of shop drawings can be achieved more efficiently using building information models, as opposed to traditional methods;
- Communication and Collaboration: Integrating all relevant information, such as participant details, construction materials, building machinery, and planning, into a single building information model. This allows stakeholders to effectively communicate and collaborate using a unified and consistent model;
- Time and Cost Management: 4D and 5D deliverables can be utilized for various activities like construction analysis, project delivery schedules, material requirement planning, and cost estimating;
- Green Building: Building information models can be exported to other software programs to conduct more analysis on the building's comfort, lighting, energy efficiency, and other factors;
- Facilities Management: BIM can be utilized for the purpose of space management and maintenance operations in the field of facilities management.

1.4. Integration of BIM and Digital Twin in the Construction Industry

The terms "BIM" and "Digital Twin" often appear interchangeably. While the major function of a Digital Twin is to mirror the object it represents, the main objective of BIM is to generate a three-dimensional representation of a real-world object. It is possible to exchange data and information with other Digital Twin simulators and programs by incorporating data and information at every stage of an asset's lifespan (Shishehgarkhaneh et al., 2022).

A key concept supporting this integration is the Digital Thread, which allows an integrated view of a physical asset and its information throughout the lifecycle across traditionally separate functions, thereby helping maintain continuity between design, construction, and operation data and reducing information loss during handover (Mokhtari et al., 2022).

The advancement of these technologies has been notable in various domains such as technology, process, and policy. However, to fully utilize the advantages of BIM, considerable modifications in workflow and project delivery processes are necessary. In this context, standardized data exchange protocols such as Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie) play an important role in enabling interoperability. COBie is an open data transfer specification developed to facilitate delivery of managed asset information, and it is built on the concept of model view definitions derived from IFC to support BIM data exchange between specific domains, particularly for operations and facility management (Tsay et al., 2022). This supports the transfer of "as-built" BIM information into downstream operational systems and Digital Twin environments.

Furthermore, the combination of Wireless Sensor Networks (WSN) and BIM has resulted in the development of a dynamic model that allows for real-time monitoring and analysis, effectively integrating Digital Twin technology into the construction industry. Digital Twin is beneficial throughout the design phase since it provides designers with effective knowledge, enabling them to make informed judgments (Nguyen and Adhikari, 2023). In addition, BIM–IoT integration has been widely recognized as a foundation for Digital Twin development in facility and asset management, because sensor data can continuously update the virtual model and support monitoring of real building conditions. These sensor networks operate through standardized communication protocols, enabling continuous data exchange between physical assets and their digital twin, thereby supporting real-time synchronization within Digital Twin systems (Mannino et al., 2021; Lu et al., 2020). Recent construction literature also describes Digital Twins as cyber-physical systems characterized by bidirectional communication between the physical and digital realms through seamless data flow, which strengthens the technical basis for using WSN and IoT data in real-time Digital Twin applications (Wang et al., 2024).

Furthermore, the data obtained using Digital Twin can be saved in a database and simply retrieved by designers for future projects. This assists them in making more informed decisions regarding material selection, energy management, procurement, supplier selection, and other relevant issues (Nguyen and Adhikari, 2023).

Using Digital Twin and BIM offers new opportunities for incorporating design and construction and digitally enhancing the construction industry. The integration of BIM and Digital Twin facilitates easy cooperation among different teams engaged in the planning, building, and maintenance of a constructed asset. These technologies have the capacity to provide fresh perspectives and enhance the ability to make informed decisions at every phase of the life cycle of the built environment (Nguyen and Adhikari, 2023).

2. Methodology

This study adopts a structured bibliometric research methodology to systematically analyze the scientific literature on BIM and Digital Twin applications in the construction industry. As illustrated in the methodology framework (Figure 1), the research process begins with a comprehensive literature review, followed by a multi-stage bibliometric analysis. The framework outlines the sequential steps of topic definition, scope selection, keyword formulation, document refinement, and analytical techniques. Data were retrieved from the Scopus database and analyzed using Biblioshiny and VOSviewer to examine publication trends, collaboration networks, intellectual structures, and emerging research themes. This structured approach ensures transparency, reproducibility, and robustness in mapping the evolution and current state of BIM and Digital Twin research.

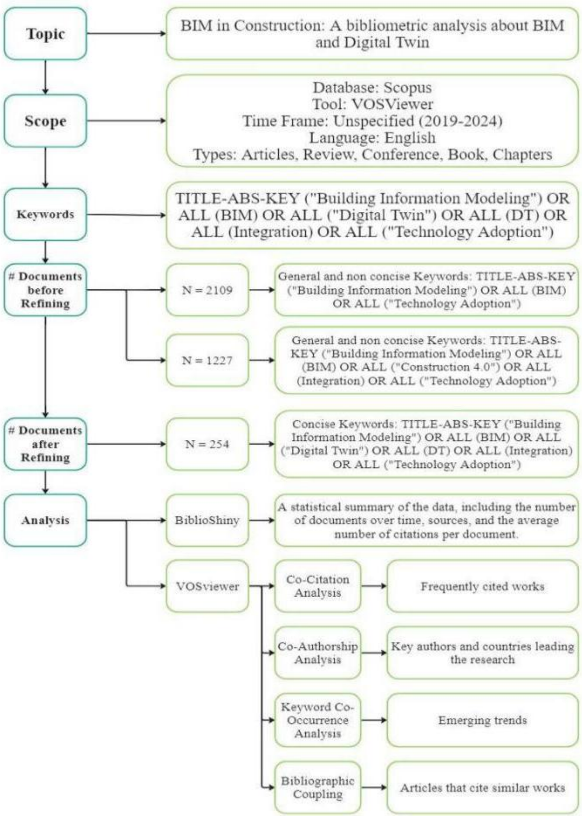


Figure 1. Methodology Framework.

2.1. Literature Review

Literature Review, also known as secondary research, is a research method that involves exploring and gathering data from existing documents and prior studies to verify or support findings. It is a cost-effective way to obtain crucial information from a range of sources, forming the foundation for the subsequent research stages. To maintain organization and accessibility, a reference list is then created for all literature and secondary data.

In this research, the secondary research involved literature review and data collection from books, web articles, and journals, as well as previous studies conducted by other researchers, public library records, and media coverage regarding BIM and Digital Twins.

2.2. Bibliometric Analysis

Creating a bibliometric analysis review for a research paper on BIM and Digital Twins involves several key methodologies that help map out the landscape of scholarly literature, detect trends, influential works, and key contributors in the field.

2.2.1. Identification of Sources

Scopus was chosen as the primary index to identify documents for this review due to its comprehensive coverage across disciplines related to sustainable campuses and sustainability, offering access to bibliographic data suitable for bibliometric analysis (Župič and Čater, 2014). Although the Web of Science also enables meta-data export for bibliometric purposes, its coverage of sustainable campus topics is considerably less comprehensive compared to Scopus (Hallinger, 2019).

The document search was guided by criteria such as time frame, document type, topical focus, and language. To accurately document the existing knowledge base, the search was not restricted to any specific publication period. Therefore, the start date remained undefined, allowing Scopus to identify all relevant documents regardless of their publication date, with the review including works published up to 2024. This approach differs from the strategy employed by (Ávila et al. 2018), who reviewed research over a ten-year period from 2005 to 2014.

Instead of being confined to a specific set of journals, the document search was deliberately open-ended. Although restricting the search to a particular group of journals is a standard approach (Hallinger, 2019; Hallinger and Kovačević, 2019), the interdisciplinary nature of BIM and Digital Twins made such a strategy impractical.

2.2.2. Data Extraction and Analysis

By utilizing Scopus, the initial keyword search contained the terms "TITLE-ABS-KEY ("Building Information Modeling") OR ALL (BIM) OR ALL ("Technology Adoption")". This search generated a total of 2146 documents. In order to refine the search, the addition of construction 4.0 was incorporated as a keyword. The search query was "TITLE-ABS-KEY ("Building Information Modeling") OR ALL (BIM) OR ALL ("Construction 4.0") OR ALL (Integration) OR ALL ("Technology Adoption")". As a result, a total of 1227 documents were obtained. The initial search was considered to lack precision, so the generic term "Construction 4.0" was replaced with the more specific term "Digital Twin". The final search query used was "TITLE-ABS-KEY ("Building Information Modeling") OR ALL (BIM) OR ALL ("Digital Twin") OR ALL (DT) OR ALL (Integration) OR ALL ("Technology Adoption")". This refinement resulted in a total of 239 documents for analysis as shown in Figure 2.

Figure 2. Keywords and Documents from Scopus (Scopus).

The bibliographic data for all 239 documents were downloaded and saved as an Excel (CSV) file.

This file included metadata for each article, such as author names, affiliations, titles, sources, references, keywords, abstracts, and citation data.

Bibliometrix, CitNetExplorer, VOSviewer, ScienceScape, Gephi, and Citspace are software tools designed to facilitate network analysis, visualization, and enhanced comprehension of large volumes of data and information using database analytic approaches (Shishehgarkhaneh et al., 2022). With VOSviewer being the most frequently employed among them, it stands out as a relatively easy-to-use and accessible scientometric mapping tool. It has been designed not just for the core scientometric community, but also for researchers in other scientific fields who are interested in bibliometric analysis. (Li et al., 2021)

To visualize and analyze trends, Biblioshiny and VOSviewer were used to create bibliometric maps (Van Eck and Waltman, 2009). Biblioshiny can generate summary tables and graphics on the trends in the database while VOSviewer can generate different types of maps, including publication, country, or journal maps based on networks (co-citation) or shared keyword networks. It also allows for the customization of keyword frequency by filtering out less relevant terms (Hudha et al., 2020). Additionally, VOSviewer is capable of performing data mining, mapping, and grouping of articles sourced from a database (Xie et al., 2020).

Co-citation analysis provides complementary insights into scholarly influence. (Zupic and Čater 2015) define co-citation as "the frequency with which two units [authors, documents, journals] are cited together". In this approach, software creates a matrix based on the reference lists within the 254 documents, allowing for the creation of different forms of co-citation analysis: journal co-citation, author co-citation, and document co-citation. Each type uses matrices of co-citation frequencies to conduct the analysis (Hallinger and Chatpinyakoop, 2019).

Co-citation analysis offers measures of similarity between documents, authors, or journals (Župič and Čater, 2015; Hallinger and Chatpinyakoop, 2019). It visually represents relationships among authors in a given field based on co-citation patterns by other scholars. In this review, VOSviewer software was used to create social network maps of relationships among features of documents knowledge base (Van Eck and Waltman, 2014). Co-citation maps can be used to analyze various relational features, such as revealing the "intellectual structure" of a field through author co-citation maps (Župič and Čater, 2015; Hallinger and Chatpinyakoop, 2019; Van Eck and Waltman, 2014).

The keyword co-occurrence analysis (co-word analysis) was employed to determine the topical structure of chosen knowledge base (Župič and Čater, 2015). Co-word analysis identifies how often two keywords co-occur in the title, abstract, or keyword list of documents in the review database (Van Eck and Waltman, 2014). It reveals frequently appearing keywords and illustrates their relationships in a network map (Župič and Čater, 2015; Van Eck and Waltman, 2014).

Co-authorship networks offer a comprehensive and detailed record of social and professional connections among authors (Newman, 2004; Kumar, 2015). Analyzing these networks can reveal various aspects, such as the degree of fragmentation or cohesion within the knowledge community and the best-connected authors. Macro-level properties provide an overview of the entire network, while micro-level properties identify influential gatekeepers or prestigious authors within the network (Kumar, 2015).

Co-authorship Analysis also serves to determine the collaborative patterns and key networks within the research community. It is crucial for identifying influential authors, leading institutions, and the geographic spread of research activity. By analyzing which authors frequently collaborate, and which institutions are involved, this method provides insights into the central figures and leading centers in BIM and Digital Twins research. Additionally, examining the countries involved can reveal the geographical distribution of research activities and pinpoint which countries are at the forefront in this area (Kumar, 2015).

Bibliographic coupling is a technique used to identify conceptual similarities based on the documents that are cited. It can also consider recently published articles that have fewer citations. A document is considered bibliographically coupled if it is referenced by two or more other documents. Like co-citation analysis, bibliographic coupling helps identify clusters based on content similarity (Pandey et al., 2024).

Bibliographic Coupling can help in analyzing commonalities across countries, documents, sources, authors, and organizations, thereby indicating which publications are in the trending research, which authors are working in similar areas, and which institutions might be leading in research innovations (Pandey et al., 2024).

A network map from VOSviewer is read as the following for analysis. In these maps, keywords are grouped into clusters that are color-coded based on thematic groupings or related research areas. Each cluster contains nodes of varying sizes that reflect the frequency of keywords within the dataset, with larger nodes indicating more prominent keywords. Lines connecting the keyword nodes represent relationships between them, and the thickness of the lines shows the strength of the association or the frequency of co-occurrence between linked keywords (Kumar, 2015; Pandey et al., 2024).

3. Discussion

3.1. BiblioShiny

A dataset summary was obtained in Table 1 from Biblioshiny bibliometric analysis which provides key insights into the bibliometric data on BIM and Digital Twins till the current year of 2024. The timespan of all published documents started and covered a relatively recent period; from 2019 to 2024, even though there was no timespan given. This indicates that the current trends and emerging research directions are heading toward these fields. The dataset included 126 sources and 239 documents but 2 were omitted due to their missing data and has a wide diversity of publication types involved in this topic. The annual research publications growth rate of 130.45% highlights the rapidly increasing interest in BIM and Digital Twins, which is likely driven by technological advancements and the rising importance of digital modeling.

Table 1. Main Information about the Dataset (BiblioShiny).

Description	Results
Main Information about Data	
Timespan	2019:2024
Sources (Journals, Books, Etc)	126
Documents	239
Annual Growth Rate %	130.45
Document Average Age	1.2
Average Citations Per Doc	16.45
Keywords Plus (Id)	1282
Author's Keywords (De)	792
Authors	802
Authors Of Single-Authored Docs	17
Single-Authored Docs	17
Co-Authors Per Doc	3.88
International Co-Authorships %	51.59
Document Types	
Article	160
Article Review	1
Book	8
Book Chapter	9
Conference Paper	7
Review	66
Review Conference Paper	1

The average document age of 1.2 years indicates that most publications are recent, reinforcing an ongoing trend in those fields. With an average of 16.45 citations per document, research in this area is impactful and well-cited, pointing to the significant influence of BIM and Digital Twins studies.

A high number of Keywords Plus (1282) and Authors' Keywords (792) indicates the diversity of themes and subtopics. With 802 authors involved in the dataset, it's clear that there is broad participation from both academia and industry. Only 17 documents were single-authored, which shows how collaborative this research area is, while an average of 3.88 co-authors per document further reinforces the teamwork and collaboration present in this research area. Over 51% of the documents involve international collaboration which further emphasizes the global importance and cooperation in this area.

Most of the publication types present in this research are research articles (160), while a significant number of review papers (67) reflects the maturity of the field. Additionally, the presence of books, book chapters (17), and conference papers (8) shows a comprehensive treatment of the topic across different formats.

Rapid growth, broad collaboration, and high impact characterize the BIM and Digital twins research area, with international partnerships and thematic diversity being particularly notable features. The diversity of document types and high citation rates demonstrate that research in this field is continuously advancing and is of increasing importance across various industries.

The Annual scientific production chart, shown in Figure 3, illustrates a notable increase in research articles focused on Building Information Modeling (BIM) and Digital Twins over recent years. There is a consistent upward trend from 2019 to 2022. In 2019, fewer than 10 articles were published while in mid 2022, it went up to 90. The graph reached a peak in 2023, with over 95 articles published, reflecting the expanding interest in digital transformation and sustainable practices within construction and this exponential growth mirrors the construction industry's adoption of digital technologies. However, 2024 shows a slight decline in scientific production, possibly due to changes in publication patterns or data collection periods, but the overall trajectory remains positive.

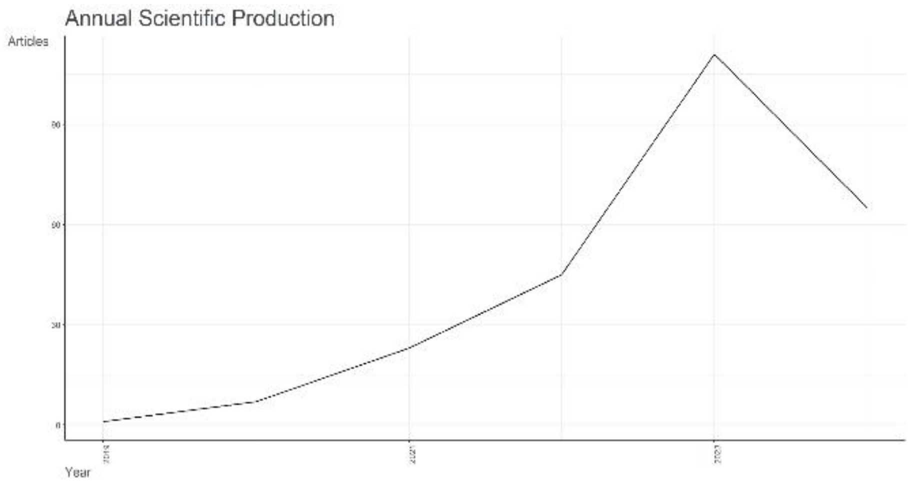


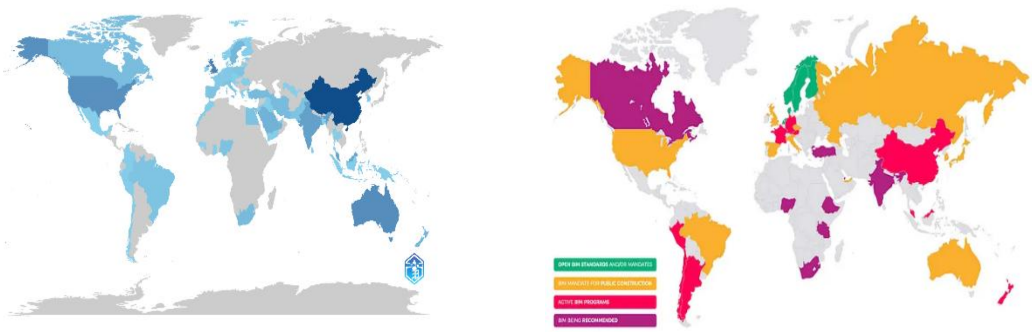
Figure 3. Annual Scientific Production (BiblioShiny).

This growth highlights the increasing importance of integrating advanced technologies into construction management, project planning, and sustainability. It also aligns with the growing global collaborations where interdisciplinary networks are forming as countries share knowledge. The sharp increase in 2021 till 2023 could also be linked to the COVID-19 pandemic, which accelerated digital adoption in the construction industry. As remote work and data analytics became crucial, interest in research surged.

Looking at the global contributions to BIM and Digital Twins research shows the geographic distribution of publications (Table 2 and Figure 4).

Table 2. Country Scientific Production (BiblioShiny).

Region	Frequency
China	114
UK	67
Australia	55
USA	52
India	38
Malaysia	34
Saudi Arabia	23
New Zealand	22
Sweden	19
South Africa	17
Turkey	17
Iran	16
Canada	15
Egypt	10
Italy	10
Nigeria	10
Brazil	9
Pakistan	9
Poland	9
Spain	9
United Arab Emirates	8



(a) (b)

Figure 4. **(a)** Country Scientific Production (BiblioShiny); **(b)** BIM Adoption Globally (Eischet, 2022).

China leads the list with 114 occurrences, highlighting the country's significant research output and investment in technological innovation within the construction industry. The United Kingdom follows with 67 publications, indicating strong academic and industrial interest in digital modeling and smart infrastructure.

Australia and the United States closely trail the UK, with 55 and 52 publications, respectively. This pattern reflects a balanced focus on digital twins in advanced economies where infrastructure development is a priority. India contributes 38 documents, emphasizing the growing importance of BIM and Digital Twins in emerging economies with rapid urbanization and construction.

Malaysia has 34 publications, and Saudi Arabia 23, illustrating that research in digital modeling is gaining traction in the Middle East and Southeast Asia. New Zealand (22) and Sweden (19) also contribute significantly to the literature, reflecting the emphasis on advanced construction techniques and smart infrastructure.

Countries such as South Africa and Turkey each have 17 publications, and Iran 16, while Canada follows closely with 15. These contributions highlight the global appeal of BIM and Digital Twins research. Other regions, including Egypt, Italy, and Nigeria, each contribute 10 publications, while Brazil, Pakistan, Poland, and Spain provide 9 each. The United Arab Emirates (UAE) is still emerging in this field with 8 documents which all are most likely to be recent as BIM is used more now in the construction industry in the UAE and is going through a significant growth especially after being a host for Expo 2020 (Al-Malkawi and Pillai, 2013; Mehran, 2016).

The global contribution of countries to the BIM and Digital Twins research can be seen to not be a reflection of the level of BIM adoption in the country as for example, The United States, then Europe, and Asia lead global BIM adoption (Figure 4), with mandates and programs integrating BIM into public projects but the USA is not leading in the research area as China is leading the research trend instead (European Parliament, 2014; Ullah et al., 2019; Wong et al., 2010; Burgess et al., 2018).

Asian nations, particularly Singapore and South Korea in Asia, have embraced BIM, which once again these 2 countries are not on the top countries in the BIM and Digital Twins research field lately. That is likely due to them already doing the research before in the past due to them being advanced in this topic (Wong et al., 2010; Ullah et al., 2019; Cheng and Lu, 2015).

The diverse regional contributions demonstrate the universal trend and importance of BIM and Digital Twins in research. Different countries are actively investigating how digital technologies can optimize construction, improve sustainability, and streamline infrastructure management, making the field both dynamic and globally relevant. The bar chart below (Figure 5) shows the most relevant authors based on the number of documents published in the field. Singh AK leads with eight documents, followed by Kumar VRP, Liu Z, and Sepasgozar SME, each with seven publications. Other notable authors include Shirrowzhan S, AlizadehSalehi S, and Kineber AF, each contributing five to six documents. These authors appear to be major researchers in the research on BIM and Digital Twins, contributing significantly to various fields.

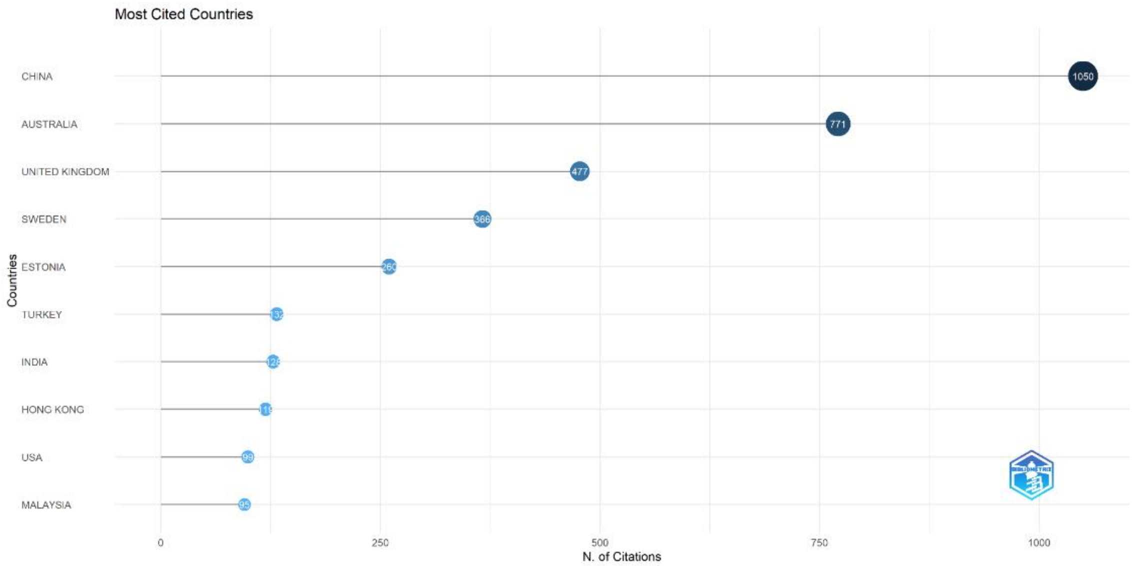


Figure 5. Most Relevant Authors (BiblioShiny).

Figure 6 highlights the countries with the most cited publications in BIM and Digital Twins research. China leads with over 1,050 citations, indicating its dominance in research output and influence in this field. Australia's 771 citations reflect the country's robust research community focusing on digital technologies in construction. The United Kingdom follows with 477 citations, showcasing its strong academic presence in digital modeling. Sweden and Turkey also contribute significantly, with Sweden accumulating 366 citations and Turkey 132. India and Hong Kong are next, emphasizing their growing involvement in this area, while the USA has 99 citations, showcasing its role in developing and applying advanced modeling techniques.

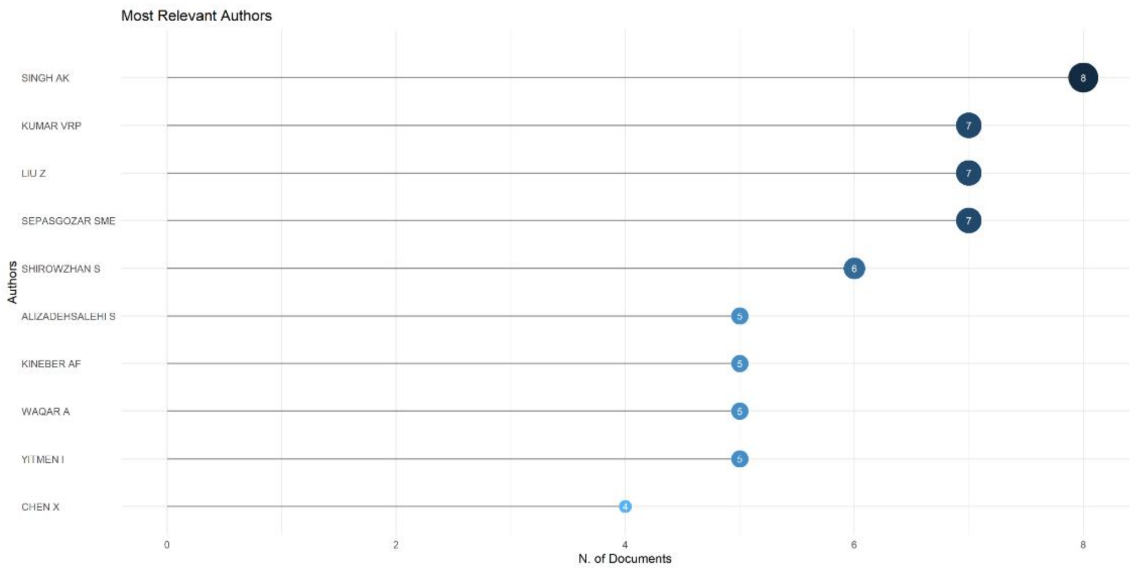


Figure 6. Most Cited Countries (BiblioShiny).

3.2. VOSviewer

3.2.1. Co-citation Analysis

The Co-citation VOSviewer network map (Figure 7) contains over 100 nodes, yielded after setting the minimum number of citations of an author to 55, which then represented influential authors and their keywords linked to BIM and Digital Twins. Each node represents a significant author or research theme, with the node size indicating the impact or relevance of that entity in the field. With approximately 197 links connecting these nodes, representing co-citation relationships, the map illustrates how often these authors or keywords are cited together. Thicker and denser lines between the nodes reflect stronger connections and frequent co-citations.

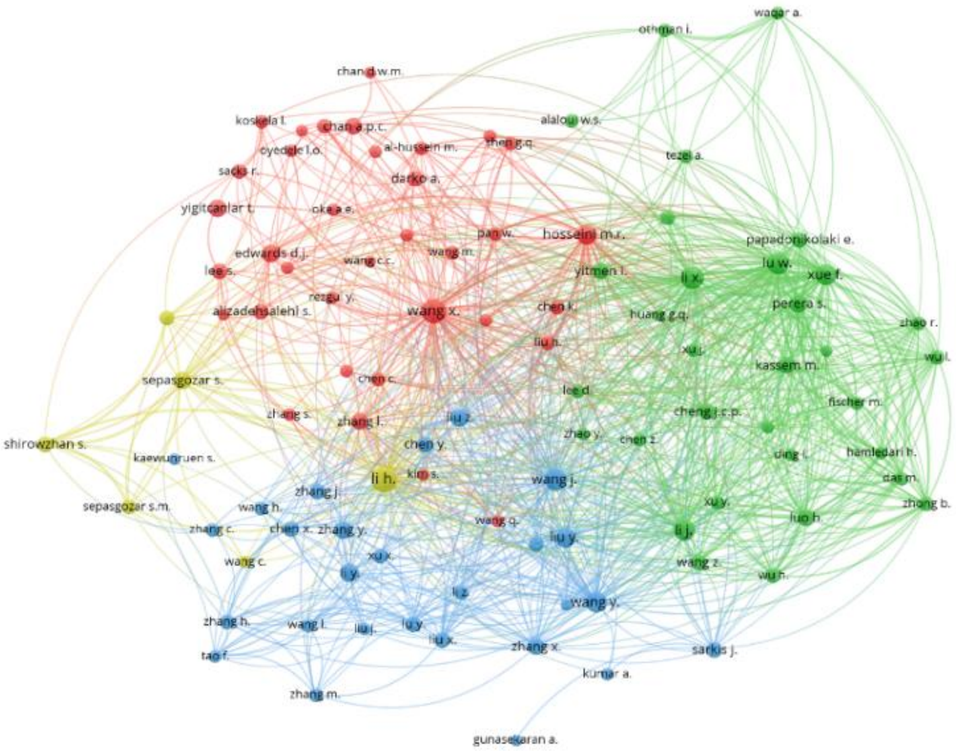


Figure 7. Most Cited Countries (BiblioShiny).

The network map reveals seven distinct thematic clusters, representing various research groups and their areas of focus. For instance, the red cluster may center on sustainability and decision-making, while the green cluster emphasizes project management and blockchain technology. Other clusters explore interdisciplinary technologies such as IoT, machine learning, and automation.

The dataset contains around 239 documents, with thousands of citations among them. China leads in terms of the number of documents and total citations, accumulating over 1,050 citations. Australia and the United Kingdom follow closely with 771 and 477 citations, respectively. Prominent authors like Singh AK and Kumar VRP frequently appear in the literature, underscoring their influential roles in this research area.

The total link strength reaches around 615, illustrating the degree of collaboration and thematic interconnection among the clusters. The collaborative and global nature of the research is evident, with the map revealing how international cooperation has shaped the field.

Key observations from the map include the prominence of the red cluster, focused on Wang X. and Chen K., which contains a high concentration of influential nodes tied to decision-making and digital twin adoption. The green cluster emphasizes blockchain and project management, featuring strong connections among authors like Kassem M. and Ding C. Meanwhile, the blue cluster includes themes such as building information modeling and virtual reality, with significant contributions from authors like Wang J. and Liu Y.

3.2.2. Co-Authorship Analysis

- Authors: Overlay Visualization;

The network map and co-authorship overlay for the Authors unit of Analysis shown in Figure 8 provide useful insights into the research patterns and agendas for BIM and Digital Twins from 2021 to 2024 with around 252 authors. Notably, larger nodes with authors "Kraus S.", "Durst S.", and "Ferreira J." indicate a high number of co-authorships, implying their critical roles as key researchers and primary collaboration hubs.

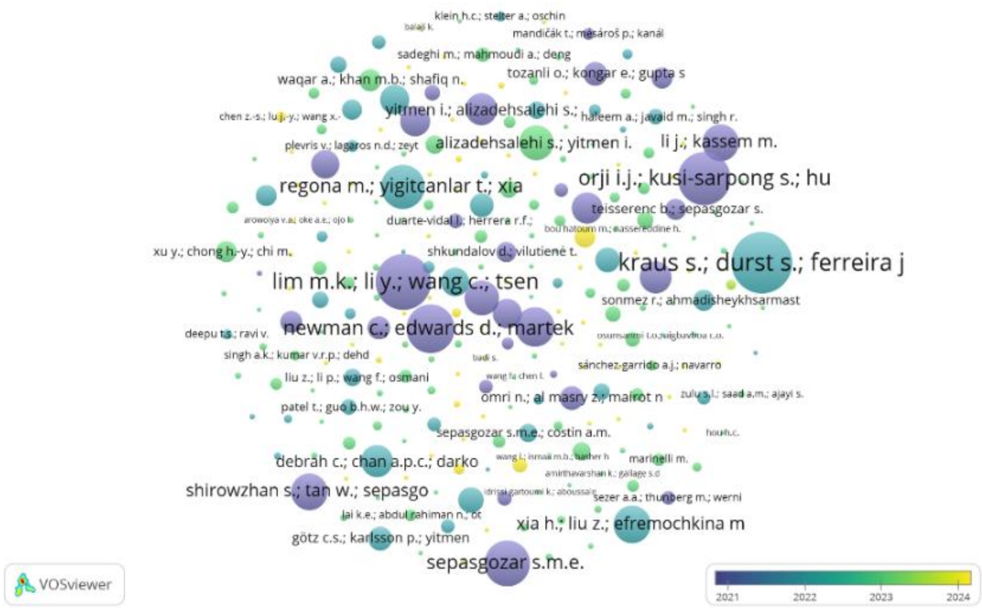


Figure 8. Co-Authorship Analysis for Authors (VOSviewer).

With reference to Figure 10, in 2021, the Co-Occurrence data visualization suggested a focus on integrating future technologies like "blockchain" and "Industry 4.0" inside construction management, emphasizing "digital transformation" and "technology adoption". Key researchers such as Sepasgozar S.M.E. and Yigitcanlar T. promoted these concepts. By 2022, the emphasis had turned to sustainability and life cycle analysis, with words like "sustainable development" and "circular economy" gaining prominence among authors such as Kraus S. and Kusi-Sarpong S. In 2023, the focus was on AI and data analytics in BIM, as led by Orji I.J. and Li J. Researchers such as Kassem M. and Ferreira J. are leading the charge to integrate intelligent systems into BIM in 2024, with an emphasis on "building industry 5.0" and "smart contracts".

Key observations include strong collaboration networks that connect various locations and areas of knowledge, as well as an increase in cross-disciplinary work between sustainability and technology adoption. The timeline shows a continual push to integrate sophisticated technologies such as blockchain, machine intelligence, and IoT into building. Emerging issues such as life cycle analysis, circular economy, and modular building are expected to influence the future of BIM and Digital Twins.

- Countries: Overlay Visualization;

The co-authorship with the country unit of analysis overlay visualization (Figure 9) shows a comprehensive view of the international collaboration network in BIM and Digital Twins research from roughly 2022 to 2023, with each node representing a country and the lines representing collaborative links. There are 25 countries from around the world in the sample with 5 distinct clusters and each cluster contains a set of countries.

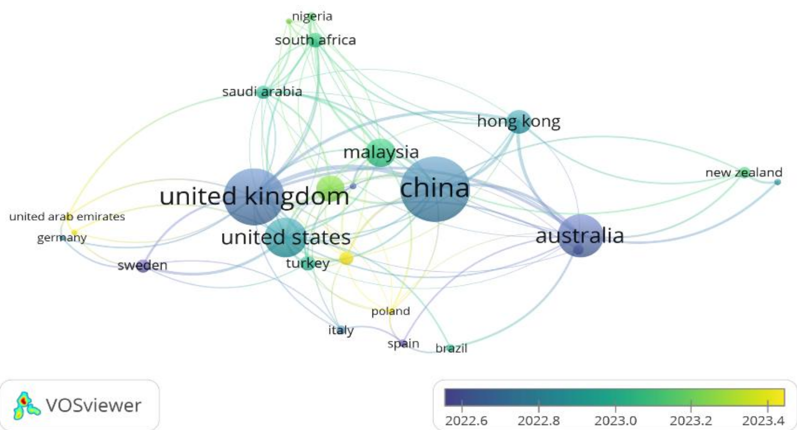


Figure 9. Co-Authorship Analysis for Countries (VOSviewer).

The United Kingdom, China, and Australia emerge as prominent nodes in the network with 50, 57, and 38 documents respectively, demonstrating their important collaborative roles in worldwide research. Their close contacts with other countries demonstrate significant cross-continental collaboration. The United Kingdom maintains significant ties with Canada, Germany, the United Arab Emirates, and India. These collaborations highlight the UK's extensive worldwide involvement in BIM research. China has several relationships, particularly with Hong Kong, Malaysia, and the United Kingdom, demonstrating its expanding scientific importance, particularly through collaboration with other Asian countries. Australia maintains strong relations with New Zealand, Singapore, and Hong Kong, demonstrating its significance in the Asia-Pacific area and global research activities.

The color gradient represents the period of collaboration, with yellowish green to light blue connections indicating fresh collaborations from 2022 to 2023. Malaysia, South Africa, and Nigeria have lately established collaborations, indicating a growing interest in the African continent and Southeast Asia for sustainable construction and smart city development. Singapore, New Zealand, and Australia are digital transformation centers in the Asia-Pacific region, with automation and Industry 4.0 continuing to impact research objectives.

The network map also shows regional networks, such as connections between European countries like the United Kingdom, Italy, and Poland. These links show how cross-border partnerships promote interdisciplinary cooperation, which stimulates innovation in sustainability and digital transformation.

- Countries: Network Visualization;

The co-authorship network map visualizes a similar relationship to the overlay visualization between countries engaging in BIM and Digital Twins research, with the difference that overlay visualization color codes with respect to its development over time, while network visualization indicates the cluster to which a node has been assigned. There are 5 clusters as mentioned earlier in this dataset for the country's analysis, where each cluster contains a set of countries as shown in Table 3 and illustrated in Figure 10.

Table 3. Co-Authorship Dataset.

Country	Documents	Citations	Link Strength
	Cluster 1		
United Kingdom	50	43	3
United States	35	26	4
Sweden	12	370	11
Germany	5	46	4
Jordan	5	1190	62
United Arab Emirates	5	452	40
	Cluster 2		
Australia	38	224	12
Hong Kong	21	479	29
New Zealand	10	1025	46
Iran	9	46	10
Singapore	6	106	8
	Cluster 3		
Malaysia	25	20	14
South Africa	13	221	27
Saudi Arabia	12	62	16
Nigeria	7	115	30
Egypt	5	244	25
	Cluster 4		
Canada	12	313	5
Italy	8	44	4
Brazil	7	53	17
Spain	7	120	4
Poland	5	58	11
	Cluster 5		
China	57	1164	49
India	23	241	23
Turkey	13	74	12
Pakistan	6	202	36

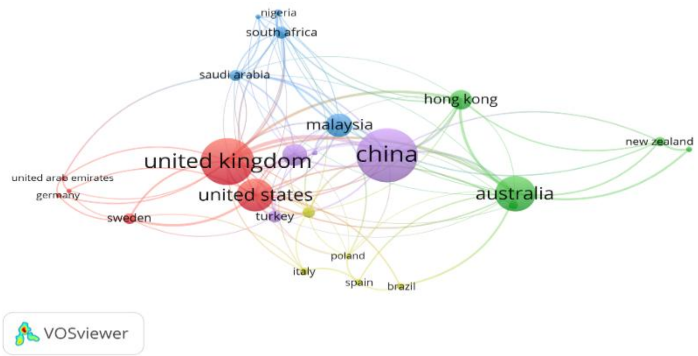


Figure 10. Co-Authorship Analysis for Countries (VOSviewer).

3.2.3. Keyword Co-Occurrence Analysis

- Network Visualization;

The VOSviewer network map (Figure 11) offers a visualization of the interconnected keyword themes and research clusters within BIM and Digital Twins. To improve the clarity and readability of the keyword co-occurrence maps, the minimum occurrence threshold was increased to 8, allowing only the most relevant and frequently occurring keywords to be visualized, yielding the analysis map to 54 nodes. Each node represents a keyword in the field. These nodes signify central research focus areas and thematic keywords crucial to the study of BIM and Digital Twins. Approximately 400 links connect these nodes, illustrating how frequently these terms or authors are cited together. The density and thickness of these links demonstrate the significance of these connections.

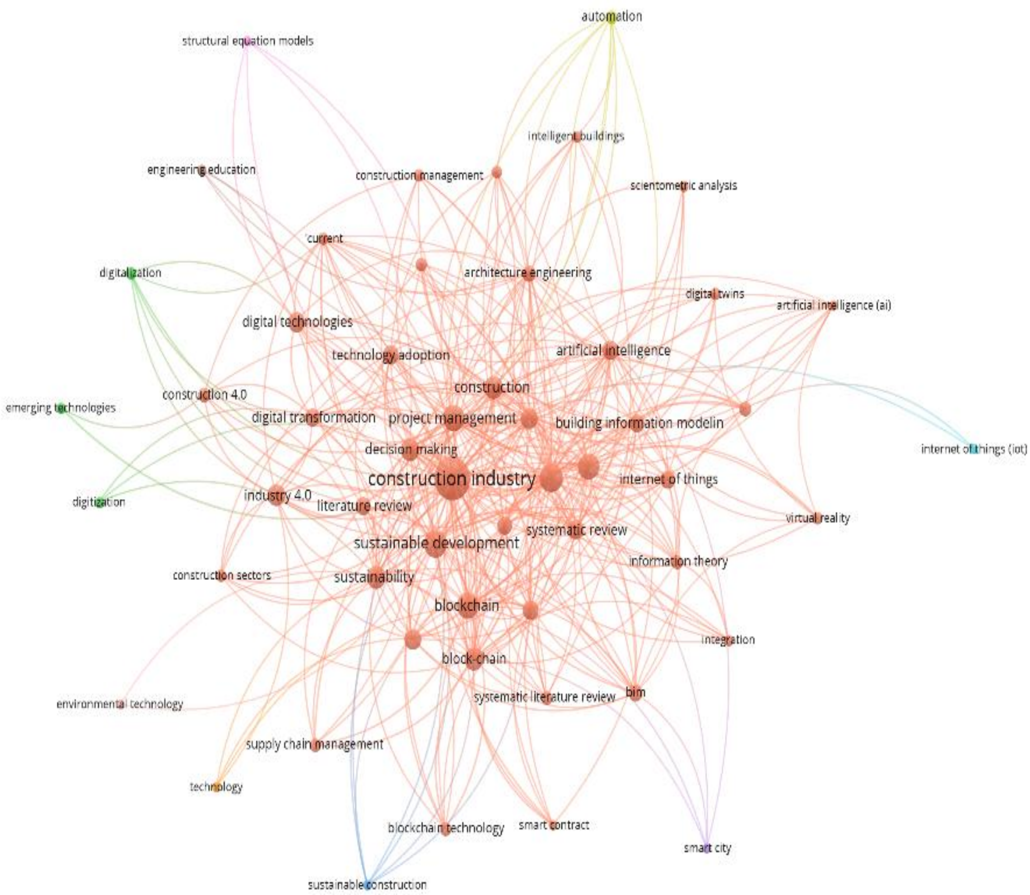


Figure 11. Co-Occurrence Analysis Network Visualization (VOSviewer).

The map reveals eight distinct clusters, each marked by a unique color to represent its research theme. For instance, the orange cluster emphasizes sustainable development, sustainability, technology adoption, centralizing emerging trends like Industry 5.0 and the circular economy. Furthermore, it focuses on project management, digital transformation, Industry 4.0, blockchain, and construction industry, which highlights the practical use of BIM and Digital Twins in optimizing project workflows. Meanwhile, the yellow cluster covers building information modeling, architectural design, and virtual reality, with research exploring how digital models can be incorporated into architectural education and engineering.

The blue cluster concentrates on interdisciplinary technologies like IoT, machine learning, and automation, highlighting how big data and artificial intelligence integrate into BIM systems. The purple cluster centers on engineering construction and operations, reflecting research on the technical aspects of using BIM in large-scale infrastructure projects.

The network map represents a dataset of over 230 documents and several thousand citations. The close interconnection of the cluster's points to high citation counts, particularly in sustainability and project management themes. Keywords such as construction industry, architectural design, blockchain, and sustainable development show strong links and frequent citations in those fields due to them being trending topics. Construction 4.0, Industry 4.0, and BIM are known to potentially be able to contribute to sustainable building development (Karmakar and Delhi, 2021; Chen et al., 2022).

Blockchain keywords had 41 occurrences, while construction industry had 83 occurrences, and sustainable development had 31 occurrences. This explains the ingoing trend in the research areas of BIM and Digital Twins in the possibilities behind the integration of BIM with other technologies like blockchain enhances sustainable construction projects by improving information management, fostering accurate data tracking, streamlining collaboration, and ensuring transparent, efficient project workflows (Karmakar and Delhi, 2021; Chen et al., 2022).

The total link strength may exceed 1,000 due to the strong interconnectedness among the research themes. The intersecting patterns between the different clusters highlights the multidisciplinary nature of BIM and Digital Twins research fields, as they all are part of construction 4.0 technologies and are semi-dependent on each other for seamlessly designing and building structures.

The dense links and thematic connections between the clusters reveal interdisciplinary collaboration in research. Isolated nodes, such as the modular construction suggests the potential gaps and opportunities for new studies where research remains limited.

- Overlay Visualization;

The Co-occurrence Analysis Overlay Visualization map (Figure 12) shows the range of studies period from 2019 to 2023 which was when the studies were first published in these fields and started seeing significant advancements in BIM and Digital Twins research. During 2019-2020, emerging technologies were increasingly integrated into BIM practices, emphasizing concepts and keywords like smart city, construction management and information management. The trend was on how advanced data analytics, digital collaboration, and distributed ledger technologies could enhance efficiency and transparency in the construction industry.

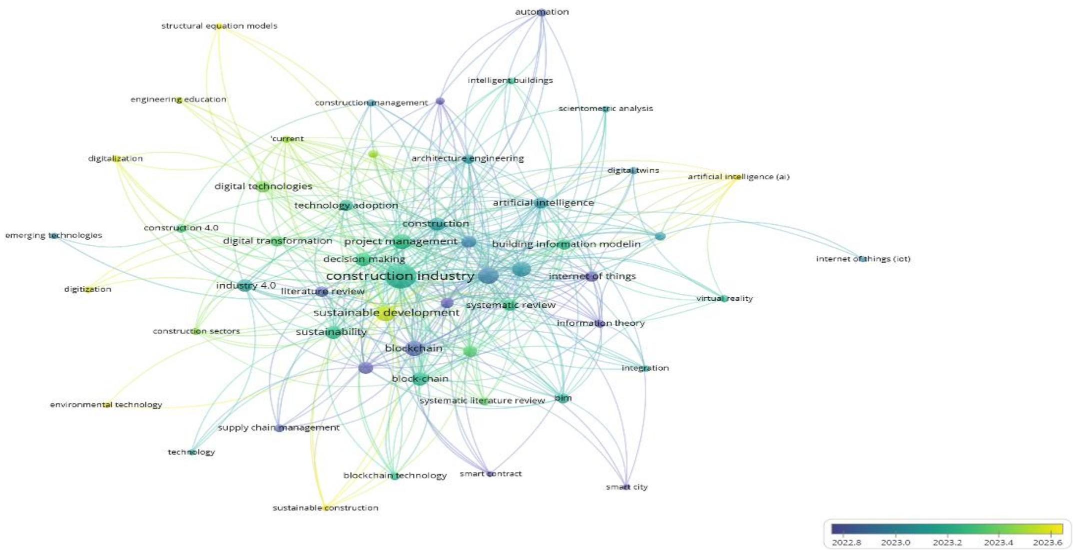


Figure 12. Co-Occurrence Analysis Overlay Visualization (VOSviewer).

In 2020-2021, the COVID-19 pandemic accelerated the adoption of digital tools to accommodate remote working conditions. Keywords such as virtual reality, digital twin, and remote monitoring highlighted the importance of immersive design and real-time data collection. The pandemic also heightened interest in sustainability, as the construction industry sought greener ways to rebuild.

The 2021-2022 period was marked by the consolidation of digital twin concepts and their broader applications. Terms like industry 4.0, automation, and artificial intelligence were increasingly tied to BIM to optimize construction processes and enhance decision-making.

In the years 2022-2023, emerging concepts and keywords like Building Industry 5.0, machine learning, and intelligent buildings showcased a vision where AI and automation seamlessly integrate with human creativity. Currently, research papers concerning the area of the construction industry have been focusing more on interdisciplinary collaboration, with keywords like sustainable development and industry 5.0.

3.2.4. Bibliographic Coupling

- Documents: Network Visualization;

Figure 13. shows this dataset that contains 237 nodes instead of 239, with 17 omitted due to their inconnectivity to other nodes. These are arranged into 10 clusters, each indicating a specific group of research based on similar references, emphasizing the closeness of subjects within the field.

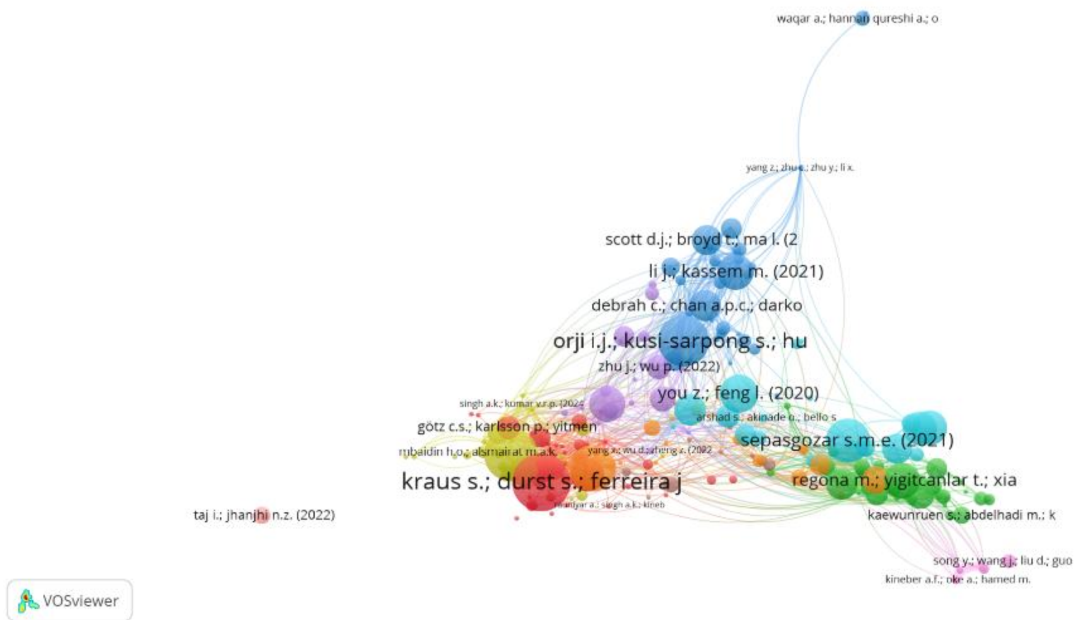


Figure 13. Bibliographic Coupling Analysis Network Visualization (VOSviewer).

Each cluster, designated by a distinct color, represents a distinctive study theme, with node sizes indicating the bibliographic coupling strength of individual papers. Larger nodes, such as Orji I. and Li J., indicate papers with great influence, as they share several references with other works in the cluster, emphasizing their foundational importance in establishing theme areas. The edges, which vary in thickness, show the strength of bibliographic ties between works, with thicker lines suggesting a greater degree of shared references and thus strong theme significance.

Among the nodes are crucial publications published by researchers such as Kraus S., Durst S., and Ferreira J., who appear significant in their own clusters. Furthermore, the significance of inter-cluster connections, emphasizing multidisciplinary relationships, points to a comprehensive movement across varied study fields. This is especially visible in the lines connecting various colored nodes, which could represent growing areas of interest that cross established study boundaries. Table 4 shows the top 10 authors with the highest bibliographic coupling strength of overlapping references.

Table 4. Top 10 Authors with the highest citation.

Document	Citations	Total Link Strength
kraus s.; durst s.; ferreira j.j.; veiga p.; kailer n.; weinmann a. (2022)	260	14
lim m.k.; li y.; wang c.; tseng m.-l. (2021)	215	40
orji i.j.; kusi-sarpong s.; huang s.; vazquez-brust d. (2020)	198	23
newman c.; edwards d.; martek i.; lai j.; thwala w.d.; rillie i. (2021)	164	21
sepasgozar s.m.e. (2021)	149	46
you z.; feng l. (2020)	109	15
xia h.; liu z.; efremochkina m.; liu x.; lin c. (2022)	102	28
regona m.; yigitcanlar t.; xia b.; li r.y.m. (2022a)	98	37
li j.; kassem m. (2021)	97	84
shirowzhan s.; tan w.; sepasgozar s.m.e. (2020)	95	1

- Documents: Overlay Visualization;

The bibliographic overlay visualization (Figure 14). shows the trend from 2021 to 2024. The map's colors represent different publishing years, ranging from blue for older publications to yellow for the most current.

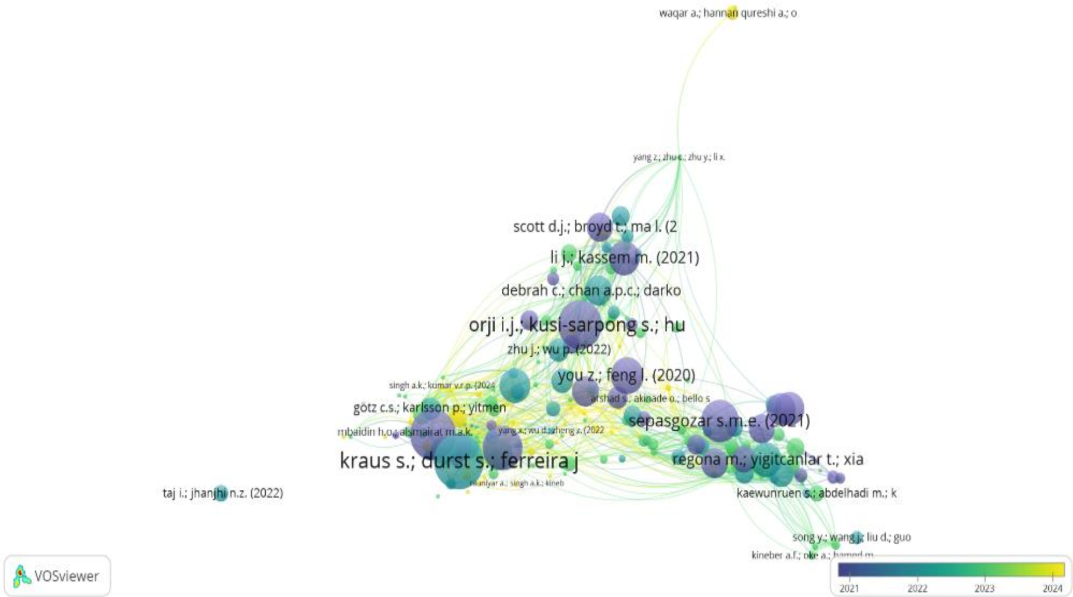


Figure 14. Bibliographic Coupling Analysis Overlay Visualization (VOSviewer).

The time overlay highlights patterns in clustering and connection among documents released in different years. Clusters ranging from blue to green in 2021-2022 focus on subjects such as "smart cities," "sustainability," and "digital transformation," involving significant authors including "Sepasgozar S.M.E.," "Kraus S.," and "Kusi-Sarpong S." Recent documents from 2023-2024, colored in yellow to orange, focus on subjects such as "AI and IoT integration," "intelligent buildings," and "automation," with authors including "Singh A.K.," "Qureshi A.," and "Kaewunruen S."

Influential authors with wide connections include "Durst S.," "Kassem M.," and "Ferreira J." These authors have a considerable impact on current research trends. Recent clusters from 2023-2024 (yellow) indicate an increasing interest in automation, machine learning, and modular building. Collaborative patterns appear from document clustering, demonstrating that research networks evolve over time. Some writers connect to numerous clusters, implying interdisciplinary partnerships. For example, the ties between "Sepasgozar S.M.E." and "Orji I.J." indicate cross-institutional collaboration in technology adoption and sustainability.

Furthermore, research gaps and possible future directions can be deducted from this visualization. Isolated clusters of documents with fewer connections may indicate emerging but unexplored areas. Concepts like "Industry 5.0" and "blockchain in construction" are gaining popularity, indicating prospects for interdisciplinary research.

4. Conclusion

This paper provides a comprehensive summary of the current advancements in BIM and Digital Twins within the construction sector. Although the integration of BIM with digital twin technologies is a relatively recent development, it has quickly become a focal point for research due to the pressing need for a technologically enhanced, sustainable built environment. Through a detailed bibliometric analysis of 254 journal articles, this review aims to lay a clear path for future research in this domain. The main outcomes are as follows:

Co-citation network map analysis emphasizes the active collaboration and citation among academics, demonstrating the field's worldwide and interdisciplinary nature, with substantial contributions from nations such as China, Australia, and the United Kingdom.

The growing research trends and key collaborative hubs in BIM and Digital Twins in the analysis of Co-authorship will emerge between 2021 and 2024. Key authors such as Kraus S., Durst S., and Ferreira J. are central nodes in vast co-authorship networks, demonstrating their critical positions in the area. The research focus has gradually shifted from integrating technologies such as blockchain and Industry 4.0 in 2021 to sustainability in 2022, and AI and data analytics by 2023. By 2024, the emphasis will be on integrating intelligent systems, demonstrating a strong trend of technological integration and cross-disciplinary collaboration in construction management.

On the other hand, the co-authorship country unit analysis overlay visualization is a strong worldwide collaboration network in BIM and Digital Twins research from 2022 to 2023. The United Kingdom, China, and Australia emerge as significant nodes, demonstrating their importance in worldwide research activities. The graphic emphasizes considerable cross-continental collaborations and the formation of new partnerships, particularly with nations in Africa and Southeast Asia, demonstrating a growing interest in sustainable construction and smart city development in these areas.

Keyword Co-occurrence Analysis study produces a thorough illustration of the interconnected keyword themes and research groups within BIM and Digital Twins. The tight relationships between the 7 separate clusters, each representing a core study subject such as sustainable development, project management, and new technologies such as IoT and machine learning.

Furthermore, the bibliographic coupling analysis shows a structured visualization of the 237 research publications arranged into 10 clusters, demonstrating theme consistency through shared references. This visualization shows prominent works and authors, such as Orji I. and Li J., who have a large impact on their clusters due to strong bibliographic connectivity. The map also follows changing research trends from 2021 to 2024, highlighting movements from digital transformation to AI and IoT integration. It emphasizes dynamic, multidisciplinary cooperation across multiple academic domains, reflecting an increasing interest in areas such as automation and machine intelligence.

In light of these findings, several directions for future research can be identified. There is a need to enhance interoperability between BIM and Digital Twin systems through the wider adoption of standardized data exchange frameworks such as IFC and COBie. Additionally, future studies should explore the integration of artificial intelligence and machine learning to improve predictive capabilities and automated decision-making within Digital Twin environments. Strengthening real-time data integration through IoT and WSN is also essential to enable more accurate and responsive Digital Twin models. Moreover, expanding Digital Twin applications from building-level implementations to urban and city-scale systems represents an important step toward supporting smart and sustainable cities. Finally, addressing challenges related to data management, cybersecurity, and system scalability will be critical for the successful implementation of BIM and Digital Twin technologies in the AEC industry.

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Conflict of Interest Statement

The authors declare no conflicts of interest.

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