

Review

Three Decades of Innovation: A Critical Bibliometric Analysis of BIM, HBIM, Digital Twins, and IoT in the AEC Industry (1993–2024)

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Abstract: Over the past 15 years, Building Information Modelling (BIM), Historic BIM (HBIM), Digital Twins, and Internet of Things (IoT) have gained prominence in architecture, construction, and building technology. This study presents a comprehensive bibliometric analysis of 5568 publications indexed in the Web of Science Core Collection between 1993 and 2024, using VOSviewer and Biblioshiny. The analysis investigates publication trends, research hotspots, citation structures, and collaborative networks, revealing evolving patterns across countries, institutions, and disciplines. The peak year was 2023 (905 papers, 2226 citations), with Automation in Construction, Buildings, and Journal of Building Engineering as the leading journals. Cheng JCP emerged as the most cited author (2059 citations, 56 papers), while Hong Kong Polytechnic University ranked highest in institutional output. China, the USA, and the UK were the top publishing countries. This study uniquely integrates BIM, HBIM, Digital Twins, and IoT as interconnected technological domains, analysing their convergence in shaping intelligent, data-driven infrastructure within the AEC sector. Unlike previous bibliometric reviews that treat these domains in isolation, this paper offers a unified framework and highlights underexplored research intersections—such as the integration of IoT in heritage documentation. The results show clear thematic clusters, a strong shift toward sustainability and interoperability, and gaps in geographic and methodological diversity. This bibliometric mapping not only synthesizes the state of research but also formulates future research directions and proposes original research questions that can guide scholars and practitioners alike.



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1. Background and Literature Review

Since 2009, Building Information Modelling (BIM) has changed information management throughout the construction process life cycle. BIM has greatly improved cooperation, cost reporting, construction sequencing, and facility management by offering a systematic, transparent, and synchronized process [1]. Especially in the field of heritage conservation, BIM has proved to be invaluable, as it offers a clear approach to the conservation management of historical buildings and records [2,3]. However, the construction industry is increasingly interested in Digital Twins (DTs), which have stimulated extensive academic debates on their application and advantages [4]. The integration of BIM and Digital Twins has started to be used, although the meaning of the integration differs for professionals and researchers. A Digital Twin is the virtual replica of a physical asset that is able to reproduce real-time operational and environmental conditions to support sustainable decision making

in financial, social, and environmental dimensions [5]. The idea of Digital Twins was invented by Professor Michael Grieves of the University of Michigan in 2003 [6]. Although it has been in use in the aerospace and automotive industries since then, its use in the AECO sector is fairly recent. It has been identified that there is still limited understanding of the concept of Digital Twins and how they can be integrated with current construction technologies such as BIM [7].

1.1. Study Rationale and Novelty

Despite the growing academic output in the domains of BIM, Digital Twins, HBIM, and IoT, existing bibliometric studies tend to address these technologies in isolation, often focusing exclusively on BIM or DTs without recognizing their growing convergence. As the AEC industry rapidly evolves toward integrated digital ecosystems, there is an urgent need to examine these technologies holistically, not only to map publication trends but also to identify shared research challenges, gaps, and innovation clusters.

This study fills that gap by conducting a comprehensive bibliometric analysis that fuses these four critical domains into a unified analytical framework. Unlike earlier reviews that focus on narrow time spans or specific technologies, this work spans three decades (1993–2024), incorporates advanced tools (VOSviewer v. 1.6.20 and Biblioshiny v. 4.1), and explores both thematic evolution and collaborative networks globally. The inclusion of HBIM and IoT in the analysis also responds to emerging research interests in heritage conservation and real-time, sensor-driven digital construction.

By visualizing and critically interpreting co-citation networks, keyword clusters, and institutional collaborations, this study offers new insights into the strategic directions of research, the evolution of digital innovation in construction, and future interdisciplinary opportunities. This holistic, cross-domain perspective makes this work not only timely but uniquely positioned to inform academia, industry, and policy.

1.2. Defining Digital Twins and Their Role in Construction

Various meanings of Digital Twins have been developed in the literature. Some scholars define it as a virtual model that runs in real time to control, reason about, and simulate the behaviour of a physical object [8]. Others see it as a digital copy of a process or an operation in the real world [9]. According to Tuhaise, Tah, and Abanda, BIM is the basis for Digital Twin development in the construction industry, where BIM manages project efficiency, cost estimation, and scheduling, and the Digital Twin enhances these functions by incorporating real-time monitoring and operational data [10]. The full potential of Digital Twins is only achievable with the application of advanced data processing, storage, integration, visualization, and interoperability [10]. Consequently, real-time monitoring techniques are vital to enable accurate and dynamic digital modelling [11,12]. Based on data flow processes, Digital Twins are explained in the literature. The Digital Shadow is a one-way data flow model which implies that data are transferred from a physical object to its digital twin. The Digital Twin is the two-way data flow model that enables online monitoring and feedback for incremental updates [13,14]. This capability to incorporate live data sources is one of the most frequent comparisons between BIM and Digital Twins [15].

Digital Twin levels were also further categorised based on the developmental stages and features [16]. Scholars generally agree on two fundamental principles: (1) a Digital Twin must mirror its corresponding real-world asset accurately, and (2) it must remain actively associated with its physical twin to update it dynamically [7]. In construction, Digital Twins offer unique benefits, including smart city modelling, construction monitoring, decision making, design optimization, real-time progress reporting, product manufacturing, and facility management [10]. BIM and Digital Twins have similar functions and goals;

therefore, they are closely related. The relation between these two technologies is the primary reason that researchers have identified three main perspectives [17,18]. Some argue that Digital Twins are a step beyond BIM, which offers passive modelling during design and construction to active management of the built product in operation. Others argue that BIM and Digital Twins are different but related approaches that apply different strategies to different project life cycles, where BIM is used in the design and construction stages, while Digital Twins are used in the operation and maintenance stage [19]. Although authors have different opinions on the evolution of BIM and Digital Twins, everyone agrees that these two technologies are vital in changing the AECO industry [20].

1.3. Challenges and Limitations in BIM and Digital Twin Integration

Although BIM and Digital Twins are very potent tools that could be used to transform the construction industry, their adoption on a large scale is limited by several factors. The current challenge with BIM is that it is not capable of embracing dynamic real-time environmental data, especially during construction and operation [21]. At the moment, the huge amount of non-geometric data collected during a building's life cycle is not fully exploited to inform decision making and cost control [22].

Furthermore, BIM models have a lack of interoperability because they have to deal with a vast amount of data and different formats. This limitation demands the application of new digital technologies for data analysis, visualization, and real-time information exchange [10]. Like Digital Twins, they face issues in connectivity with their physical twins for continuous updating, which is a challenge in terms of data security, storage, and computation [7].

1.4. The Role of BIM in Heritage Documentation

The application of BIM in the construction industry has led to the development of Historic Building Information Modelling (HBIM), which has been useful in the documentation, restoration, and management of heritage structures [23–26]. The HBIM framework was first introduced by Murphy et al. [26] and Dore and Murphy [27] and has since been used as a vital tool in architectural heritage conservation. Previous research works have also been conducted on the use of HBIM for modelling accuracy, semantic richness, and structural performance assessment [3,27,28]. The integration of laser scanning, photogrammetry, and point cloud processing has greatly improved the HBIM's capability to create Digital Twins for heritage buildings [25,29–31].

Recent advancements in HBIM have also explored the integration of real-time monitoring technologies using sensor networks embedded in historical structures. This integration allows for continuous data acquisition of parameters such as structural movement, humidity, temperature, and material degradation—enabling predictive maintenance and long-term conservation strategies. The incorporation of sensor data within HBIM environments enhances the model's value by linking geometric documentation with operational performance over time, particularly for buildings at risk of deterioration due to environmental or structural factors [32,33].

1.5. The Integration of IoT in Digital Construction

This makes it possible to achieve real-time dynamic management of the built environments with the help of BIM, Digital Twins, and IoT. The combination of IoT sensors, real-time data analytics, and cloud-based platforms such as ACC enhance the monitoring, simulation, and predictive capabilities of BIM models through Digital Twins. In this regard, some scholars have regarded Digital Twins as an evolution of BIM to provide more dynamic information on the performance of the built environment [6].

This paper aims to explore how BIM integrated with Digital Twins enhances sustainability outcomes including energy performance, environmental impacts, and resource use. Digital Twins are expected to become more important in climate-responsive building designs, smart infrastructure management, and carbon emissions reduction as the world focuses more on sustainable construction [20].

1.6. AI-Enhanced Digital Twins

AI-enhanced Digital Twins are the highest level of integration of artificial intelligence technologies with digital twin models that greatly enhance the efficiency and accuracy of BIM processes in the architecture, engineering, and construction (AEC) industry. The latest developments [34–36] have shown that by applying machine learning algorithms and real-time data analysis, digital twins can update BIM models in real time to support predictive maintenance, energy management, and decision making throughout a building's life cycle. For example, deep reinforcement learning techniques have been applied effectively in the performance monitoring and simulation accuracy enhancement of BIM-based Digital Twins [37]. In addition, the integration of generative AI methods allows for the identification and solution of BIM model issues, thereby facilitating the transition from static documentation to dynamic, self-updating models that better represent the actual conditions [38]. Therefore, Digital Twins driven by AI do not just improve the functions of conventional BIM but also create a foundation for intelligent, adaptive, and sustainable built environments [39].

1.7. Research Gaps and Study Objectives

Although there is a vast amount of research available on BIM applications, there is limited research that examines BIM's relationship with Digital Twins, HBIM, and IoT. Some of the current research studies are based on conventional BIM implementation, while there is limited emphasis on the new and emerging aspects of BIM, such as real-time monitoring, automation with the help of artificial intelligence, and improved data security through blockchain in construction. This study intends to fill these research gaps by offering a systematic review of the literature on BIM, HBIM, Digital Twins, and IoT with regard to the following:

- The development of BIM research and its relation to Digital Twins and IoT.
- New approaches to BIM in heritage conservation based on HBIM approaches.
- IoT-enabled Digital Twins' role in increasing construction automation and sustainability.

Through analysis of the literature and the identification of the main topics, this study presents a conceptual framework for the definition of the state of the art and the future of BIM, HBIM, Digital Twins, and IoT in the AECO sector. A general view of the study's research framework is shown in Figure 1, which shows the interconnection between BIM, heritage modelling, digital transformation, and IoT-based construction technologies.

1.8. Research Contribution

In this study, a systematic bibliometric analysis of the literature on Building Information Modelling (BIM), Historic BIM (HBIM), Digital Twins, and Internet of Things (IoT) is carried out to shed light on the evolution of research, significant findings, and gaps in the existing literature. Different from previous bibliometric reviews, this review covers a longer time span and uses more sophisticated bibliometric tools, including VOSviewer and Biblioshiny to visualize the citation patterns, keyword co-occurrences, and collaborative networks. The main contributions of this study are to map global research trends, to identify emerging topics, and to analyse industry adoption of these technologies including interoperability, AI-enhanced applications, and real-time data integration. There is however

one important limitation of this study: it is based solely on the Web of Science database. This was done in order to guarantee the quality and indexing of the data to be used for bibliometric analysis. Nevertheless, the omission of databases such as Scopus, IEEE Xplore, and Google Scholar may introduce biases in bibliometric analysis—especially with respect to geographical diversity and the inclusion of applied engineering and interdisciplinary research. As highlighted in studies published in *Scientometrics* and *QSS*, different bibliographic databases have varying coverage by language, region, and subject area, and selecting a single source (e.g., WoS) may limit representativeness [40–42].

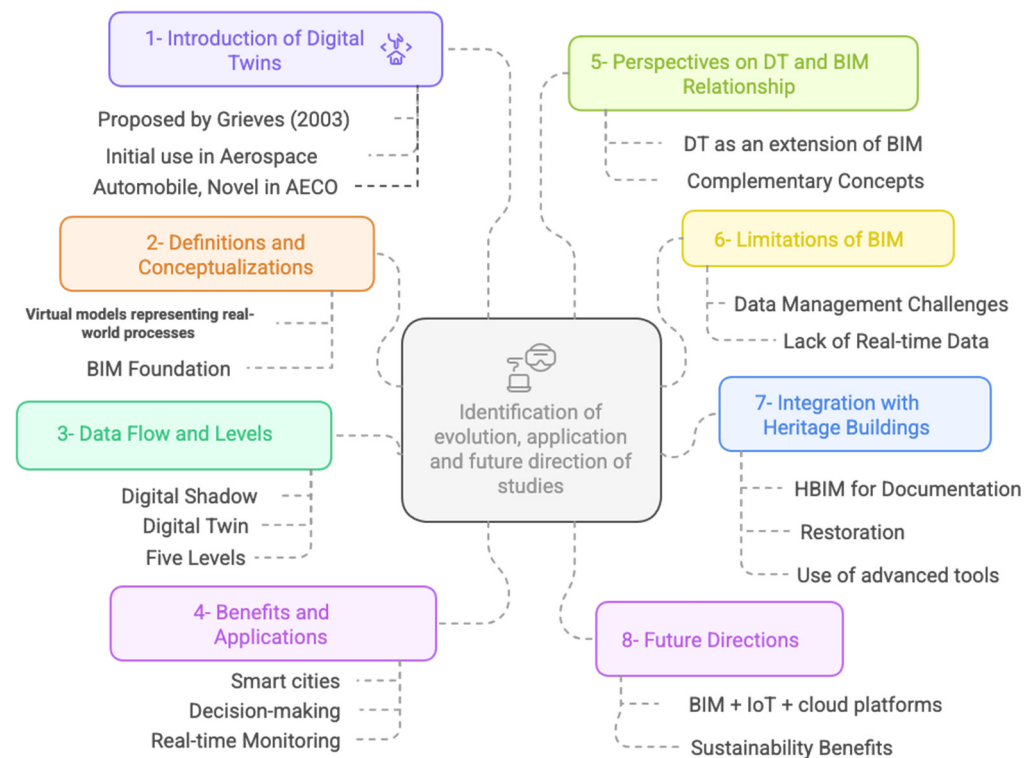


Figure 1. Identification of evolution, application, and future direction of studies (author).

To overcome this limitation, it is suggested that in the future, more databases should be incorporated to cross check and build on the findings in order to provide a more holistic picture of the developmental trends in research. Despite this, the current study is still useful for researchers investigating digital transformation in the AEC industry, practitioners who want to improve their BIM, HBIM, Digital Twins, and IoT practices for better project performance, and policy makers who are looking to promote the development of sustainable digital infrastructure in construction and heritage conservation.

2. Research Methods

This study uses bibliometric analysis as the main method for collecting data, which is a quantitative approach to the assessment of the scholarly output in the area of Building Information Modelling (BIM), Historic BIM (HBIM), Digital Twins (DT), and the Internet of Things (IoT) within the field of architecture, construction, and building science and technology. Bibliometric analysis is the application of statistical and mathematical methods to determine research trends, key contributions, and the overall impact of the scholarly work. At the level of bibliometrics, this study uses scient metric analysis which is the systematic study of scientific communications, citation linkages, and collaborative research structures [43]. Through the application of bibliometric methods, this study seeks to determine high-impact papers, the most productive authors, leading institutions, and

new emerging areas of research in BIM, HBIM, Digital Twins, and IoT. The analysis also provides insights into the growth rate of publications, citation patterns, and international collaboration. To achieve this, the current study employs bibliographic databases and citation analysis tools in alignment with established practices in bibliometric studies. Notably, similar methodologies have been adopted in previous high-impact analyses, such as those published in *Scientometrics* and *Quantitative Science Studies* [40–42], which emphasize the systematic evaluation of scientific output and collaborative patterns through platforms like Web of Science and Scopus.

2.1. Search Strategy and Data Collection

To obtain the bibliographic data, a systematic search query was conducted and executed in the Web of Science database. The search terms were chosen to match the primary research domains of the study. The search string used was as follows: TS = (“Building Information Modelling” OR “BIM”) OR TS = (“HBIM” or “Historic or Heritage BIM” or “H-BIM”) OR TS = (“Digital Twin”) OR TS = (“Internet of Things” OR “IoT”).

The data for this study were collected from the Web of Science Core Collection, including the Science Citation Index Expanded (SCI-EXPANDED) and Social Sciences Citation Index (SSCI) from 1993 to 2024. While Web of Science provides a high level of indexing quality, recent studies have noted its limitations in disciplinary, linguistic, and regional coverage—suggesting the importance of incorporating multiple databases such as Scopus or Dimensions for more comprehensive bibliometric mapping [44,45].

To refine the dataset, language and document type filters were used: only English-language publications were reviewed. Excluded document types were meeting or film reviews, fiction, creative prose, excerpts, dance performance reviews, reprints, record reviews, art exhibit reviews, publications with expression of concern, notes, data papers, letters, or news items. The research areas were limited to construction building technology and architecture to exclude publications from other fields.

To ensure the quality, relevance, and consistency of the dataset, the following inclusion and exclusion criteria were applied:

- Inclusion criteria:
 - Peer-reviewed journal articles and review articles indexed in the Web of Science Core Collection.
 - Publications written in English.
 - Articles published between 1993 and 2024.
 - Records containing at least one of the following search terms in the title, abstract, or author keywords: “Building Information Modelling” OR “BIM” OR “HBIM” OR “Historic BIM” OR “Digital Twin” OR “Internet of Things” OR “IoT”.
 - Publications indexed under SCI-EXPANDED and SSCI, specifically within the fields of construction building technology and architecture.
- Exclusion criteria:
 - Non-English publications.
 - Document types unrelated to scholarly research, including but not limited to the following: meeting or film reviews, fiction, creative prose, reprints, letters, news items, notes, data papers, art exhibit reviews, and similar non-peer-reviewed outputs.
 - Articles from unrelated domains (e.g., healthcare, literature, pure physics) that mentioned target keywords but were determined to be contextually irrelevant to the AEC industry upon manual inspection.

This filtering approach ensured that only the most relevant articles were selected for the bibliometric analysis, maintaining focus on the digital transformation of the AEC sector. This resulted in 5568 articles.

To improve transparency and reproducibility, a sample version of the search query and its structure is included in Appendix A. Due to session-based limitations of Web of Science, a permanent direct URL is not available, but the search is easily replicable using the provided terms and filters.

2.2. Data Extraction and Processing

The search was carried out on 29 February 2024, and the initial list of documents included 156,267. The data refinement steps were as follows:

- Exclusion of irrelevant document types: 275 publications were removed. This includes non-scholarly and non-peer-reviewed document types such as editorials, book reviews, letters, meeting abstracts, news items, reprints, fiction, and creative prose, which do not contribute meaningfully to citation-based bibliometric analysis.
- Language filtering: 1719 non-English publications were eliminated.
- Domain-specific filtering: This excluded 148,705 publications that were not in the construction, building technology, and architecture research areas.

To address the balance between theoretical and practical contributions in the dataset, a content-level classification was performed during the data analysis phase. Each article was categorized based on its abstract and keywords into one of the following:

- Theoretical focusing on conceptual frameworks, method development, or model formulation without immediate real-world application.
- Practical—emphasizing real-world implementation, case studies, technology adoption, and industry-specific solutions.
- Hybrid—combining both theoretical foundations and practical case applications.

This classification helped to ensure a more nuanced understanding of the literature and to examine how research trends align with industry needs. Of the 5568 articles analysed, approximately 39% were theoretical, 44% practical, and 17% hybrid in nature. Notably, the share of practically oriented studies has increased over the past decade, especially with the rise of IoT-enabled Digital Twins and AI-enhanced BIM applications. This trend reflects the growing integration of academic innovation into real-world construction and heritage conservation practices.

The data extraction and refinement process are depicted in Figure 2, which shows the overall methodology used in a structured manner.

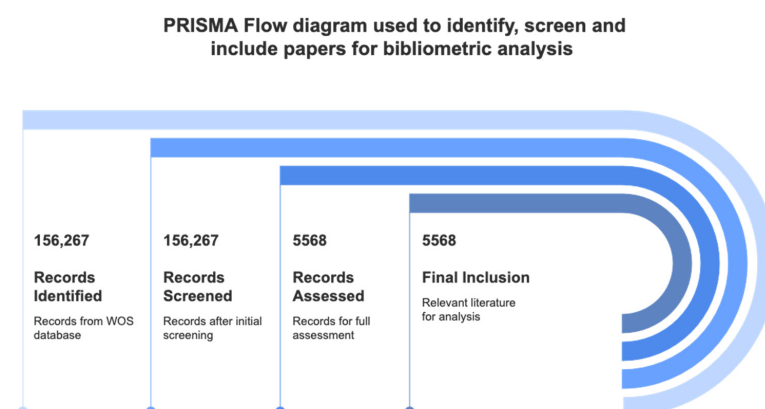


Figure 2. PRISMA flow diagram used to identify, screen, and include papers for bibliometric analysis (author).

2.3. Data Analysis Tools and Techniques

The final dataset was downloaded in plaintext and tab-delimited text formats to make sure it is compatible with bibliometric analysis software. For the purpose of analysis, the following bibliometric tools were used:

- VOSviewer [46]: For the network visualization and co-authorship analysis and to determine collaborative research patterns among authors, institutions, and countries.
- Biblioshiny [41,47]: A bibliometric software package to facilitate the mapping of keyword co-occurrence, thematic trends, and citation analysis.
- Microsoft Excel: For data cleaning, aggregation, and statistical representation of bibliometric indicators.

In applying these tools, this paper systematically examines research patterns, emerging trends, and influential contributions in the BIM, HBIM, Digital Twins, and IoT research domain.

The structured methodology ensures rigorous data processing, visualization, and interpretation to present a comprehensive understanding of the evolution and impact of digital transformation in the built environment.

3. Analysis

This bibliometric analysis offers a comprehensive analysis of research trends in Building Information Modelling (BIM), Historic BIM (HBIM), Digital Twins (DT), and Internet of Things (IoT) in the architecture, engineering, and construction (AEC) sector. The research covers 5568 documents from 439 sources and reveals a distinct growth trajectory with a 17.39% annual increase in publications. There are 11,892 authors in the dataset, with a notable 25.86% international collaboration rate, which suggests a highly cooperative research environment. Sustainability, AI integration, and digital transformation have become more important in recent years, as they reflect the changing priorities of the industry. Figure 3 shows an overview of research trends, highlighting the rapid growth in publications and international collaboration within BIM, HBIM, DT, and IoT in the AEC sector.

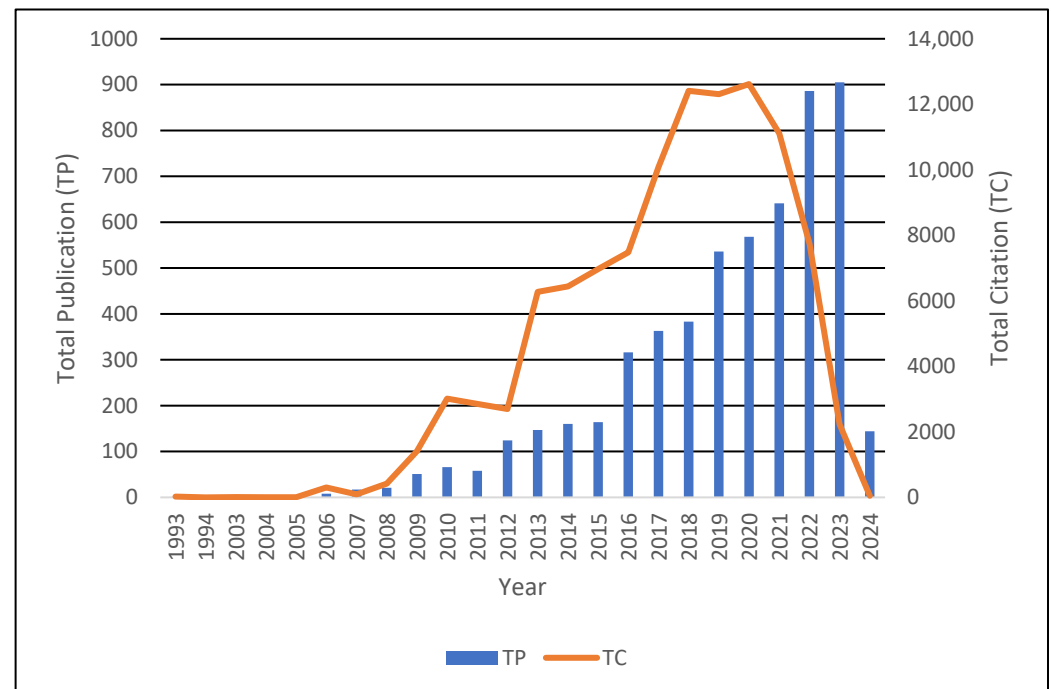


Figure 3. An overview of the research trends highlighting the rapid growth in publications and international collaboration within BIM, Historic BIM (HBIM), Digital Twins (DT), and Internet of Things (IoT) in the architecture, engineering, and construction (AEC) sector.

3.1. Yearly Growth of Publication and Citation Trends

Research in BIM, HBIM, DT, and IoT has been on the rise since 2006, but publications picked up significantly after 2012. The peak was in 2023, with 905 publications and 2226 citations, which indicates the growing academic interest. Although the total number of publications has been on the rise, the citation trends are rather fluctuating and the most intense trends is seen in 2020, with 12,615 citations. These variations indicate that foundational studies that have been carried out in the past keep on having a significant impact on subsequent research.

As shown in Figure 4, there has been a noticeable increase in the number of publications in recent years. While this growth reflects rising scholarly interest and technological advancements in BIM, Digital Twins, and IoT, it should also be noted that part of this increase can be attributed to the expansion of the Web of Science Core Collection itself. Recent studies (e.g., Liu et al., 2024 [48]) have observed that changes in WoS indexing policies, the inclusion of additional journals, and broader disciplinary coverage have influenced publication trends in bibliometric analyses. Therefore, the rising curve should be interpreted with this contextual factor in mind. It is anticipated that the implementation of Digital Twins and AI-based BIM applications in the last two years will also enhance research productivity. However, it should be noted that the data for 2023 and particularly for 2024 may be incomplete due to indexing delays in the Web of Science Core Collection. As the search was conducted in February 2024, some recent publications may not yet have been fully indexed, and citation counts for these years are likely to be lower due to the short time available for scholarly citation accumulation. This temporal limitation should be considered when interpreting the sharp increase in recent publications and the relatively low citation figures in the most current years.



TP=Total Publication, TC=Total Citation

Figure 4. Yearly growth of publication and citation trends.

3.2. High-Impact Sources in BIM, HBIM, DT, and IoT Research

The top 10 sources for research in this domain are mainly high-impact journals, with *Automation in Construction* being the leading journal with 1012 publications and an h-index

of 118. This is followed by *Buildings* and the *Journal of Building Engineering*, which are also well represented in the literature. The dominance of publications from Elsevier and MDPI journals reveals the preference for construction technology journals as specialized publications [49,50]. Table 1 summarizes the leading publication sources, and their role in determining research directions.

Table 1. Top 10 sources of BIM, HBIM, DT, and IoT in the construction, building technology, and architecture field.

Rank	Sources	ISSN(s)	TP	TC	TC/TP	H Index	PY Start	JIF	Publisher	Country
1	Automation in Construction	0926-5805	1012	52,299	51.68	118	2006	10.3	Elsevier	The Netherlands
2	Buildings	2075-5309	553	4434	8.02	31	2013	3.8	MDPI	Switzerland
3	Journal of Building Engineering	2352-7102	224	4437	19.81	35	2015	6.4	Elsevier	The Netherlands
4	Journal of Construction Engineering And Management	0733-9364/1943-7862	215	5595	26.02	39	2009	5.1	ASCE	USA
5	Sustainable Cities and Society	2210-6707/2210-6715	205	7870	38.39	51	2013	11.7	Elsevier	The Netherlands
6	Energy and Buildings	0378-7788/1872-6178	141	4182	29.66	40	2013	6.7	Elsevier	Switzerland
7	Building and Environment	0360-1323/1873-684X	132	4213	31.92	35	2010	7.4	Elsevier	UK
8	Advances In Civil Engineering	1687-8086/1687-8094	129	1573	12.19	22	2013	1.8	HINDAWI	USA
9	International Journal of Construction Management	1562-3599/2331-2327	124	2054	16.56	27	2011	3.9	TAYLOR & FRANCIS	UK
10	Construction Innovation-England	1471-4175/1477-0857	110	1290	11.73	23	2016	3.3	Emerald	UK

3.3. Leading Authors in BIM, HBIM, DT, and IoT Research

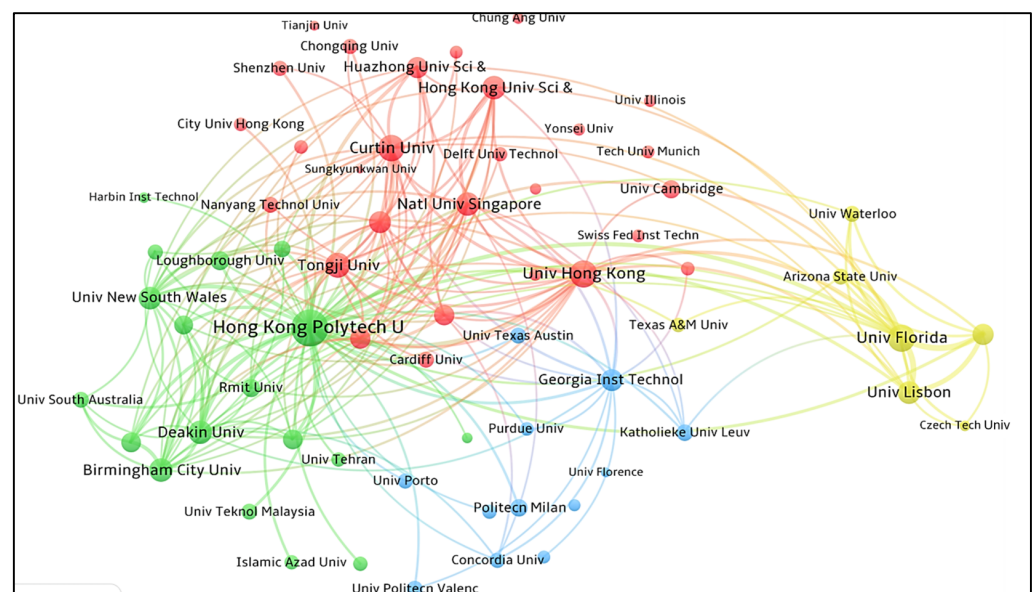
Only a number of exemplary researchers have made considerable contributions to the field. The highest ranking is Cheng JCP from Hong Kong University of Science & Technology with 56 publications and 2059 citations associated with BIM interoperability and AI-enabled applications. Other key contributors include Li H (Hong Kong Polytechnic University) and Wang J (Western Sydney University). An interesting finding is that the citation per publication ratio (TC/TP) of Wang XY is 73.21, which suggests that sometimes, important problems can be solved with a smaller number of publications. Table 2 presents the most influential authors and their contributions.

3.4. Leading Research Institutions in BIM, HBIM, DT, and IoT

An institutional analysis reveals that the Hong Kong Polytechnic University is the most productive with 129 publications and 5437 citations, while Politecnico di Milano and Tongji University are second and third, respectively. The universities, along with others such as Curtin University and Georgia Institute of Technology, define a global network of BIM and Digital Twin research and collaboration across disciplines. Figure 5 gives a visual representation of the top 64 research institutions contributing to BIM, HBIM, DT, and IoT.

Table 2. Top 10 authors of BIM, HBIM, DT, and IoT research in the construction, building technology, and architecture field.

Rank	Author	Affiliations	Country	TP	TC	TC/TP	H Index	PY Start
1	Jack C.P. Cheng	Hong Kong University of Science & Technology	China	56	2059	36.77	24	2010
2	Heng Li	Hong Kong Polytechnic University	China	36	1232	34.22	17	2010
3	Jun Wang	Western Sydney University	Australia	36	1259	34.97	11	2013
4	Xiangyu Wang	Curtin University	Australia	34	2489	73.21	21	2010
5	Weisheng Lu	University of Hong Kong	China	29	895	30.86	14	2010
6	Hanbin Luo	Beijing Normal University	China	27	1399	51.81	17	2013
7	M. Reza Hosseini	The University of Melbourne	Australia	26	1344	51.69	17	2016
8	Jiansong Zhang	Zhejiang University	China	25	387	15.48	9	2014
9	David J. Edwards	Birmingham City University	UK	24	1251	52.13	17	2017
10	Yi Liu	Chinese Academy of Sciences	China	24	145	6.04	6	2013

**Figure 5.** The visualization displays 64 high-yield organizations, each issuing at least 25 documents. Source: VOSviewer software.

3.5. Global Research Contributions by Country

The VOSviewer approach utilizes co-authorship analysis to examine the collaboration across countries in academic publications. Using a minimum of 25 documents and 0 citations as criteria for inclusion, 45 out of 103 countries have met the criteria. This results in five clusters, as shown in (Figure 6).

Cluster 1: This is the second largest cluster, which comprises 19 countries (Austria, Belgium, Brazil, Canada, Chile, Czech Republic, Denmark, France, Germany, Italy, The Netherlands, Norway, Portugal, Scotland, Slovenia, Spain, Sweden, Switzerland, and Turkey) with 2192 publications and 37,274 citations.

Cluster 2: This cluster includes ten countries (Egypt, Finland, India, Ireland, Pakistan, Russia, Saudi Arabia, United Arab Emirates, the United Kingdom, and Wales) with 1115 publications and 25,934 citations.

Cluster 3: This is the largest cluster, consisting of seven countries (China, Poland, Singapore, South Korea, Taiwan, and the USA), demonstrating the highest level of productivity

in terms of both total publications (2763) and total citations (64,713). These nations have the highest aggregate number of articles and citations among the 45 selected countries.

Cluster 4: This cluster consists of six countries, namely Australia, Iran, Lithuania, Malaysia, Nigeria, and South Africa, with 838 publications and 21,009 citations.

Cluster 5: This is the smallest cluster of three countries, Japan, New Zealand, and Vietnam, with 150 publications and 1732 citations.

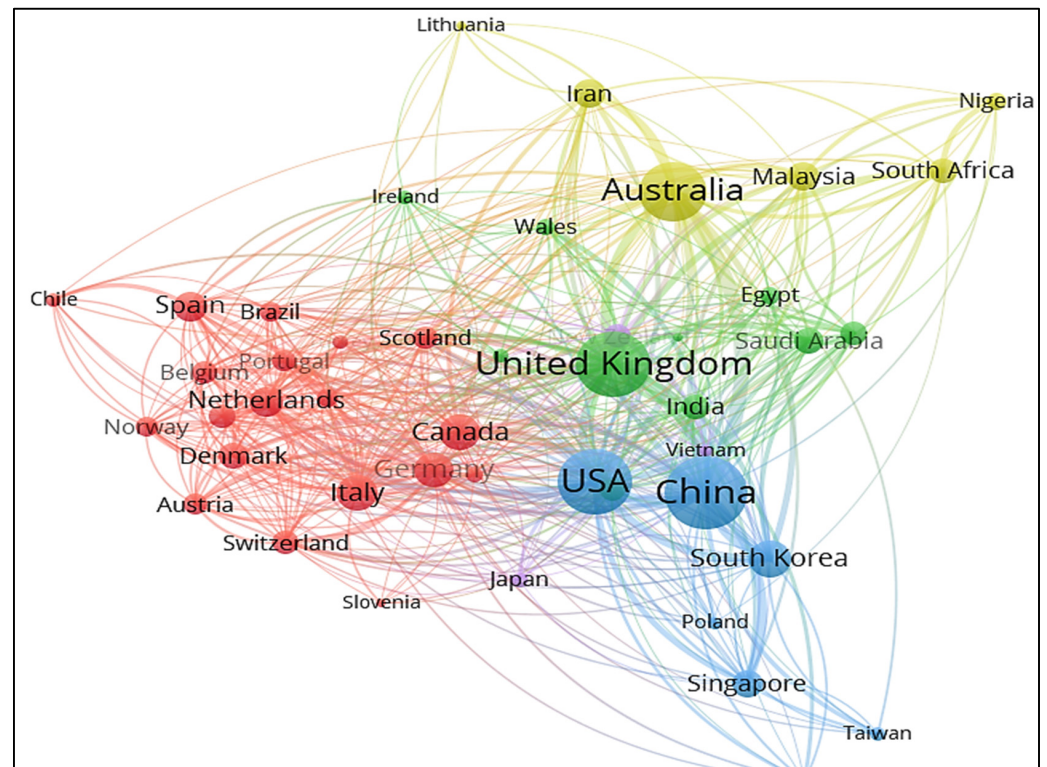


Figure 6. Visualization of 45 high-yield countries, considering 25 the minimum number of documents of a country. Source (Vosviewer software).

The figure reveals that most of the research in the field is contributed by China, with 1196 publications and 22,084 citations, followed by the USA, which ranks second in total publications with 956 TPs, while the USA ranks first in citations, with 24,801 citations. Shkundalov and Vilutienė (2021) found similar results, with China ranking first and the USA ranking second in their bibliometric analysis. The UK followed with 539 publications and 14,080 citations, Italy with 465 publications and 4578 citations, and Australia with 425 publications and 14,984 citations. Vietnam was the least productive, as shown in Figure 4, with 27 publications and 286 citations among the 45 selected countries.

The analysis reveals that countries like China, the USA, the UK, and Australia have led the production of scientific research publications due to substantial research and development investment, well-established academic and research institutions, rapid urbanization, and supportive government policies. Economic development drives innovation, while industry, academic, and international collaboration bolsters research productivity.

3.6. Most Cited Papers in BIM, HBIM, DT, and IoT Research

The following are the most frequent references in the area of BIM, HBIM, Digital Twins, and the IoT in the construction, building technology, and architecture domain. These papers address critical challenges, technological advancements, and theoretical frameworks that have influenced academic discourse and industry practices. Figure 7 shows the citation impact of the top 10 most influential papers in Building Information

Modelling (BIM), Historic BIM (HBIM), Digital Twins (DT), and Internet of Things (IoT) within the construction and architecture sectors. The visualization clearly highlights the prominence and influence of these foundational studies in shaping academic research and industry practices. Table 3 summarizes the top 10 most cited papers, highlighting their contributions and impact.

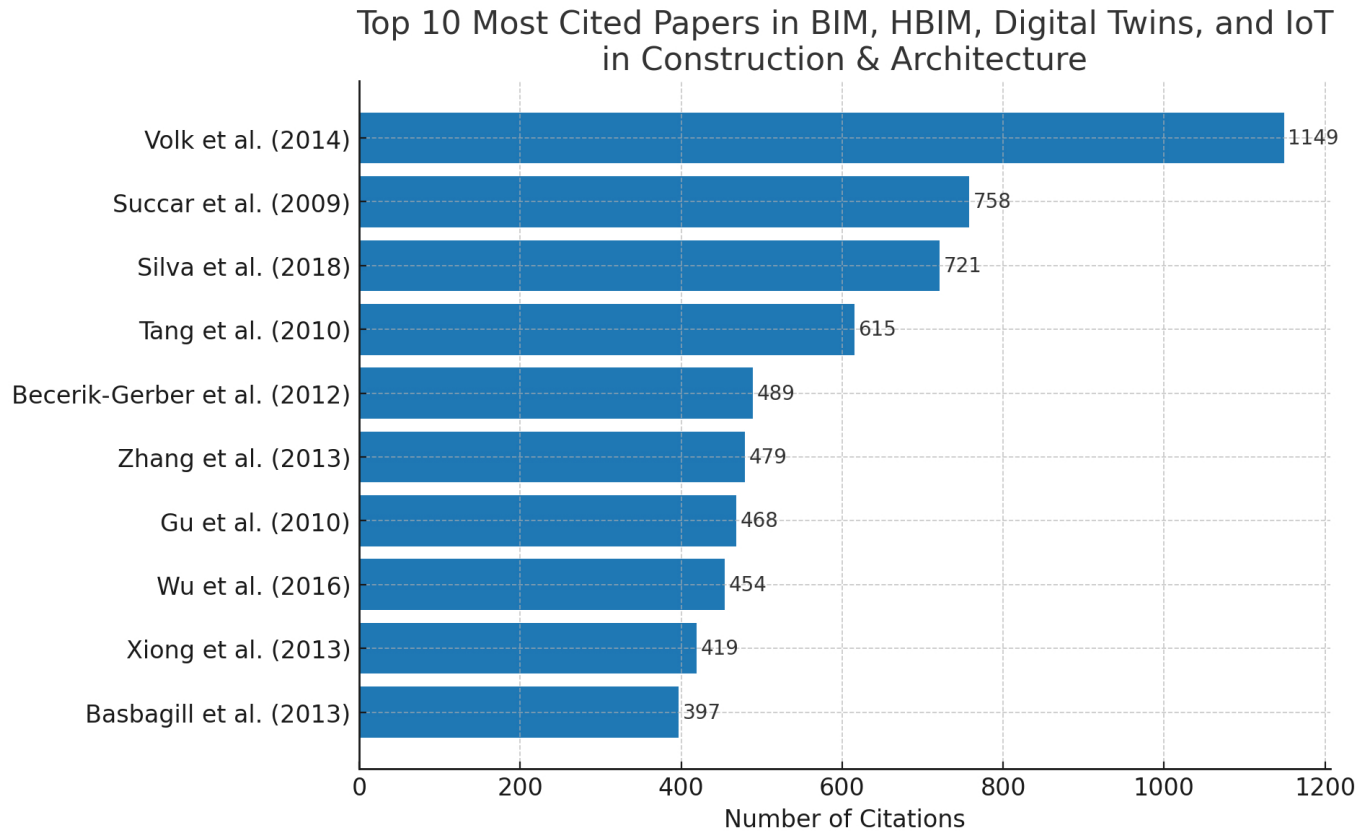


Figure 7. The citation impact of the top 10 most influential papers in BIM, Historic BIM (HBIM), Digital Twins (DT), and Internet of Things (IoT) within the construction and architecture sectors. The visualization clearly highlights the prominence and influence of these foundational studies in shaping academic research and industry practices [21,51–59].

The most cited paper is “Building Information Modelling (BIM) for Existing Buildings—Literature Review and Future Needs” by Volk et al. (2014) [51], and this paper has been cited 1149 times. This paper conducted a systematic literature review of applying BIM to existing buildings to determine the gaps in BIM usage for facility management and adaptive reuse, aiming to inform the next generation of HBIM and Digital Twins for historical and existing structures.

The second most cited work is “Building Information Modelling Framework: A Research and Delivery Foundation for Industry Stakeholders” by Succar (2009) [52] which has been cited 758 times. Succar proposed a systematic approach for the implementation of BIM and defined the BIM maturity levels and competences that are necessary for the effective implementation of BIM. This framework has since been widely adopted in the development of BIM policies and standards.

A more recent contribution is “Towards Sustainable Smart Cities: A Review of Trends, Architectures, Components, and Open Challenges in Smart Cities” by Silva et al. [53] in 2018, which has been cited 721 times. The authors explored the integration of BIM, IoT, and AI in urban sustainability, with a focus on real-time data monitoring and intelligent

infrastructure for smart cities. This study has been very valuable in the growth of Digital Twin applications in urban planning.

Table 3. The top 10 most cited papers in the field.

Rank	Title	Author, Year, and Source	Total Citations	TC/Year	Normalized TC
1	Building Information Modeling (BIM) for existing buildings—Literature review and future needs	VOLK R, 2014, AUTOMAT CONSTR [51]	1149	104.45	28.58
2	Building information modelling framework: A research and delivery foundation for industry stakeholders	SUCCAR B, 2009, AUTOMAT CONSTR [52]	758	47.38	27.46
3	Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities	SILVA BN, 2018, SUSTAIN CITIES SOC [53]	721	103	22.25
4	Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques	TANG PB, 2010, AUTOMAT CONSTR [21]	615	41	13.47
5	Application Areas and Data Requirements for BIM-Enabled Facilities Management	BECERIK-GERBER B, 2012, J CONSTR ENG M [54]	489	37.62	22.51
6	Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules	ZHANG SJ, 2013, AUTOMAT CONSTR [55]	479	39.92	11.22
7	Understanding and facilitating BIM adoption in the AEC industry	GU N, 2010, AUTOMAT CONSTR [56]	468	31.2	10.25
8	A critical review of the use of 3-D printing in the construction industry	WU P, 2016, AUTOMAT CONSTR [57]	454	50.44	19.18
9	Automatic creation of semantically rich 3D building models from laser scanner data	XIONG XH, 2013, AUTOMAT CONSTR [58]	419	34.92	9.82
10	Application of life cycle assessment to early stage building design for reduced embodied environmental impacts	BASBAGILL J, 2013, BUILD ENVIRON [59]	397	33.08	9.3

The fourth most cited paper is “Automatic Reconstruction of As-Built Building Information Models from Laser-Scanned Point Clouds: A Review of Related Techniques” by Tang et al. [21] in 2010, which has been cited 615 times. Tang et al. conducted the first study on Scan-to-BIM techniques that help in the generation of a 3D model from laser-scan data. Their study has had a lasting impact on HBIM and heritage documentation.

In the area of BIM-enabled facility management, “Application Areas and Data Requirements for BIM-Enabled Facilities Management” by Becerik-Gerber et al. [54] in 2012 has been cited 489 times. Becerik-Gerber et al. explained how BIM data can improve facility management and physical asset management. Their study identified existing interoperability issues and formed the basis of subsequent studies on IoT-integrated facility management systems.

Another influential paper is “Building Information Modelling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules” by Zhang et al. [55] in 2013, which has been cited 479 times. Their paper focused on the automation of safety compliance checks within the BIM environment. Their research is still current in construction risk assessment and has led to the development of safety monitoring systems based on artificial intelligence.

In the domain of BIM adoption and barriers, “Understanding and Facilitating BIM Adoption in the AEC Industry” by Gu et al. [56] in 2010 is also among the top cited articles with 468 citations. Gu et al. presented a study on the challenges and methods of BIM adoption in the AEC industry. Their work has been frequently cited in studies

on the development of BIM implementation policies and digital transformation in the AEC industry.

A more technologically advanced contribution is “A Critical Review of the Use of 3D Printing in the Construction Industry” by Wu et al. [57] in 2016, which has been cited 454 times. Their paper reviewed the integration of BIM with 3D printing technologies to determine their integration. The paper suggested the potential of automated construction and prefabrication with the help of AI, and this has remained a subject of study in construction automation.

The ninth most cited paper is “Automatic Creation of Semantically Rich 3D Building Models from Laser Scanner Data” by Xiong et al. in 2013 [58], which has been cited 419 times. In their paper, the authors proposed semantic enrichment techniques for point cloud data, which can help improve HBIM methods. Their research has greatly contributed to the improvement in HBIM model accuracy and data structuring.

Last but not least, “Application of Lifecycle Assessment to Early-Stage Building Design for Reduced Embodied Environmental Impacts” by Basbagill et al. in 2013 [59], which has been cited 397 times, reviewed BIM-based environmental impact assessment, including one of the first frameworks for evaluating sustainability in early design stages.

The analysis of the top ten most cited articles reveals that the majority (70%) of them appeared in *Automation in Construction*, which indicates the journal’s importance in the dissemination of research on BIM, HBIM, Digital Twins, and IoT in the construction industry. At the same time, other influential papers were published in other journals, such as *Sustainable Cities and Society*, *Building and Environment*, and the *Journal of Construction Engineering and Management*, which proves the multidisciplinary nature of this research domain.

The above publications have high citation counts because they offer a detailed review of BIM use in existing buildings, future research directions, and integration with new technologies. Their methodological rigour, theoretical contributions, and practical significance have essentially determined the development of the field and thus their importance in the academic world and in the real world.

3.7. Authorship Patterns in BIM, HBIM, DT, and IoT Research

Authorship trends reveal that collaboration is common, with a lower citation impact for papers written by multiple authors. The least complex authorship format is three authors (1369 publications, 28,529 citations), followed by two-author collaborations.

There are only 487 single-author papers, which is further evidence of the interdisciplinary nature of this research field. Figure 8 provides further evidence for the significance of collaborative efforts through presenting the authorship pattern distribution.

3.8. Keyword Analysis: Emerging Research Themes

Keyword co-occurrence of author keywords involves investigating the frequency at which specific author keywords occur in scholarly papers. This strategy facilitates the identification of relations and associations between multiple research topics or themes within a particular field of study. Through analysing keyword co-occurrence patterns, researchers can obtain valuable knowledge about the fundamental organization of scholarly research, identify emerging trends, and understand the interrelationships among different research fields. Vosviewer software was used to analyse the co-occurrence of author keywords. Keywords with at least 25 occurrences were examined, yielding 78 keywords out of 11,715. After merging, the analysis found 63 keywords and formed seven themes/clusters, as shown in Figure 9.

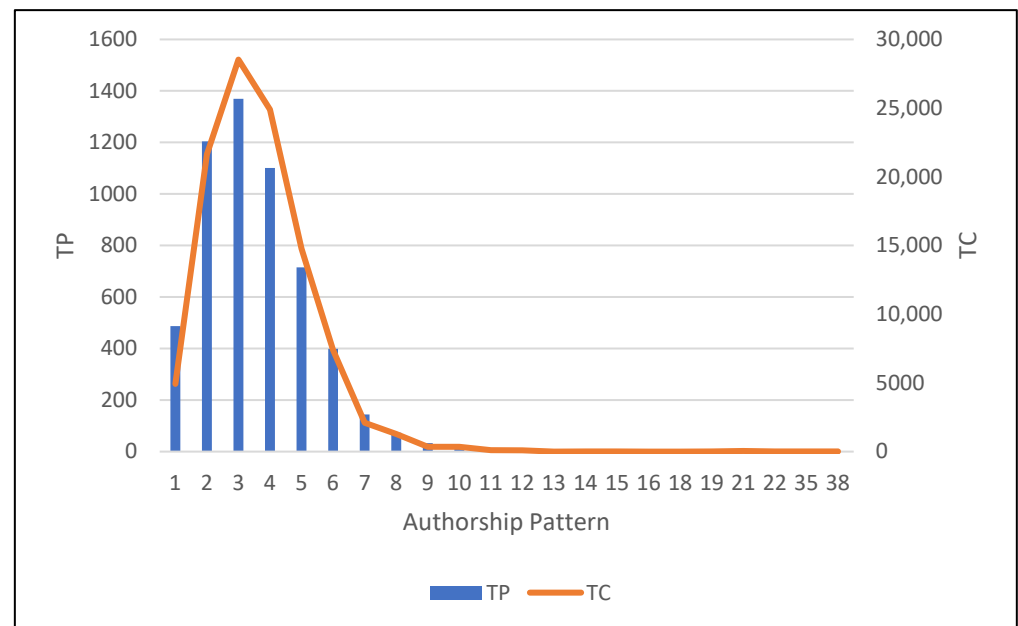


Figure 8. Authorship pattern.

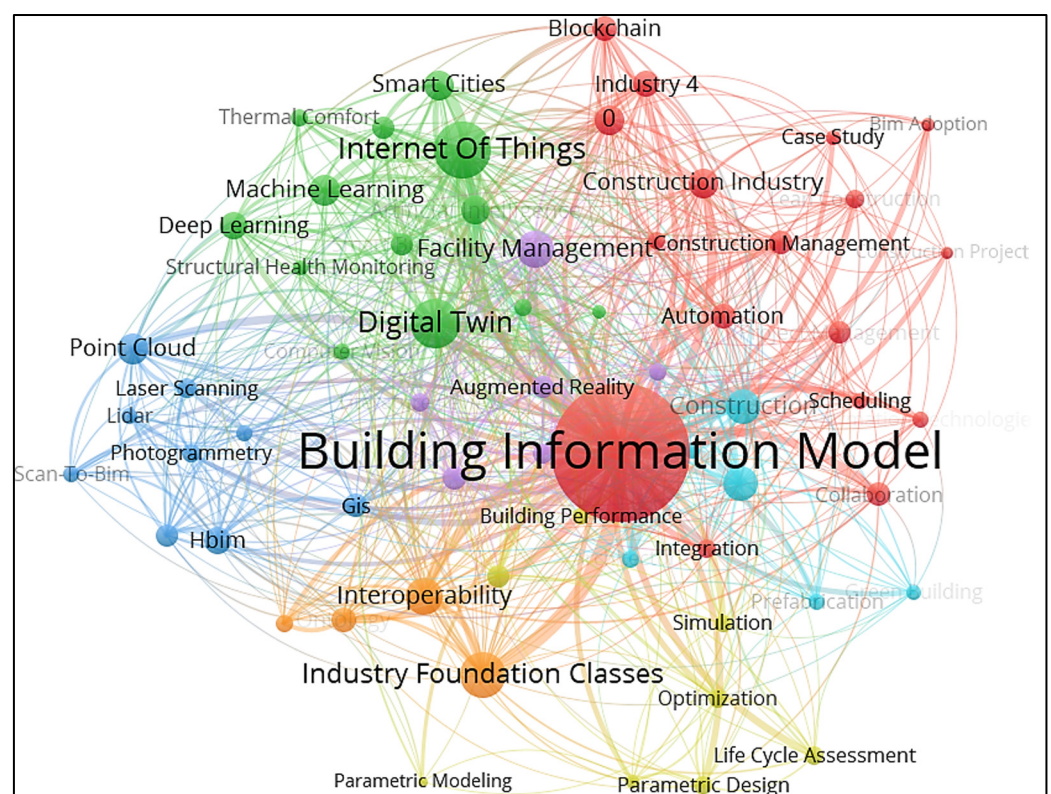


Figure 9. Mapping author keywords with a minimum co-occurrence 25. Source (Vosviewer software).

Cluster 1: This cluster is composed of 17 author keywords that appeared 3108 times. The primary themes of cluster 1 revolve around the digital transformation and integration of advanced technologies like BIM, blockchain, and automation to improve collaboration, project management, and efficiency in the construction industry. The leading topics of this cluster are Automation, BIM Adoption, Blockchain, Building Information Model, Case Study, Collaboration, Construction Industry, Construction Management, 0, Construction Projects, Digitalization, Industry 4, Information Technologies, Integration, Lean Construction, Project Management, and Scheduling.

Cluster 2: This cluster includes 13 author keywords that collectively appeared 1240 times. The focus is mainly on advances in intelligent, data-driven technologies enhancing safety, efficiency, and sustainability in smart construction and infrastructure. The most important topics in this cluster are Artificial Intelligence, Asset Management, Big Data, Computer Vision, Construction Safety, Deep Learning, Digital Twin, Internet of Things, Machine Learning, Smart Building, Smart Cities, Structural, Health Monitoring, and Thermal Comfort.

Cluster 3: Cluster 3 also includes nine author keywords which appeared 466 times. The central theme of this cluster is digital surveying and 3D modelling technologies for documenting, preserving, and managing cultural heritage through advanced tools like HBIM, LiDAR, and photogrammetry. The main topics in this cluster comprise 3D Modelling, Cultural Heritage, GIS, HBIM, Laser Scanning, Lidar, Photogrammetry, Point Cloud, and Scan-To-BIM.

Cluster 4: The fourth cluster consists of eight author keywords which collectively appeared 324 times. The theme revolves around performance-driven and sustainable building design using parametric modelling, simulation, and optimization to enhance energy efficiency and assess life cycle impacts. The primary topics in this cluster are Building Performance, Energy Efficiency, Generative Design, Life Cycle Assessment, Optimization, Parametric Design, Parametric Modelling, and Simulation.

Cluster 5: This cluster is composed of six author keywords. The theme centres on immersive and digital technologies like AR and VR for improving information management, visualization, and facility management in built environments. The most appealing keywords in this cluster are Augmented Reality, Facility Management, Information Management, Literature Review, Virtual Reality, and Visualization.

Cluster 6: This cluster includes six keywords that appeared 336 times in the documents. It focuses on Architecture, Construction, Green Building, Prefabrication, Review, and Sustainability. The theme focuses on sustainable architecture and construction practices, emphasizing green building, prefabrication, and environmental review processes.

Cluster 7: The theme centres on enhancing data interoperability in construction through standardized frameworks like Industry Foundation Classes and semantic technologies such as ontologies and the Semantic Web. The selected four author keywords appeared 236 times. The primary topics of this cluster are Industry Foundation Classes, Interoperability, Ontology, and Semantic Web.

The analysis reveals that the building information model was the most used author keyword in the field of construction, building technology, and architecture ($n = 2405$), followed by Internet of Things ($n = 410$), Digital Twin ($n = 242$), Industry Foundation Classes ($n = 191$), sustainability ($n = 127$), facility management ($n = 115$), interoperability ($n = 11$), HBIM ($n = 109$), machine learning ($n = 105$), and point of cloud ($n = 88$).

3.9. Analysing Word Cloud

Figure 10 below shows the key research themes in building construction technology through a word cloud analysis. Among these, 'Building Information Modelling (BIM)' is the most frequent term ($n = 774$), which shows the importance of digital models in construction project workflows. Following closely are 'design' ($n = 574$) and 'management' ($n = 509$), which highlights a high focus on improving project planning, execution, and coordination within the architecture, engineering, and construction (AEC) industry.

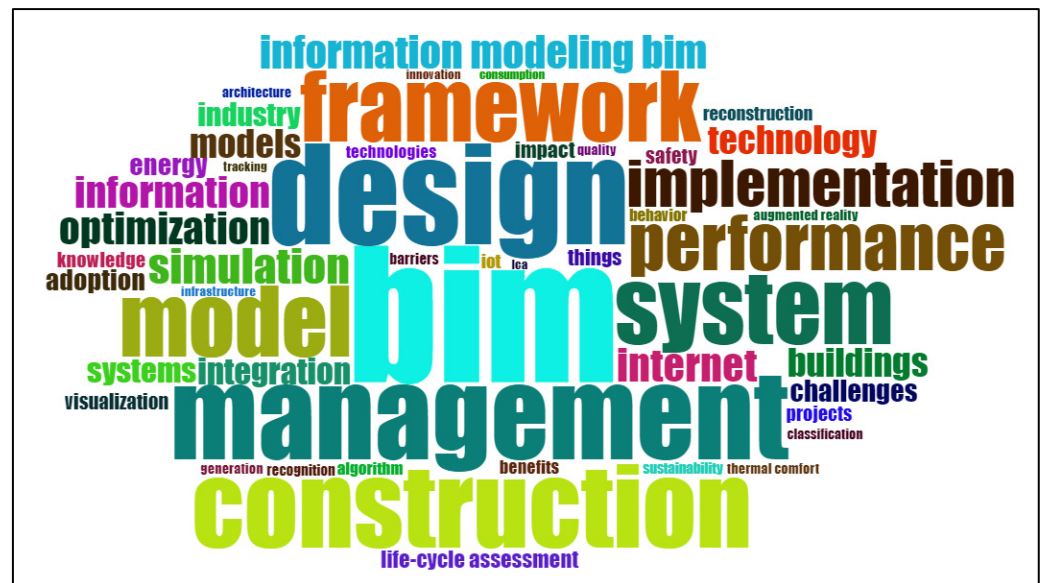


Figure 10. Word cloud of keywords using Biblioshiny software.

Also, the use of terms such as ‘system’ ($n = 420$), ‘framework’ ($n = 403$), and ‘model’ ($n = 403$) shows a conscious effort of developing systematic approaches and conceptual frameworks to enhance construction productivity. Performance optimization ($n = 315$) is also a recurring theme, denoting the continuous activity of enhancing the efficiency of projects, automation, and decision making. Moreover, keywords like ‘sustainability’ ($n = 63$) and ‘energy’ ($n = 122$) show a gradually rising trend toward sustainable construction and energy conservation.

Furthermore, keywords such as ‘integration’ ($n = 149$), ‘technologies’ ($n = 75$), and ‘innovation’ ($n = 56$) also indicate the increasing trend of adopting new technologies, interdisciplinary research, and digitalization in construction. However, some important research gaps can be seen. In particular, there is virtually no attention paid to interdisciplinary approaches; the ethical and social aspects of technology implementation; long-term environmental and social effects; and user-centred design principles.

Moreover, the lack of concern with policy and regulatory issues also points to a lack of understanding of how legislation and governance affect technology adoption in construction. The absence of these would help to achieve a more holistic integration of technological innovations and enhance sustainable and effective construction practices that are compatible with regulatory and ethical concerns.

3.10. Research Trends over Time

A temporal analysis of the period 2016–2023 shows a progression from traditional BIM adoption to the use of AI for enhanced decision making and Digital Twin integration:

- 2016–2017: Emphasis on integrated design, laser scanning, and 4D BIM.
- 2018–2019: Moved to construction safety, CAD, and genetic algorithms.
- 2020–2021: The emergence of AI, IoT and Digital Twin implementation.
- 2022–2023: Growth to BIM-IoT integration, real-time data analysis, and smart city frameworks.

Figure 11 provides a synopsis of these evolving research topics.

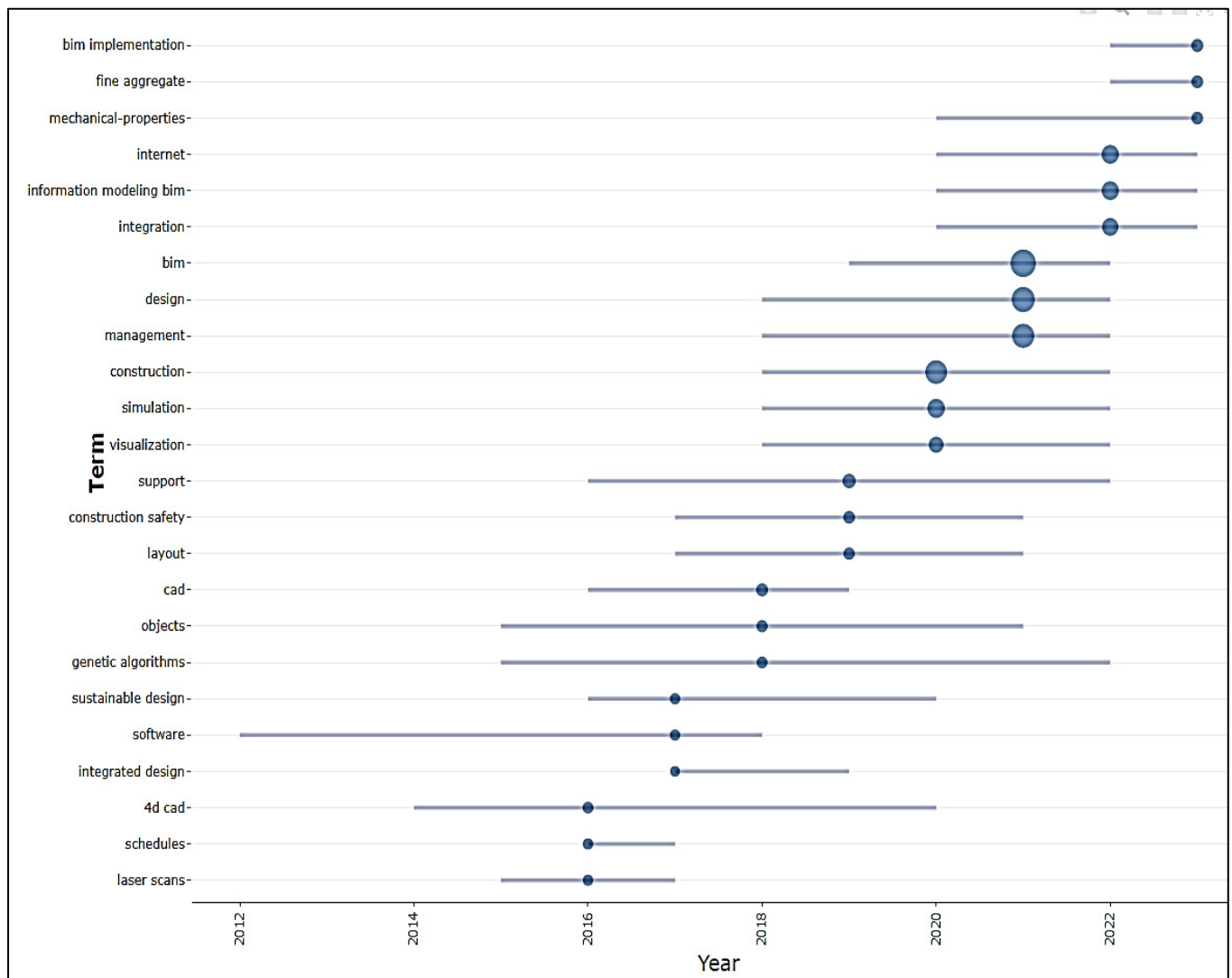


Figure 11. Analysis of trends in topics.

3.11. Factorial Analysis of Keywords

Using Multiple Correspondence Analysis (MCA), trends were grouped into two primary dimensions in the research:

- Dim 1: Management, innovation, AI-driven BIM, and technology adoption.
- Dim 2: IoT and Digital Twins for real-time monitoring.

Cluster 1 focuses on BIM optimization, sustainability, and safety, and Cluster 2 emphasizes smart construction based on IoT. Figure 12 provides a conceptual structure map that shows research intersections.

3.12. International Collaboration in BIM, HBIM, DT, and IoT Research in Map

As shown in Figure 13, global collaboration networks are depicted, with China–Australia having the highest number of joint publications (110 joint publications), followed by China–UK (109) and China–USA (90). Other notable collaborations are USA–Canada, Australia–Iran, and UK–Germany, which are consistent with the international coverage of this field.

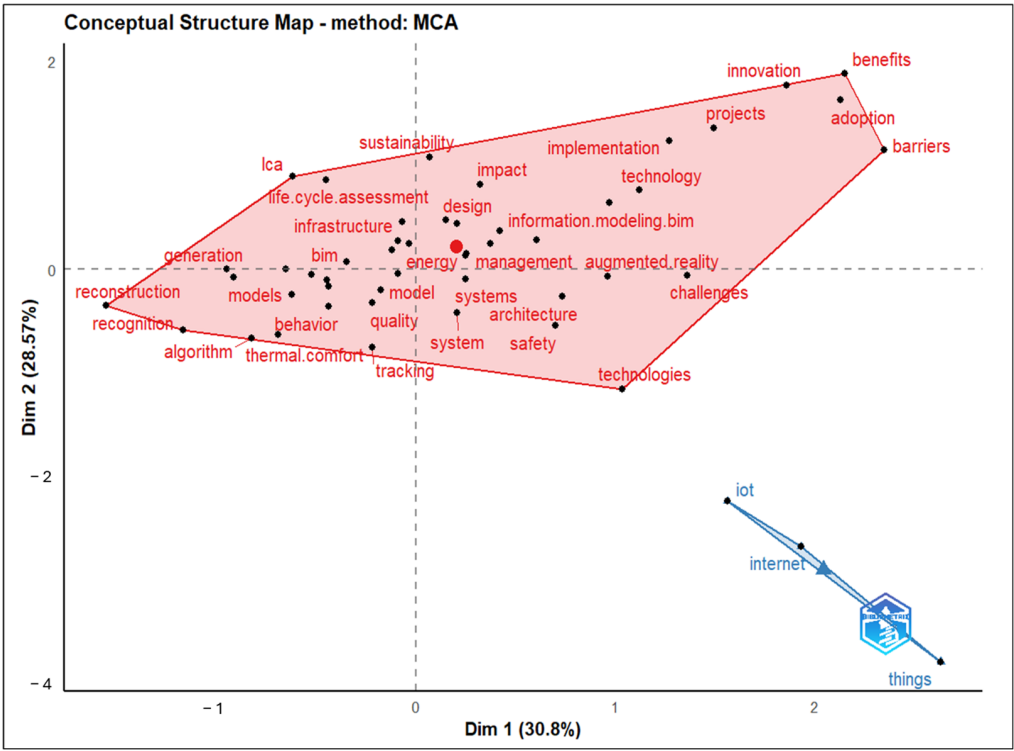
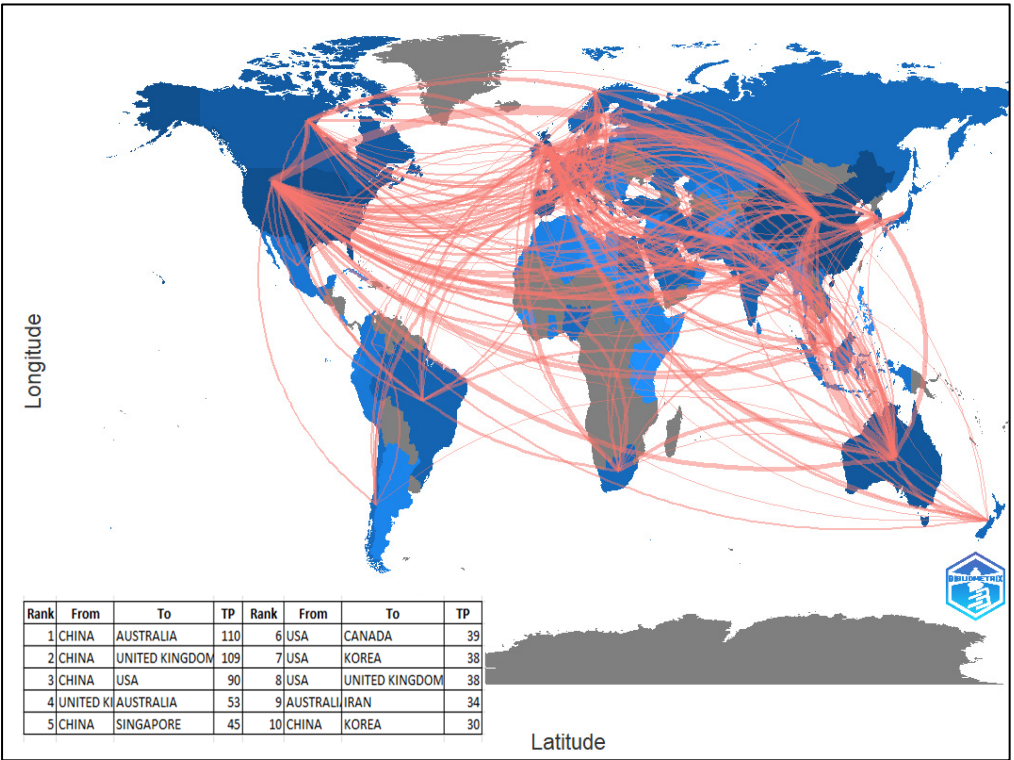


Figure 12. Conceptual structure map and factorial analysis of keywords.



Red lines refer to the collaboration network amongst countries.
Dark blue represents the collaborated countries.
Figure 13. Country collaboration map.

3.13. *The Real-World Application of BIM, HBIM, Digital Twins, and IoT in the AEC Industry*

Building Information Modelling (BIM), Historic BIM (HBIM), Digital Twins, and Internet of Things (IoT) have changed the architecture, engineering, and construction (AEC) industry by increasing the efficiency, sustainability, and asset management of a project. BIM has turned into a common practice in digital construction planning and has facilitated work planning, cost control, scheduling, and facility management by ensuring effective collaboration among project stakeholders [51]. HBIM is an extension of BIM and has a significant application in heritage conservation through the use of laser scanning and photogrammetry to digital documentation and restoration of historic structures [23].

Construction management has been enhanced by the concept of Digital Twins, providing real-time data synchronization between physical and digital models for predictive maintenance, energy management, and better decision making in smart buildings [14]. The integration of IoT with BIM and Digital Twins has enabled real-time monitoring of sites and built assets through sensor networks, resulting in data-driven decisions and increased operational performance [12]. For example, IoT has enabled BIM applications to be effectively used in smart cities for the management of dynamic energy consumption, environmental monitoring, and automatic safety checks [53]. These technologies are not only having a cascading effect on improving construction workflows but also changing the way we manage built environments through their convergence, over the life cycle, to produce more resilient and intelligent urban infrastructure.

4. Discussion

This paper offers a full bibliometric review of BIM, HBIM, Digital Twins (DT), and IoT in the AEC industry based on a large dataset covering the period from 1993 to 2024. Furthermore, the analysis started in 1993 as this is the year that the first articles on BIM were published in Web of Science and the other years had nearly no articles related to this field index. Moreover, as recent bibliometric studies have shown, the Web of Science Core Collection has limitations in identifying older publications, as well as non-English and regionally published research. These limitations have been highlighted by Liu (2021) [45], Archambault et al. (2011) [60], and Mongeon & Paul-Hus (2016) [44], who note that WoS tends to overrepresent English-language and Western research, resulting in potential geographic and linguistic biases in bibliometric analyses.

The research trend shows a sharp increase in publications especially after 2012, which can be ascribed to the increasing popularity of BIM in construction policy, the enhancement of AI-based BIM technologies, and the enactment of government requirements on digital construction. This phenomenon is in sync with the study by Liu, F. (2023) [61] on the analysis of retrieval strategies and the increase in the indexed content in Web of Science which can also be responsible for the perceived abnormal growth in research output. Key research trends, most cited papers, leading countries and institutions, and emerging research themes are discussed. These insights are integrated to show the digital transformation of construction, the current state of knowledge, and future research directions.

4.1. *Research Trends and Key Contributions*

Over the last decade, since 2012, the research interest in Building Information Modelling (BIM), Heritage BIM (HBIM), Digital Twins, and Internet of Things (IoT) has surged, reaching the highest level in 2023. This increase can be attributed to three broad industry shifts: (1) the uptake of digital technologies in construction; (2) the transition from the initial use of BIM software to the integrated application of BIM with AI and IoT; and (3) global smart city projects that require data-driven solutions for infrastructure development.

The most influential studies in this domain have identified critical gaps and developed innovative methodologies to address them, influencing industry practices.

Volk et al. (2014) [51] was identified as a systematic review of BIM applications in existing buildings and revealed serious gaps in facility management and HBIM execution—gaps that later guided other research in heritage documentation. Succar's (2009) [52] BIM maturity model was widely adopted because it offered the first holistic framework for evaluating BIM readiness, which served as a key tool in establishing industry benchmarks and recommendations for policy makers. Volk et al. (2014) [51] gained popularity during the smart city boom by developing the theoretical underpinning of BIM integrated with IoT and AI, while Tang et al. (2010) [21] were first to propose the Scan-to-BIM method that significantly influenced heritage conservation approaches.

Other significant contributions represent the growing field in specific applications: Becerik-Gerber et al. (2012) [54] solved the issue of data interoperability in facility management; Zhang et al. (2013) [55] addressed the industry's need for automated safety solutions; Wu et al. (2016) [57] explored the potential of construction 3D printing; and Xiong et al. (2013) [58] improved HBIM through semantic enrichment. These studies, collectively, propelled BIM from a design tool to an all-encompassing digital platform, with standardization efforts, application in smart cities, predictive maintenance, and automated construction. Their impact endures through continuous citation, which attests to their contribution in developing the literature and influencing real-world implementations in the architecture, engineering, and construction industry.

4.2. Global Influence: Leading Countries and Institutions

The dominance of BIM research by China, the USA, and the UK is attributable to the heavy government and industrial support of digital construction technologies. China has the highest number of papers published (1196 papers), but the United States has the highest citation impact of its papers (24,801 citations). The UK, Italy, and Australia have also contributed significantly, often in collaboration with the top research hubs.

From the institutional analysis, it is evident that the Hong Kong Polytechnic University, Politecnico di Milano, and Tongji University are some of the most productive in BIM, Digital Twins, and IoT research, respectively. These institutions have also established collaborative research frameworks, particularly in automation, AI integration, and sustainability-driven BIM applications. The collaboration network also identifies regional clusters of research dominance, where China–Australia, USA–UK, and Germany–Italy partnerships advance smart construction, urban sustainability, and AI-enhanced facility management, respectively.

4.3. Emerging Research Themes

The analysis of the research trends in BIM, HBIM, Digital Twins, and IoT shows the emergence of several key themes that have shaped the field in recent years. First, the research focus was on the basic adaption and use of BIM in the construction industry and the benefits identified with its use included digital workflows, life cycle management, and collaborative project delivery [51]. However, as technology advanced, research was also extended to more specific areas such as HBIM and heritage documentation, for which methods such as Scan-to-BIM have been useful in the preservation of historical structures and the improvement in conservation efforts [21,58].

Another significant theme is the integration of Digital Twins and IoT-based smart infrastructure, which focuses on real-time monitoring, predictive maintenance, and intelligent decision making [53]. This shift is in line with broader trends in AI-driven automation, machine learning applications, and the optimization of construction processes

through data analytic employees [57]. Sustainability concerns have also percolated into research on BIM, with scholars examining the role of BIM in energy-efficient building designs, green construction materials, and life cycle assessment (LCA) frameworks [59]. Nevertheless, interoperability challenges have remained a critical topic, especially in the development of Industry Foundation Classes (IFCs) to improve data exchange between different BIM platforms [52].

Of late, research has also been focused on the use of augmented and virtual reality (AR/VR) in BIM. This has led to better design visualization and stakeholder engagement because of the immersive experience [55]. This increasing interest in digital transformation, automation, and interdisciplinary collaboration can be seen as a part of a larger trend towards the future of intelligent, sustainable, highly efficient construction systems. Nevertheless, while these research areas are expanding, some gaps still exist, and therefore, more studies are needed to bridge the gap between technological advancements and industrial adoption.

4.4. Content Analysis of Top Cited Articles

To deepen the understanding of influential research trends in the fields of BIM, HBIM, Digital Twins, and IoT, this section presents a qualitative content analysis of the ten most cited articles (in Table 3) identified in the bibliometric dataset. These publications not only shaped academic discourse but also had considerable practical influence across various subdomains of the AEC industry. Each article was analysed based on its objectives, methods, key contributions, limitations, and the factors contributing to its high citation impact.

The most cited article, Volk et al. (2014) [51], offers a comprehensive literature review on the application of BIM for existing buildings. It critically synthesizes over 180 publications and highlights major challenges, such as data uncertainties, high modelling efforts, and the lack of standardized procedures in HBIM. The paper's value lies in identifying future research needs in modelling as-built environments, making it a cornerstone in heritage and retrofit BIM research. Despite the lack of empirical validation, its systematic review format and clear research agenda have contributed to its significant academic impact.

Succar (2009) [52] proposed a structured BIM framework that serves as a foundational reference for BIM implementation strategies across different stakeholder groups. The study uses a conceptual methodology to map BIM stages and deliverables, supporting consistent communication and execution in BIM-based projects. Its flexibility and scalability across contexts have led to wide adoption in both academic and professional environments. The main limitation of this work is its abstract nature, as it lacks case-based validation. Nonetheless, its influence stems from being one of the earliest attempts to define BIM systematically from a process-oriented perspective.

Silva et al. (2018) [53] reviewed smart city concepts, including architecture, enabling technologies, and sustainability concerns. Although broader than the core focus of BIM, this work has strong interdisciplinary relevance due to its focus on IoT integration and urban systems thinking. The paper's strength is its synthesis of trends in digital infrastructure development, though the wide scope may limit its technical specificity. Its influence arises from offering a holistic framework for cities navigating digital transformation—appealing to policy makers, researchers, and urban planners alike.

Tang et al. (2010) [21] focused on the automatic reconstruction of BIM models from laser-scanned point clouds. Their review mapped available methods and tools for Scan-to-BIM, highlighting both the potential and challenges such as model accuracy and processing efficiency. While the study is theoretical and lacks experimental implementation, its early identification of automation as a future priority helped establish the Scan-to-BIM pipeline

as a research area. Its influence endures due to the growing importance of automated as-built documentation in both new construction and heritage contexts.

In Becerik-Gerber et al. (2012) [54], the authors explore how BIM can be utilized in facility management (FM), a topic underrepresented in earlier BIM research. Based on surveys and interviews with FM professionals, the study identifies key application areas (e.g., asset tracking, maintenance scheduling) and necessary data types for effective integration. Although the sample size is limited and findings may not be generalizable, the paper significantly contributes to closing the gap between construction and post-occupancy building management.

Zhang et al. (2013) [55] examined the potential of using BIM to automatically assess construction safety risks. Through the development of rule-based algorithms, the study showed how safety constraints could be integrated into construction models and schedules. The limitation of the paper lies in its narrow application scope and dependency on predefined rules. Still, its practical orientation and forward-thinking use of BIM for proactive risk management make it a highly cited work with lasting influence in digital safety planning.

Gu et al. (2010) [56] offered one of the earliest qualitative studies on BIM adoption challenges within the AEC industry. Through interviews and case studies—mainly within the Australian context—the paper proposed a framework that outlines organizational and technological factors influencing BIM uptake. Though geographically limited, it remains influential due to its practical recommendations and actionable insights that have been broadly applicable across institutional contexts.

Wu et al. (2016) [57] provided a critical review of the role of 3D printing in construction. It summarizes emerging techniques, materials, and limitations in additive manufacturing while discussing future opportunities for large-scale applications in construction. Although the field has rapidly evolved since its publication, the article remains highly influential due to its early consolidation of a fragmented topic and its relevance to innovation and sustainability in digital construction methods.

Xiong et al. (2013) [58] contributed significantly to the automation and intelligence of BIM modelling by developing methods to generate semantically rich 3D models from laser scanner data. Their work emphasizes algorithm development for semantic enrichment, facilitating object recognition and classification in 3D point clouds. The study's limitation is its technical specificity, which may restrict its generalizability. Nonetheless, it opened new possibilities for automated, intelligent modelling in both new builds and heritage environments.

Finally, Basbagill et al. (2013) [59] introduced life cycle assessment (LCA) into early stage building design, focusing on how to reduce embodied environmental impacts. The study links design decisions to sustainability outcomes, offering a methodological bridge between BIM and environmental performance. Though limited to early design phases, the paper's lasting impact stems from advancing green BIM and integrating environmental metrics into architectural decision making.

These top cited papers share several characteristics: a strong focus on emerging technologies and their applications, a balance between theoretical frameworks and practical relevance, and contributions that laid the groundwork for further research. Their enduring impact is a result of both methodological innovation and alignment with the evolving digital priorities of the AEC industry.

4.5. Limitations and Research Gaps

As valuable as the following conclusions are, there are several limitations to them. The first major limitation is the focus only on the Web of Science database. Web of Science is one of the most extensive academic databases, but it is not all-inclusive; it could exclude

important studies that are available in Scopus, IEEE Xplore, and Google Scholar. This could result in a partial representation of the research landscape in terms of trends, especially for interdisciplinary studies that cut across various disciplines. Future work should include a multi-database approach to provide a more holistic and extensive view of international research trends [22]. Another major limitation has to do with the quality and availability of metadata in Web of Science. Previous research has pointed out problems such as errors in author affiliations, missing author addresses, and anonymous authorship, which can lead to inaccuracies in bibliometric studies [40–42]. Moreover, Web of Science has a strong regional bias, favouring publications from North America and Europe while underrepresenting research from developing regions. This bias may affect the visibility and recognition of studies conducted in non-Western countries. Furthermore, the database predominantly indexes English-language journals, leading to an English-language bias that overlooks valuable contributions from researchers publishing in other languages. These metadata and indexing limitations should be considered when analysing the results, and future studies should integrate multiple databases to minimize biases.

To better understand the financial landscape shaping research in BIM, HBIM, Digital Twins, and IoT, this study analysed funding acknowledgments from the Web of Science dataset. The most frequently cited funding agencies include the National Natural Science Foundation of China (NSFC), the European Union's Horizon 2020 Framework Programme, and the Australian Research Council (ARC). These bodies have consistently supported large-scale, interdisciplinary research on digital construction, smart cities, and sustainability. However, it is important to acknowledge the limitations of funding data in bibliometric studies. Not all authors report funding sources uniformly, and funding acknowledgment fields are inconsistently indexed across journals and regions. As highlighted in prior research (e.g., Scientometrics and JASIST), such inconsistencies may lead to underreporting or misrepresentation of funding trends. Future research should consider integrating data from platforms like Open AIRE, Dimensions, or national grant databases to construct a more accurate funding landscape.

However, it is important to note that funding information in Web of Science has inherent limitations. Not all publications disclose funding sources, leading to potential underreporting. Additionally, some funding acknowledgments are not standardized, making it difficult to track specific grants and financial contributors (Scientometrics, JASIST studies) [42,44,45].

Future studies should consider integrating multiple data sources to obtain a more comprehensive view of funding trends.

Apart from the restrictions connected with the use of databases, this study also has some limitations in terms of interdisciplinary integration. While the analysis reveals key aspects of the development of BIM, HBIM, Digital Twins, and IoT from an engineering and technology perspective, it does not fully capture the socio-economic, ethical, and policy dimensions of digital transformation in the construction industry. Given the growing adoption of BIM, it is essential to understand its broader impact on the labour market, regulatory frameworks, and environmental sustainability [56].

Furthermore, the bibliometric method used here helps in identifying research trends and citation patterns but does not offer a qualitative appraisal of the methods, findings, or real-world applications of BIM technologies. Consequently, it is advised that future studies combine bibliometric analysis with systematic literature reviews and case studies to provide a more in-depth assessment of BIM's development and its evolving role in the AEC industry.

4.6. Future Research Directions

Building on the identified bibliometric trends and research gaps, several forward-looking directions emerge to guide future investigations into BIM, HBIM, Digital Twins, and IoT within the AEC industry. These directions aim to foster a construction sector that is not only technologically advanced, but also inclusive, sustainable, and socially responsive.

- People-Centred and Socially Informed Research

Future work should adopt a people-centred approach to BIM research to better understand the social implications of digital construction technologies. Topics such as stakeholder engagement strategies, workforce adaptation to BIM, and the impacts of automation on labour dynamics deserve deeper exploration [55]. This line of inquiry can ensure that technological advancements are aligned with social equity, worker inclusion, and the preservation of employment quality in the industry.

- AI and Automation in Digital Construction

The integration of artificial intelligence into Digital Twins presents significant opportunities in areas such as predictive analytics, generative design, and real-time decision making [58]. Future research could focus on how AI algorithms can further automate BIM processes, optimize resource allocation, and enhance risk modelling [57]. These advancements may substantially improve project efficiency, cost control, and sustainability outcomes.

- BIM and Smart Cities

Another promising area is the role of BIM in the development of smart cities—particularly in urban planning, traffic optimization, and intelligent infrastructure systems [54]. Combining BIM with IoT technologies could enable real-time data collection and automation for maintenance, energy management, and public safety systems in complex urban environments.

- Blockchain for Enhanced Interoperability and Collaboration

Interoperability remains a critical issue in digital construction environments. The use of blockchain technology could be further investigated to improve the security, transparency, and efficiency of data exchange between project stakeholders [52]. Blockchain-enabled BIM systems may also facilitate better contract management and data integrity throughout the construction life cycle.

- Regulatory and Policy Frameworks

The influence of legal and regulatory structures on the adoption of BIM and related technologies should not be overlooked. Research on policy frameworks, national mandates, and procurement standards could provide insights into how governments shape digital transformation in construction [56]. Understanding these dynamics will support better alignment between technological development and institutional readiness.

Through these directions, future research can address both the technological and socio-regulatory challenges facing the AEC industry. By combining innovation with human-centred design, policy awareness, and collaborative technologies, scholars and practitioners can contribute to the development of a more integrated, participative, and resilient construction sector.

4.7. Summary of Key Findings

The bibliometric analysis presented in this study generated several new insights into the state and evolution of research on BIM, HBIM, Digital Twins, and IoT in the AEC industry. First, this study revealed a sharp increase in scholarly output after 2012, with 2023 marking the peak in both publication volume and citation activity—indicating a

growing convergence between construction technologies and real-time data systems. Second, the keyword and thematic trend analysis highlighted the emergence of sustainability, interoperability, and artificial intelligence as dominant themes, while exposing the continued underrepresentation of research in HBIM and IoT applications. Third, this study uncovered geographic disparities, with most research concentrated in China, the United States, and the United Kingdom, while contributions from developing regions remain limited. Fourth, the analysis of author and institutional collaboration networks revealed a high degree of concentration among a few academic clusters, suggesting a need for more inclusive and globally diverse collaborations. Finally, the prominence of practically oriented, application-driven studies—such as those in facility management, smart cities, and automated construction safety—reflects a clear shift toward real-world impact, moving beyond conceptual frameworks into practice-oriented implementation.

These findings provide a more detailed understanding of the intellectual structure, regional dynamics, and thematic priorities of digital construction research, offering a roadmap for scholars and practitioners navigating this rapidly evolving domain.

5. Conclusions

This paper offers a systematic bibliometric analysis of the literature exploring general tendencies and patterns of research in Building Information Modelling (BIM), Historic BIM (HBIM), Digital Twins (DT), and Internet of Things (IoT) in the architecture, construction, and building technology domains from 1993 to 2024. Based on the analysis of the rate of publications, citation per article, authorship details, and cooperation pattern, some important conclusions are made on the development of digital technologies in the architecture, engineering, and construction (AEC) industry.

The results show that China, the USA, the UK, and Australia are the main contributors, and HK PolyU, Politecnico di Milano, and Tongji University are the most active universities in terms of research output. Moreover, this review reveals that “*Automation in Construction*” is the leading impactful journal, with *Buildings* and the *Journal of Building Engineering* coming second and third, respectively. Moreover, Cheng JCP from Hong Kong University of Science & Technology is recognized as the most active author with 56 papers and 2059 citations, followed by Li H and Wang J from Hong Kong Polytechnic University and Western Sydney University, respectively.

This paper also aimed to identify the ten most influential papers that have contributed to the discourse on BIM, HBIM, Digital Twins, and IoT in the built environment. At the top of this list is “Building Information Modelling (BIM) for Existing Buildings—Literature Review and Future Needs” by Volk et al. (2014) [51] which has added to knowledge on the role of BIM in facility management and historical conservation. Other important articles are those by Succar (2009) [52] and Silva et al. (2018) [53] who developed frameworks for BIM adoption and smart city integration, respectively.

New research interests include BIM implementation, technology transfer, environmental performance, integration, and virtual and augmented reality in construction management. Keyword analysis shows that the prevailing topics include BIM, digital modelling, design processes, and project management; however, the analysis reveals critical research gaps in interdisciplinary collaboration, ethical issues, sustainability assessment, and user-centred design approaches. Factorial analysis reveals two main thematic directions: first, management and innovation in the adoption of BIM; second, the integration of digital technologies like IoT and AI in construction operations.

This paper contributes to the development of knowledge on BIM, HBIM, Digital Twins, and IoT through a systematic literature review, highly cited paper identification, and future research direction suggestions. It also highlights the need for future work to

address interdisciplinary studies, especially in the area of public policy implications, ethical issues, and life cycle sustainability assessment of digital construction technologies.

The results are useful for academics, practitioners, and policy makers who are interested in the development and effectiveness of digital technologies in the AEC industry. Future work should go beyond these results by including other bibliometric databases, performing a full-text content analysis, and investigating new areas such as BIM enhanced by AI, construction management with the help of blockchain, and smart cities. Resolving these issues will lead to sustainable, effective construction technologies integrated with the latest technological innovations to support the digital revolution in the built environment.

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Appendix A

Replicating the Web of Science Search

The bibliometric dataset for this study was retrieved from the Web of Science Core Collection on 29 February 2024.

The following search query was used:

TS = ("Building Information Modelling" OR "BIM") OR TS = ("HBIM" OR "Historic BIM" OR "H-BIM") OR TS = ("Digital Twin") OR TS = ("Internet of Things" OR "IoT")

Filters applied:

- Language: English.
- Document types: article and review.
- Timespan: 1993–2024.
- Indexes: SCI-EXPANDED and SSCI.
- Subject categories: construction, building technology, and architecture.

This search can be replicated using the Advanced Search function in Web of Science at <https://www.webofscience.com/wos/woscc/advanced-search> (accessed on 5 May 2025).

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