Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 14, No. 3, 2025

Use of Digital Twin Technologies in Facility Management and Related Industries: A Bibliometric Review

Yuming Shi[1, *]

[1]University of Malaya, Kuala Lumpur 50603, Malaysia
[*] Corresponding author

Abstract: Digital twin (DT) technology is one of the technological innovations that has transformed the discipline of facility management (FM); it has changed the way facility management practices are planned and executed. Therefore, it is important to consider the current status and future development trends of this field in the academic community. This study explores the application of digital twins in facility management and related fields by creating a visual description of relevant research topics to improve understanding. This bibliometric analysis of DT-FM was conducted in the records of the past 5 years (2019 to 2025) of the WOS database, and 147 DT-FM-related publications were analyzed using Citespace and R-Bibliometrix software. Trends in DT applications in FM include technology integration and innovation, implementation and adoption strategies, sustainability and energy efficiency, education and professional development, and data management and analysis. Overall, this study enriches a relatively new and rapidly developing field and proposes possible future research paths to further develop this field.

Keywords: Digital Twin, Facility Management, BIM, IoT, Bibliometrics.

1. Introduction

1.1. Background

Facility management recognizes Digital twin (DT) technology as an emerging paradigm to enable a multitude of applications through real-time monitoring, predictive maintenance assessment, and evidence-based decision-making capabilities (Arsecularatne et al., 2024). By creating virtual replicas of physical assets, DT helps stakeholders to optimize operations, work towards energy efficiency, and to improve sustainability. Building Information Modeling (BIM) in combination with the Internet of Things (IoT), a robust addition to FM, is expected to empower in-depth data for better building asset management and decision-making, especially in mega projects (Abdelalim et al., 2024). Moreover, digital twins enable smart building management through service monitoring, energy optimization, and occupant comfort (Ghansah, 2024).

However, with these benefits, there are several obstacles that DT (Digital Transformation) in FM (Facilities Management) must contend with. The integration of technology and issues related to data consistency are still major barriers that can be overcome through standardized data formats and universal design frameworks for interoperability (Mousavi et al. 2024). Therefore, successful implementation cannot be achieved until the strategic planning and information gaps are filled in by different stakeholders in the plan (Abdelalim et al., 2024). Cybersecurity issues are another major challenge, as DTs depend on real-time data transfer, demanding strong data privacy and security measures (Arsecularatne et al., 2024).

Many studies have investigated different dimensions of DT in FM. Zhang et al. (2024) analyzed the significance of DT for sustainability, primarily in carbon emission reduction and resource optimization. Yang and Ng (2024) identified the importance of pilot projects and collaborations with industry actors to speed up DT implementation. Lee et al. (2025) presents a framework for entity management in IoT and aimed at simplifying complex DT implementations. These studies highlight the increasing relevance of DT in FM and the need for ongoing research and development to overcome current challenges and realize the full potential of these technologies.

The deepening research on building information modeling (BIM) and its application in facility management (FM) has led to digital twin (DT) technology, as the further development direction, which can realize the functions of real-time monitoring, predictive analysis, and operation optimization. The integration of DT, BIM and the Internet of Things (IoT) is regarded as a key driving force for the digitalization of facility management, which can enhance decision-making efficiency and optimize asset performance. However, there are still many requirements in regards to the use of DT in facility management, such as data processing, interoperability and management of maintenance documents. Moreover, although the research in this domain has increased steadily, there is no systematic bibliometric analysis evaluation on the current research profile, research gap exploration, and development direction guidance for the future of DT in FM.

1.2. Key challenges of Digital Twin Technology applied in the Facility Management

Processing of and interoperability with data

As the integration of DT with BIM and IoT relies on the efficient data exchange among these systems, the lack of unified standard protocols and compatible data formats leads to limited interoperability, which in turn limits the collaborative efficiency of FM operations (Olimat et al., 2023; Matarneh et al., 2019).

Document management for maintenance

Ensuring integrity and consistency of documents is extremely important in the use of DT tech, especially in highly regulated industries like healthcare where facility management has extremely tight requirements. Many facilities currently do not have routine maintenance records, and DT thus loses its predictive maintenance and operation optimization role (Ebiloma et al., 2023).

Data availability data

DT models have their accuracy dependent on verification and optimization with empirical data, but acquiring the actual operational data is difficult, limiting the reliability and application promotion of DT in the FM field (Hou et al., 2023).

The importance of bibliometric analysis of digital twin research in facility management domain

Since DT has been increasingly applied in FM, a systematic bibliometric analysis is necessary to clarify the existing research state and facilitate future studies.

1.3. Research trends and growth

Bibliometric studies indicated that the number of studies with DT in the field of FM has increased more since 2018, indicating an increased interest in its potential value (Olimat et al., 2023; Siccardi & Villa, 2022).

Recognization of the key contributors to research

With the help of the bibliometric methods, many researchers, institutions, and countries that have made an active contribution in the fields of DT and FM can be identified, thus providing references for academic collaboration (Olimat et al., 2023; Shishehgarkhaneh et al., 2022).

Future research directions

Through an analysis of research networks as well as citation relationships, bibliometric analysis can identify research hotspots and knowledge gaps, thus paving the way for future high-impact research (Bhandal et al., 2022; Shishehgarkhaneh et al., 2022).

The study is organized as follows: Section 1: Introduction. It provides the context of research and describes the statement of the problem. Section 2: Research Methods. It presents a detailed explanation of the research methods used in this paper, including the research design, data collection and analysis. Section 3 is our main results. Section 4 presents the bibliometric analysis results, then lays a foundation for the discussion of the research outcomes. Section 4 Results. They are discussed to see the importance of theit results. Section 5 revisits and re-affirms contributions of the study, re-summarizes the research findings and discusses possible future research avenues.

2. Research Methodology

2.1. Research Design

The workflow of this paper is shown in Figure 2.1. The first is the data collection stage. The keyword combination (digital twin) and (facility management or facility management or FM) is searched through Web of Science. After preliminary screening, journal articles on the keyword combination are available. After preliminary screening, 195 articles were obtained, ranging from 2019 to February 2025. After further screening and excluding articles that are not related to the research topic, 147 articles were finally generated as the data source for this study. The second stage is the data analysis stage, and it is recommended to use R-bibliometrix and Citesoace for bibliometric analysis. Next is the data visualization stage. Relevant charts will be obtained from R-bibliometrix and Citespace. Finally, the data will be interpreted and the research results will be discussed.

2.2. Data Collection

This paper aims to search for potential studies through the Web of Science database. The articles were initially screened using various search criteria. (1) Keyword combination = (digital twin) and (facility management or facility management or FM). (2) Document type = article. (3) Time span = 2019-2025. (4) Language = English. (5) Index = Web of Science Core Collection. After the initial screening, reasonable inclusion and exclusion criteria were developed and the articles were screened for a secondary period to exclude articles not relevant to the topic.

2.3. Data Analysis

For bibliometric research, different methods and software have been proposed to draw bibliometric graphs and interpret themes. The data analysis phase will use Citespace and R-Bibliometrix for bibliometric analysis.

2.3.1. CiteSpace

CiteSpace is a software tool for visualizing and analyzing trends and patterns in the scientific literature. It is particularly valuable for discovering the intellectual structure of a research field, tracing the development of scientific ideas, and charting the changes and evolution of research topics over time. It enables researchers to mine citation patterns, scientific symbols, semantic webs, and other features hidden in large collections of documents. This gear is a key part of bibliometric analysis [a mature research field that uses citation data to assess the impact and trajectory of research (Raan, 2010).

Closer to the empirical era is "citation network visualization and burst detection analysis", which can help scholars identify major contributors (authors, institutions, journals) within scientific disciplines and understand the evolution and consistency of their mid-term transformations (Ioannidis et al., 2014; Hand, 2012). By using temporal analysis, it is possible to further identify emerging trends and the development of trends over time (Noorden, 2013).

In addition, CiteSpace can be combined with other tools (such as VOSviewer or R) for better bibliometric analysis, providing more comprehensive insights into references and research dynamics (Hicks et al., 2015).

CiteSpace is a widely used tool, but the effectiveness of this work is highly dependent on dataset fidelity and secure datasets. To identify trends in this research and their impact, researchers must employ multiple analytical methods and critically evaluate their findings (Ioannidis et al., 2014; Holbrook et al., 2013). CiteSpace allows researchers to explore and visualize citation networks and co-citations, enabling them to identify key contributors, often with the help of other bibliometric tools.

2.3.2. R-Bibliometrix

R-Bibliometrix is a comprehensive scientific analysis tool and a robust literature database management system. It assists researchers in discovering current research trends, evaluating scientific results, and building shared visual analysis networks. The tool can perform citation analysis, co-citation analysis, and collaboration network analysis. Additionally, it provides various bibliometric indicators and visualizes the relationships between authors, institutions, and countries (Moral-Munoz et al., 2020; Hassan & Duarte, 2024).

It is frequently used for applied research evaluation, trend analysis, and mapping collaboration networks. Its analyses can include the impact of researchers and institutions, identification of high-impact literature, examination of keyword changes over time, revelation of research hotspots, and visualization of collaboration patterns and core research centers (Lyu et al., 2023).

R-Bibliometrix is an open source tool that enables flexible and customizable analysis, while its Biblioshiny interface does not require any programming knowledge, making research not only satisfying but also simple and fast. Rich documentation and user support open the door for novices, but researchers need to choose tools to meet their goals and understand the limitations imposed by the methods (Arruda et al., 2022; Petrovich et al., 2024).

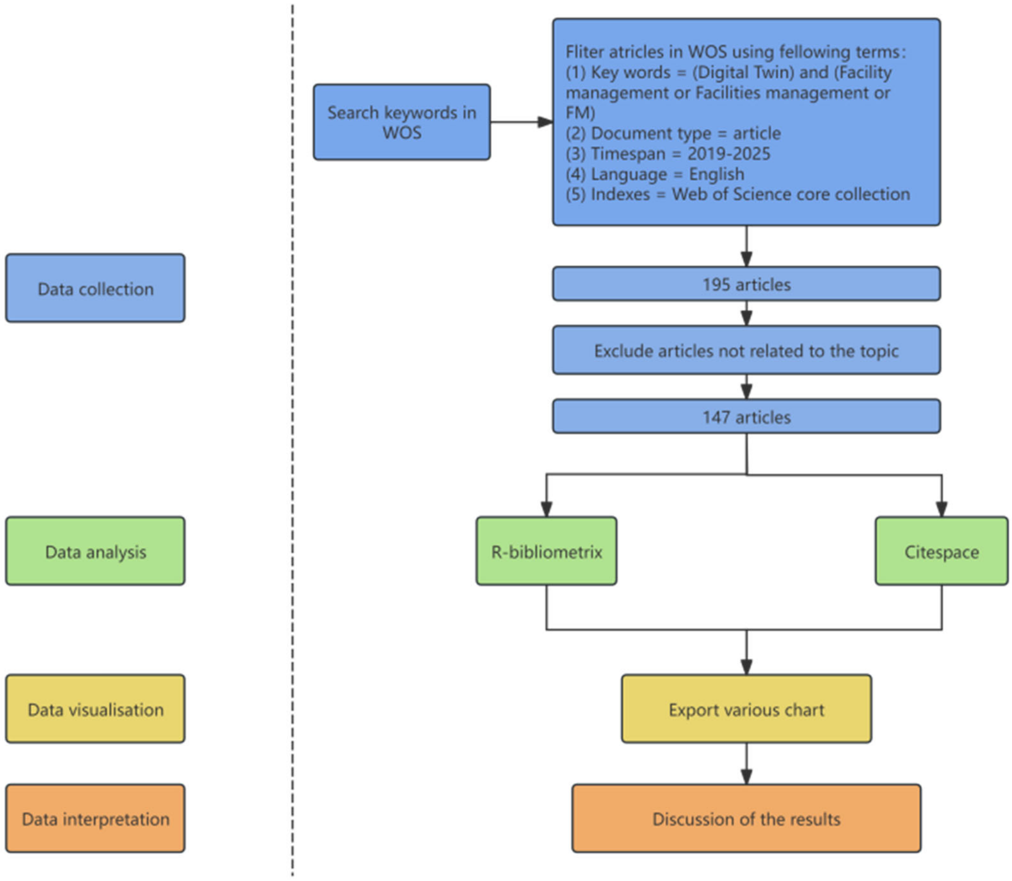

Figure 2.1 Research path design for this paper

2.4. Data Visualization

Heersmink et al. (2011) first described this capability for bibliometric networks, their modeling or visualization. According to Raan (2010), Citespace serves to identify the knowledge structure of a research field, trace the evolution of scientific ideas and map the development of research topics. Conversely, Aria and Cuccurullo (2017) demonstrated that R-Bibliometrix can construct bibliometric networks through the Plot function. As outlined by Cobo et al. (2011), bibliometric approaches can be classified based on their unit of analysis.

The data visualization step is significant in bibliometric studies. Convert bibliometric data to visual or graphical representation: In this step, the collected bibliometric data is analyzed and transformed into visual and graphical representation (creation of graphs and charts). These representations include, but are not limited to, network analysis diagrams, heat maps, dendrograms, scatter plots, histograms, bar charts, and thematic maps. In this article, we highlight the importance of data visualization for bibliometric researchers. It helps researchers to detect quickly patterns, trends, and relationships in large data sets, thus enabling geras scientific research and scholarly communication.

2.5. Data Interpretation

This study is based on 147 articles obtained from the WOS database. This analysis applied R-Bibliometrix and Citespace that supports descriptive methods like bibliometric coupling, co-occurrence analysis, and co-citation analysis. A systematic mapping approach was used to collate existing literature and establish research parameters through classification. This included developing research questions, performing literature reviews, and synthesizing key findings. The data was analyzed to visualize trends, gaps, and thematic clusters in maps and charts.

This review presents a revision of academic research papers connected to digital twin technologies in FM. Per the inclusion criteria, the dataset was prepared, followed by an analysis with Citespace and R-Bibliometrix, which visualizes the pattern and relationship between keywords.

The entire procedure of data processing was scrupulously recorded, leaving no corner untouched with respect to transparency and reproducibility. The produced knowledge graph can map out topic relationships and help identify main research areas and research gaps in existing literature on digital twins in FM. It also helps in offering important information for future exploration.

3. Analyze Results

Key Findings on the Utilization of Digital Twin (DT) Technologies in Facility Management (FM) The summarized literature review encompasses contributions pertaining to DT-FM research during the period spanning 2019 to 2025, with an insightful analysis of the temporal evolution of academic publications. As such, the analysis was able to reveal the relations between influential journals, authors, institutions, and countries who contributed most to the researches on DT-FM … consequently shed light on prominent scholars, and their research impacts. A keyword analysis is also performed to reveal dominant themes and research trends found in relevant articles, providing insights into pressing challenges and future directions. This systematic mapping provides a comprehensive overview of the evolution of DT-FM research to date, highlighting emerging trends and identifying novel opportunities that can help further develop this topic within the FM field.

3.1. General Descriptive Analysis

A bibliometric analysis based on the data from the Web of Science (WOS) core database of research publications on digital twin (DT) applications for facility management (FM) published between January 2019 and February 2025 shows major publication trends analyzed using R-Bibliometrix (The rest of the bibliometric overview can be found in Figure 3.1). The dataset consists of 147 articles published in 76 journals, with an annual growth rate of publication 20.09%. Based on the distribution of publications across years, we can identify two periods in the production of DT-FM knowledge for the last five years (see Figure 3.2). Before 2022, the growth rate stayed fairly small. The increasing trend of DT in FM related research content based on published articles is not observed until 2022, according to the data presented, signifying research interest in the domain is an increasing trend. This upward trend sheds light on the acceptance of DT as an enabling technology developed for improving FM practices.

Figure 3.1 General information on the literature on DT-FM.

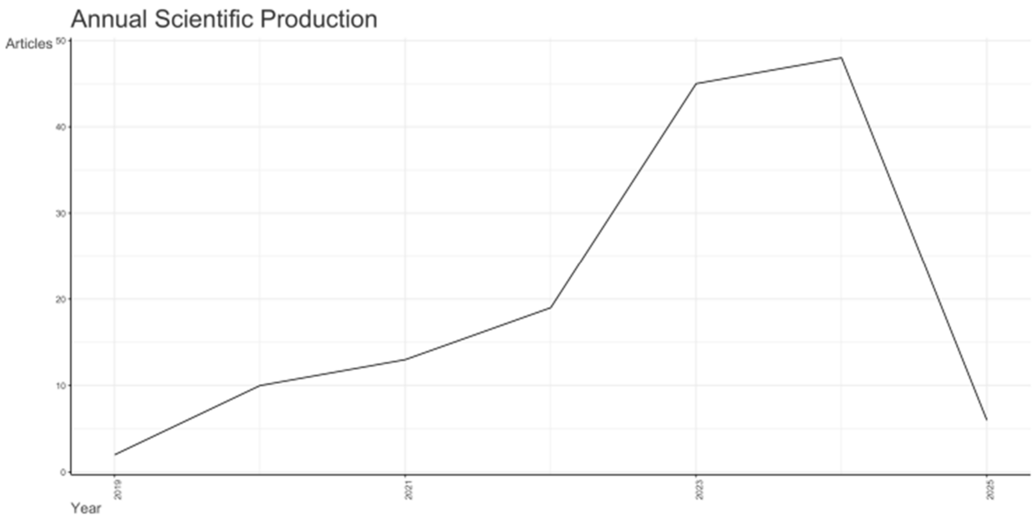

Figure 3.2 Annual scientific production on DT-FM research.

3.2. Bibliographic coupling analysis

3.2.1. Bibliographic Coupling of Sources

Figure 3.3 illustrates the inter-linkage between academic sources of DT and FM within the same pool by at least one common reference. In bibliographic coupling, two sources (e.g., documents, authors, journals) are coupled if they cite the same third source. For example, larger nodes (e.g., Automation in Construction and Buildings) represent journals with many publications that are co-cited with other sources in the dataset more frequently than other journals, indicating their influential contribution in shaping academic conversation in the field.

As shown in Figure 3.4, the top ten journals combined account for a total of 46.2% of the publications in DT-FM. Applied Sciences-Basel is the most relevant source of them. The leading journals are Applied Sciences-Basel, Automation in Construction, and Buildings with 10, 9, and 8 papers, respectively. Apart from that, Journal of Building Engineering contributed a total of 8 papers and IEEE Access contribution was 7 papers. Energy and Buildings and the Journal of Information Technology in Construction have published 6 papers each, and the remaining journals have published less than 5 papers.

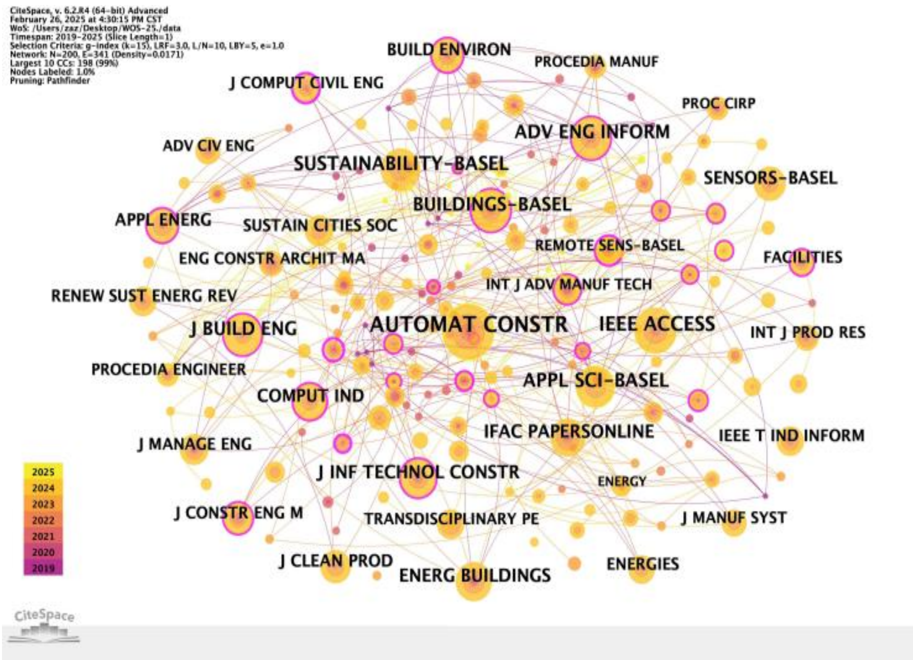

Figure 3.3 Bibliographic coupling of citation sources

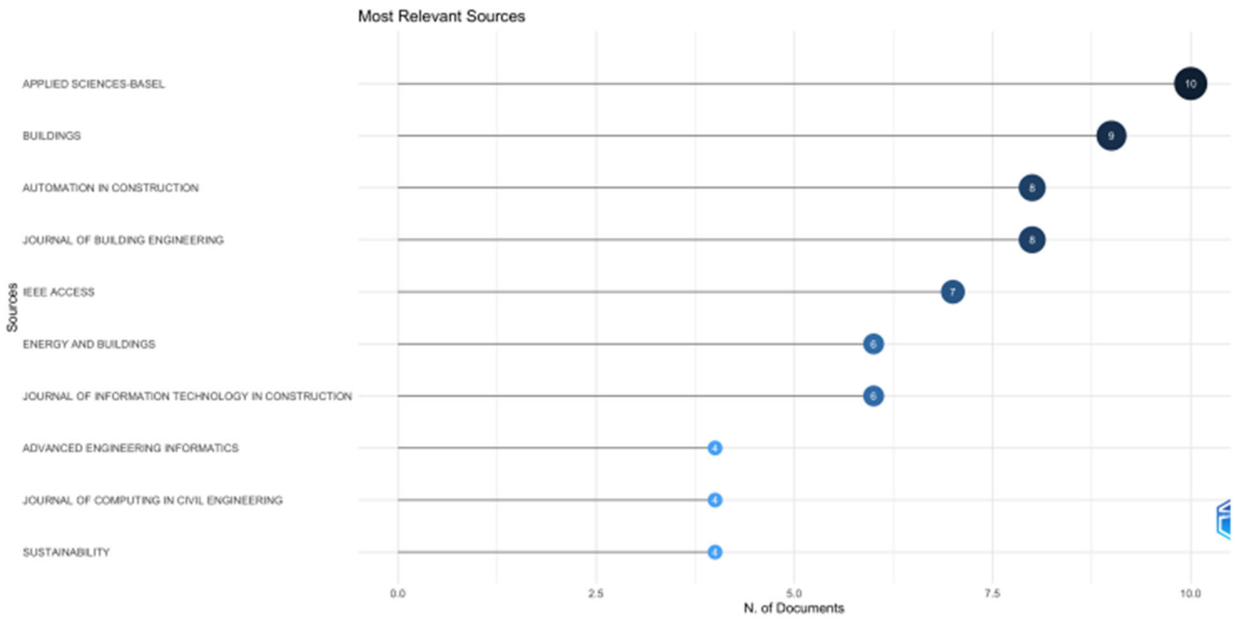

Figure 3.4 Top 10 most relevant sources in DT-FM research.

3.2.2. Author citation network

An analysis of the top 10 authors based on local citations in the realms of DT and FM is shown in Figure 3.5. Local citations indicate how often an author's work cited in the dataset used in this study. Parlikad AK and Xie X are the most influential scholars with a total of 31 local citations each indicating a substantial contribution to this domain. The two DT-FM leading author papers ranking follow Lu QC and Schooling JM, with 24 total citations each as well, reflecting the academic popularity of the authors involved in DT-FM research. Nielsen HK, Svennevig PR, and Svidt K were also cited 19 times each, suggesting moderate but significant influence. Key contributors are also Hosamo HH (17 citations), Anumba CJ (14 citations) and Ozturk GB (13 citations).

This network in the case of the author, which is the graph of the author citation network, showing how the researchers are collaborative, is shown in Figure 3.6 For ensuring high-quality scholarly output, strengthening research alliances is widely regarded as an important strategy. The network shows various clusters, with the biggest circles in each cluster representing the most influential authors. The study also reinforces the dynamic and developing nature of DT literature with collaborative work between prominent academics, emerging new research areas, and the influence of leading institutions.

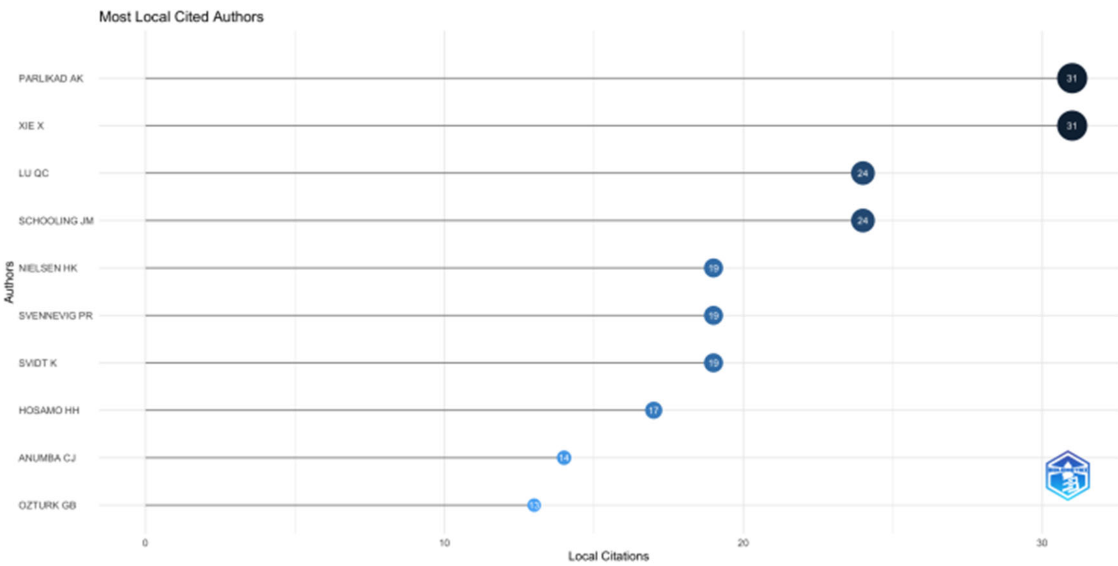

Figure 3.5 The 10 most cited authors.

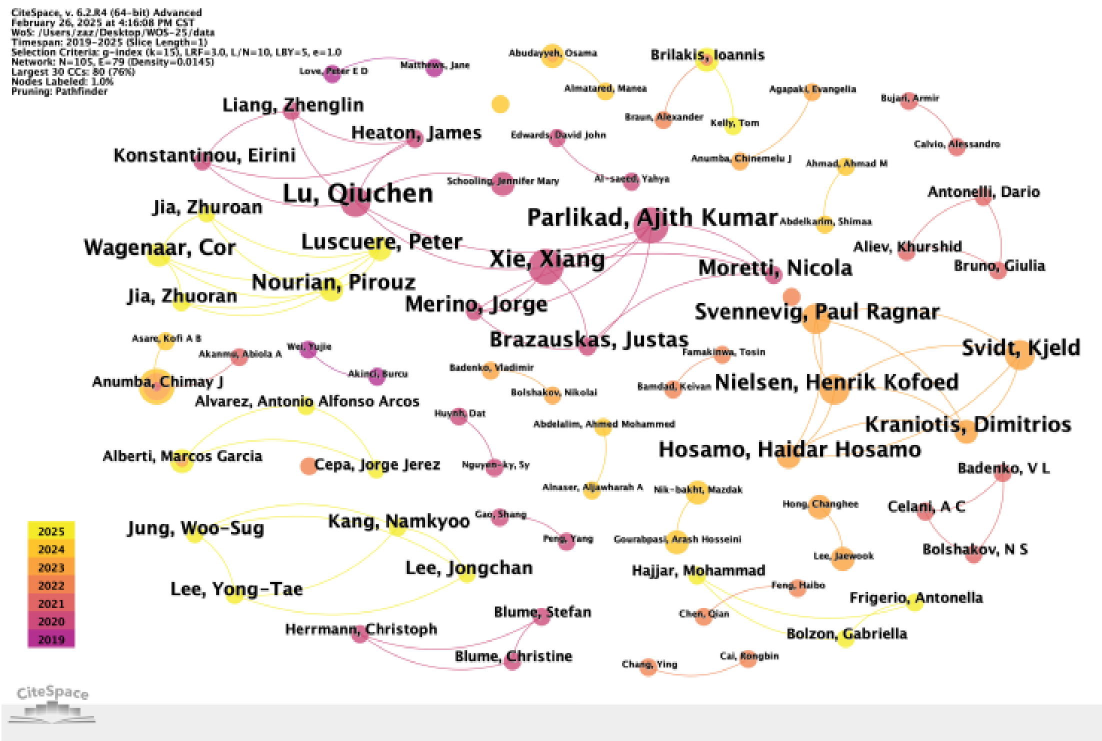

Figure 3.6 Author collaboration network

3.2.3. Bibliographic coupling of organizations

The top 10 organizations by the number of publications are shown in Figure 3.7 From the figure, we can see that the first place is taken by the University of Cambridge with 14 papers, far ahead of other institutions. This indicates a signficant amount of such research being conducted at the University of Cambridge, and their output of research resulting in papers that is largely of interest to other academic researchers. The top three most active institutions are the Polytechnic University of Milan, State University System of Florida and University of Florida, all publishing 9 papers respectively. These institutions may be holders of some academic influence in certain research fields or methods, and may have established close academic cooperation of part or all with other research institutions. According to the data, there were Egyptians Knowledge Bank (EKB) and National University of Singapore published 7 papers each, which reflects the industry contribution of research institutions in different regions in this field. The research results of National University of Singapore may be the most significant and developing trend of this field in Asia in particular. Universidad Politécnica de Madrid, University College London (UCL), and University of London published 6 papers each, reflecting a sustained European university interest in this area of research. This may result in the diversification of designs in specific application scenarios and methodologies. It's a number relatively small but still indicates that Central Queensland University has a certain academic influence in this field. It may also mean that the institution has professional strengths in particular sub-disciplines and warrants more focus.

As shown in Figure 3.8, the paper output of different academic institutions from 2019 to 2025, the research trend of major institutions in the field shows different growth trends. Similar trends have been seen at the University of Florida, which has retained the top spot in research output from the recent dataset and has seen the number of papers grow from about 6 in 2019 to around 12 in 2025, suggesting that it has continued to invest in this domain. Cambridge becomes a major contributor after 2021, with its growth accelerating between 2023 and 2024, finally mitigating at level of around 8 papers, making it the second biggest contributor. From the data from National University of Singapore and Central Queensland University, the increase of the papers is very fast, respectively, to reach 7 and 6 papers in 2025, it shows that their influence in this area little by little rising. The growth of the Polytechnic University of Milan appears slower and later in comparison but becomes faster after 2023 and eventually approaches 5 papers in 2025. In summary, the University of Florida, the University of Cambridge and the National University of Singapore are the main contributors to this research area, while the research output of Central Queensland University and the Polytechnic University of Milan have been steadily increasing in recent years as well, which reflects the continuous growth of academic institutions in various parts of the world towards this research area, and may also accompany more international cooperation and research funding.

The institutional coupling analysis from the years 2019 to 2025 clearly indicates the significant research partnership between academic institutions and industrial agents (Figure 3.9). Key research centres, such as the University of Cambridge, Politecnico di Milano, Curtin University and the University of New South Wales show extensive global connectivity. UCL, the University of Macau and Aalborg University also helps to grow partnerships in academia. Moreover, the Institute of Electronics and Telecommunications serves as a vital link in interdepartmental co-operation. This involvement has been supplemented by industry players such as Amazon Web Services and FuseForward. Regional and global research have been strengthened by the National University of Singapore, City University of Toronto and the Hong Kong University of Science and Technology. The increasing international focus is evident with rising contributors such as Lomonosov Moscow State University and Babcock International Group, which also reflects the increasingly diverse academic ecosystem.

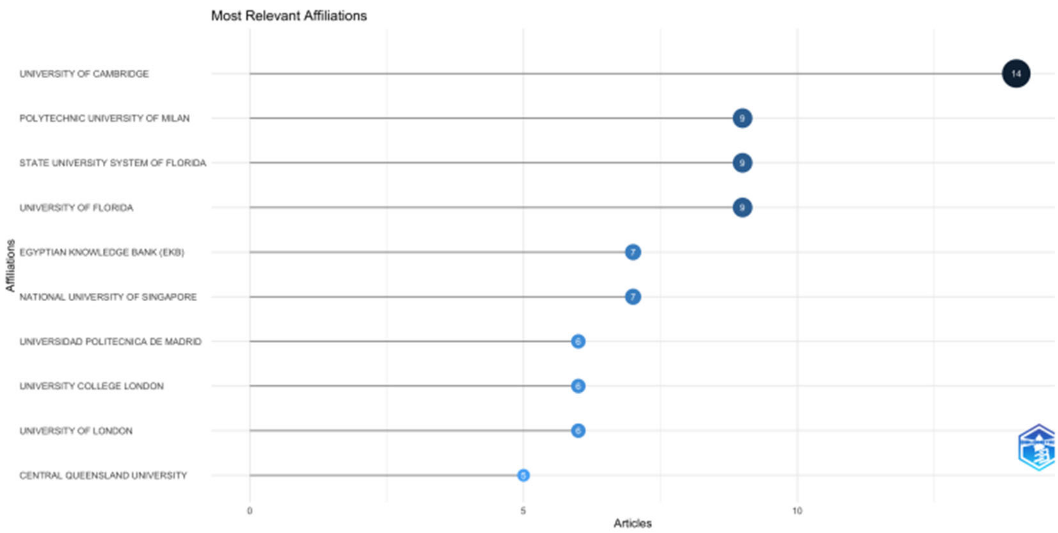

Figure 3.8 The top 10 contributing organizations.

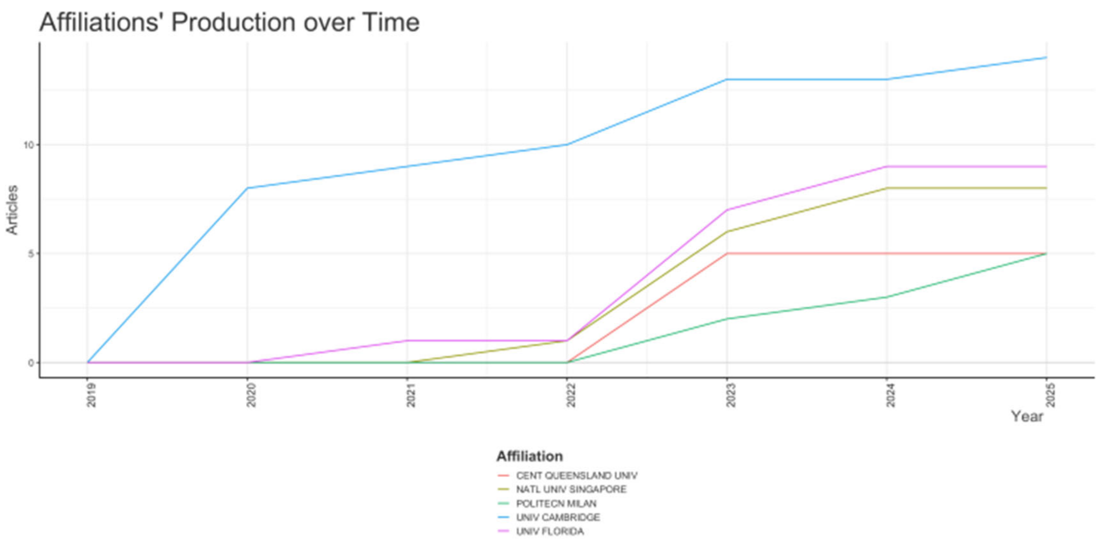

Figure 3.9 The production of affiliations over time.

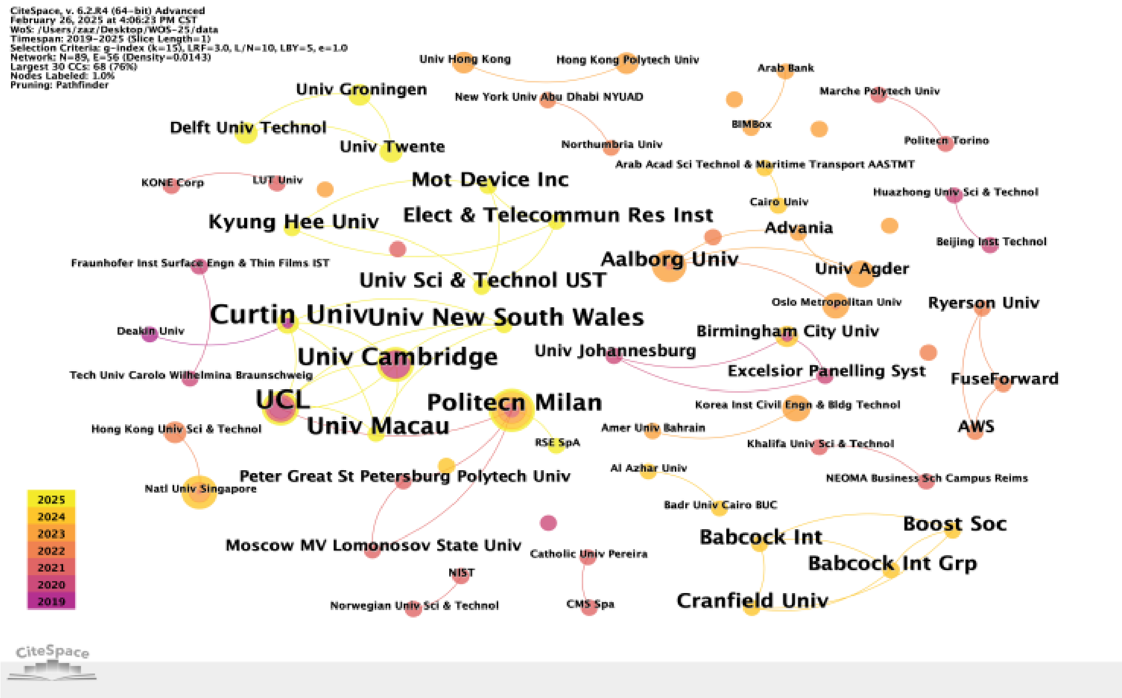

Figure 3.9 Bibliographic coupling of organizations

3.2.4. Bibliographic coupling between countries

According to recent data from WOS, at least 44 countries published research on DT-FM in the last 5 years. Of these, 6 countries published 10 or more articles. In fact, both China, the United Kingdom, and the United States have produced more than 20 articles.

Figure 3.10 shows publication output trends of five countries (China, Italy, South Korea, the United Kingdom, and the United States) from 2019 to 2025. The most dramatic increase in research activity is for China which rises steeply after 2021 all other countries after 2022. In the United States, the curve continues to rise steadily, and its positioning on the field remains strong. Similar to China and the U.S., the U.K. is also composed of a diverse group of industries and careers that still seem to be steadily growing.

Figure 3.11 This visualization maps the main countries that contribute to the DT-FM field, where node sizes represent publications and connecting lines represent collaborations. China is the leading research center in the field, with the highest publication output and far-reaching collaboration in terms of international engagement. In addition, the United Kingdom and the United States are also well represented, creating central nodes in the network. Italy and Germany remain top players, reinforcing their form in the sector. Newer scientific players like South Korea, Norway, and the United Arab Emirates show up in other such rankings, which suggests a broader influence in research. Thick lines of connection meaning frequent and strong collaborations are present in key countries especially for China, United States, and United kingdom. The rising involvement of other countries especially as Australia & Saudi Arabia indicates that there will be a much larger international global approach to research. This trend highlights the growing internationalization of DT-FM research, likely as a consequence of knowledge transfer, funding initiatives, and scientific collaborations.

Visualizations are shown for some major contributor countries to the DT-FM field (see Figure 3.11 and Figure 3.12), where the size of the circles indicates the number of publications (i.e., the number of papers) and solid lines between circles are indicative of inter-country collaboration (i.e., how many times that country collaborated with another country). The highest volume of international collaboration was seen, with China being the leading research center for publication output. United States and United Kingdom also showed very strong research influence with respective centralities in the nascent knowledge structure. Italy and Germany also kept their strong positions and re emphasised their active engagement in the field. Newcomers, such as South Korea, Norway and the United Arab Emirates, show an increase in their research impact. Lines connecting significant countries, which are thick, suggest regularize and strong collaboration — especially between the China, the US, and the UK. Increased involvement of other countries like Australia and Saudi Arabia suggests a larger international push for research. This trend also indicates the gradual internationalization of DT-FM research worldwide, facilitated by the exchange of knowledge, funding programs, and strategic partnerships.

The improvement in the interaction and collaboration of all countries in the world and the Deep Technology development in FM will be the main driver of these. Interestingly, for the sake of developing fields, learning from more developed available technology can promote a small collective advancement.

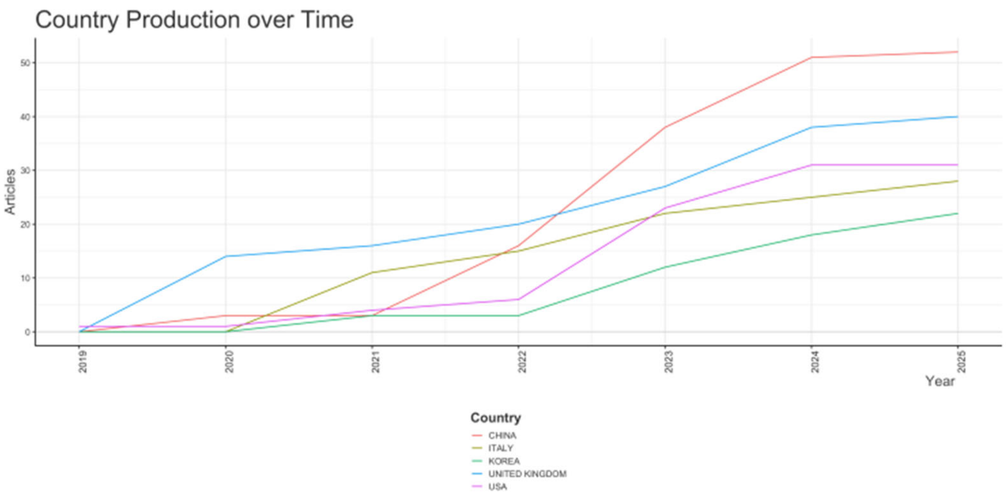

Figure 3.10 Research results of the five major countries in DT-FM over the years.

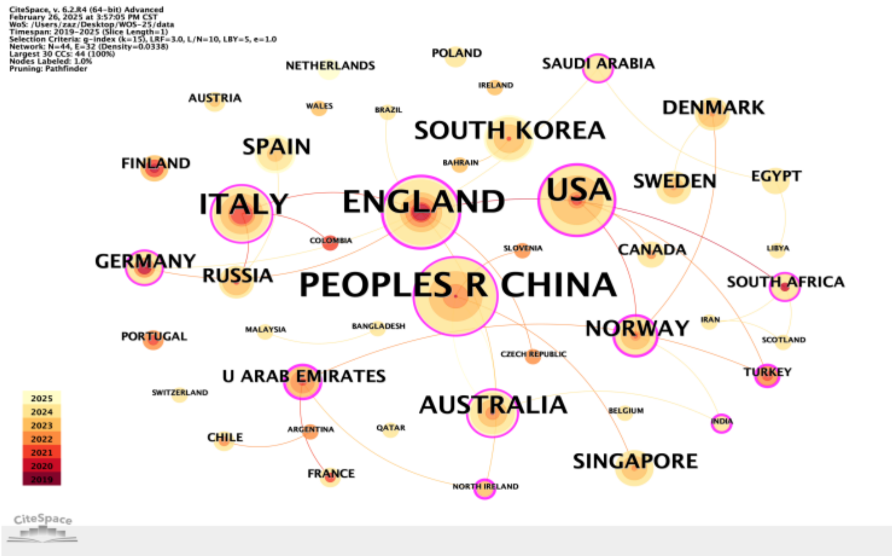

Figure 3.11 Bibliographic coupling of countries

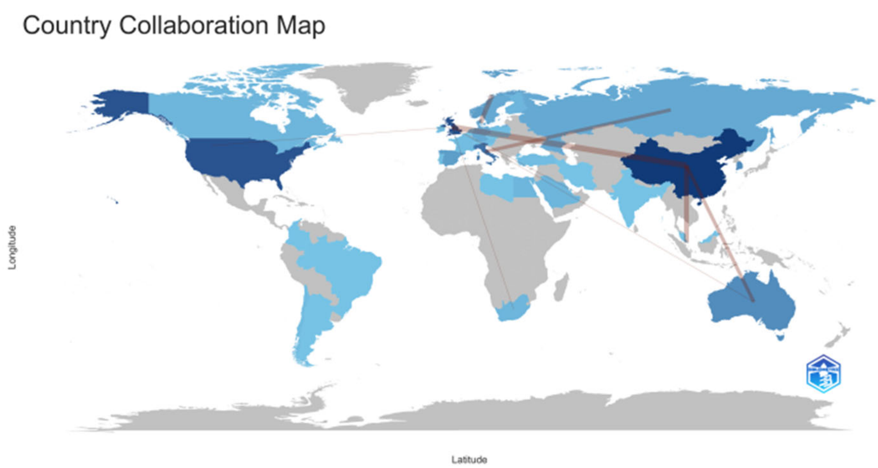

Figure 3.12 National cooperation map

3.3. Co-occurrence analysis of all keywords

Keywords briefly summarizes the scholarly literature, The analysis indicates BIM, wiring, and digital twins as the three main themes of DT-FM research within 2019 – 2025, signifying the rising penetration of digital twin technologies in facility management procedures. Terms like the Internet of Things, artificial intelligence, augmented reality, and machine learning reveal the growing importance of intelligent automated systems in facility operations. The emergence of predictive maintenance, fault detection, and asset management also reflect an evolution towards proactive maintenance techniques to drive enhanced efficiency and sustainability. Additionally, recognition of ideas such as Industry 4.0, smart cities, and cyber-physical systems suggests that the research for DT-FMs is part of a larger trend toward digital transformation that enables automation, real-time monitoring of data, and improved decision-making. Moreover, various energy usage, thermal comfort and sustainability issues point toward an increasing attention to environmental performance and occupant well-being. The overall review of the response indicates a shift towards a highly digitalized, automated and data-driven approach in facility management and future studies will likely expand on the integration of BIM and emerging technologies to improve operational performance and resilience of the built environment.

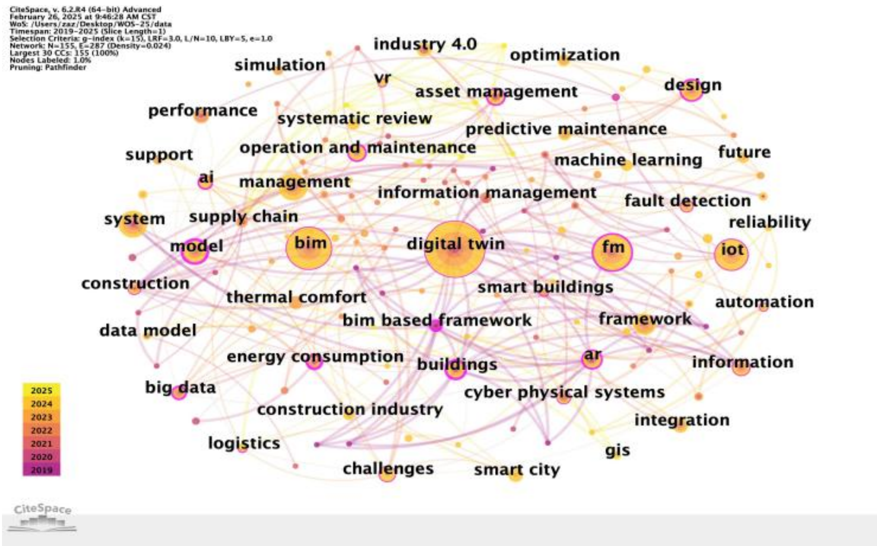

Figure 3.13 Co-occurrence analysis of all keywords.

3.4. Future research trends

The trend analysis from 2020 to 2024 shows a significant shift in research on Building Information Modeling (BIM) and Facility Management (FM). The rising repetition of key buzzwords such as “BIM,” “management,” “framework,” and “integration” indicates a growing focus on digitalizing facility management through the use of digital technologies to improve operational efficiency and decision-making capabilities. “Challenges” emerged as one of the main research targets for 2024, reflecting the growing awareness that there are barriers to BIM implementation—such as interoperability issues, data security issues, implementation costs, and organizational reluctance. In addition, terms such as “systems” and “information” were emphasized to indicate a move toward structured data management and systematized workflows to improve operational performance. The rising research interest in “operation” suggests that another potential research area is the use of BIM for real-time decision-making, predictive maintenance, and lifecycle cost optimization. The emergence of “integration” as a key theme confirms that discussions at this forum will revolve around BIM with the latest digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), and digital twin systems to improve automation, data analysis, and asset management.

Advances in BIM technologies, such as artificial intelligence and machine learning, have the potential to provide predictive analytics for project outcomes before a project even begins. Another research direction is to establish a standardized policy framework to promote BIM adoption across industries. As the built environment begins to go digital and become more dependent on data analytics, robotics, and artificial intelligence, future research may explore the integration of BIM with other digital technologies, such as cybersecurity, cloud computing, and blockchain, which will promote secure, interoperable, and scalable digital facility management solutions.

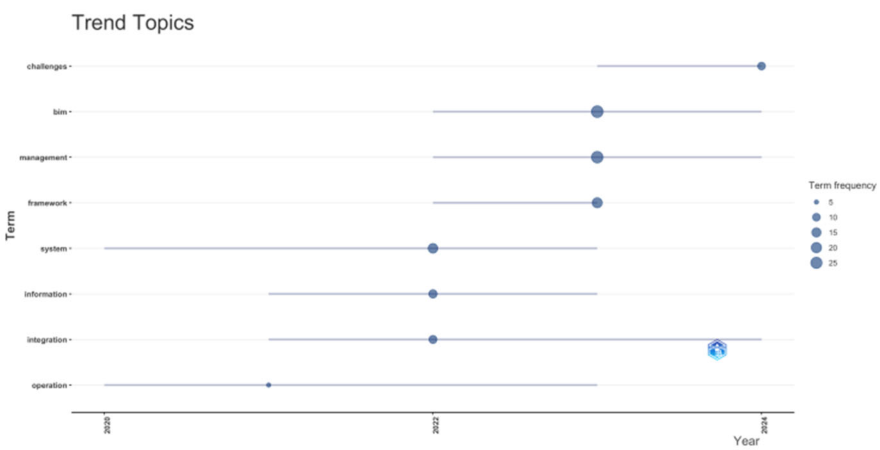

Figure 3.14 Trend topics in DT for FM.

4. Discussion DT for FM

Digital twin technology is helping to shape the future of facility management by offering a digital representation of physical assets that improves the visualization, control, and optimization of building performance. It combines multiple digital solutions and practices to enhance the efficiency, sustainability, and decision-making processes. Digital twins utilization in facility management includes technology integration and innovation, implementation, sustainability, as well as data management and professional development. Together, these aspects are critical for the successful implementation and use of digital twins across various industries.

Technology Integration and Innovation

The integration of technological concepts such as Building Information Modeling (BIM), IoT, AI, etc., rendering total models of facilities, is allowed by digital twins(Siccardi & Villa, 2022).

They facilitate the acquisition and processing of data in near-real-time, which could enhance the simulation, monitoring, and analysis of building operations (Zhang et al., 2022).

Digital twins can be used in the integration with energy management systems to optimize energy consumption and to reduce carbon footprints(Yu et al., 2022).

Implementation and Adoption Strategies

Therefore, the successful implementation of digital twins relies on a bottom-up method with consideration of data integration and standards to achieve broader acceptance(Zhao et al., 2022).

According to Zhao et al., 2022, the empirical analysis demonstrates the importance of digitized control over data standards as a determinant in adopting digital twins in the facility management sector, which can serve as the basis for the construction of a conceptual framework for the establishment of a digital twin; hence all stakeholders are modeled interconnected with each other.

In order to unlock its full potential, we must attempt to transcend certain obstacles, increase level of data interoperability, and complexity of connecting virtual and physical environments (Motlagh et al., 2023).

Sustainability and Energy Efficiency

Another instance is Digital twins that enhance sustainability through improved energy management and minimizing environmental footprint with streamlined building operations(Bortolini et al., 2022).

They assist in identifying the main influencing factors of energy consumption and enable the retroactive tracing of energy events for enhanced sustainable practices(Jiao et al., 2023).

It also contributes towards designing and developing energy-efficient buildings and their assimilation with renewables(Yu et al., 2022).

Data Collection and Storage

The basic information supports the storage sys-tems and helps the creation of digital twins to the assets for maintaining the status of digital twin(Zhang et al., 2022).

Data collection is critical in the context of facility management, and IoT devices and sensors, which can be integrated into smart spaces, enhance this capability (Motlagh et al., 2023).

The development and implementation of cohesive policy frameworks that address issues of data security, privacy, and standardization is essential if digital twins are to be deployed successfully(Ghansah & Lu, 2023).

Education and Professional Development

As such, the use of digital twins requires the cultivation of a skilled workforce that can both manage and make use of these technologies in an effective manner(Ghansah & Lu, 2023)

Facility managers must receive training in the use and implementation of digital twins through educational programs and continuing professional development initiatives(Siccardi & Villa, 2022).

Academia and industry partnership could aid in transferring knowledge from theory to the practice of digital twin technologies(Ghansah & Lu, 2023).

Although there are many advantages of using these digital twin technology for facility management, there are some obstacles related to its adoption. Challenges including data interoperability, standardization, and the difficulty of integrating digital and physical systems must be resolved. Moreover, the booming of aspirational o4cials in the landscape and the consolidation of clear implementation frameworks are very important to be able to fully exploit the potential of these digital twins in the industry. With rapid proliferation of technology, it will be essential to work together on research and cooperate between stake holders to address these challenges and foster innovation in facility management.

5. Conclusion

Digital twin technology has emerged as a transformative innovation in facilities management (FM), offering real-time data integration, predictive analytics, and enhanced decision-making capabilities. By creating virtual replicas of physical assets, digital twins enable continuous monitoring, performance optimization, and proactive maintenance, ultimately improving operational efficiency and sustainability.

At present, digital twin use-cases in FM center on predictive maintenance, energy management, and space optimization. AI-assisted predictive maintenance makes use of real-time sensor data collected with the help of AI-driven analytics to mitigate downtime and increase asset longevity. For energy management applications, digital twins can be used to simulate the performance of buildings for optimization, leading to significant energy savings and lower carbon footprints. They also enable ever efficient analysation of space, give insights into workplace design, and resource allocation.

Evolution of digital twins: Looking forwardDigital twins will see more widespread adoption in the future as nature towards wide adoption of digital twins driven by advances in AI, IoT and cloud computing. Digital twins will be made more robust through integration with building information modeling (BIM), IoT (internet of things)-enabled smart sensors, and blockchain (for trusted data sharing). In addition, the integration of digital twins with the metaverse and augmented reality (AR) is likely to offer immersive and interactive facility management experiences. Challenges like high implementation costs, data interoperability issues, and cybersecurity risks still stand as major barriers to widespread adoption.

The bibliometric analysis presented in this article offers significant insights into the research landscape of digital twin applications in FM. The study through publication trends, keyword co-occurrence networks and citation analysis identifies prominent author, major researches areas and future directions. This provides insight into the evolution of digital twin research and helps identify areas of research that remain unexplored.

However, the study has some limitations. First, it depends only on data from particular datasource that may omit relevant publications outside those databases. Secondly, the analysis focuses on quantitative metrics, without any qualitative insights regarding the content and challenges in the implementation in real life. Finally, although the study recognizes research trends, it does not critically discuss the practical barriers to adopting digital twin technology in FM Future studies could further add qualitative case studies and expert interviews in order to broaden the view of the field beyond the bibliometric perspective presented here.

References

[1] Arsecularatne, B., Rodrigo, N., & Chang, R. (2024). Digital Twins for Reducing Energy Consumption in Buildings: A Review. Sustainability, 16(21), 9275. https://doi.org/10.3390/su16219275

[2] Abdelalim, A. M., Essawy, A., Alnaser, A. A., Shibeika, A., & Sherif, A. Digital Trio: Integration of BIM–EIR–IoT for Facilities Management of Mega Construction Projects. Sustainability 2024, 16, 6348. https://doi.org/10.3390/su16156348

[3] Ghansah, F. A. (2024). Digital twins for smart building at the facility management stage: a systematic review of enablers, applications and challenges. Smart and Sustainable Built Environment. https://doi.org/10.1108/SASBE-10-2023-0298

[4] Mousavi, Y., Gharineiat, Z., Karimi, A. A., McDougall, K., Rossi, A., & Gonizzi Barsanti, S. (2024). Digital Twin Technology in Built Environment: A Review of Applications, Capabilities and Challenges. Smart Cities, 7(5), 2594-2615. https://doi.org/10.3390/smartcities7050101

[5] Zhang, Z., Wei, Z., Court, S., Yang, L., Wang, S., Thirunavukarasu, A., & Zhao, Y. (2024). A review of digital twin technologies for enhanced sustainability in the construction industry. Buildings, 14(4), 1113. https://doi.org/10.3390/buildings14041113

[6] Yang, J., & Ng, S. T. (2024). Prospects for digital twin technology in the building modular construction and operation phases: A game theory-based analysis. Journal of Cleaner Production, 470, 143344. https://doi.org/10.1016/j.jclepro.2024.143344

[7] Lee, Y., Baek, M. S., & Yoon, K. (2025). Digital Entity Management Methodology for Digital Twin Implementation: Concept, Definition, and Examples. IEEE Transactions on Broadcasting. https://doi.org/10.1109/TBC.2024.3517138

[8] Olimat, H., Liu, H., & Abudayyeh, O. (2023). Enabling technologies and recent advancements of smart facility management. Buildings, 13(6), 1488. https://doi.org/10.3390/buildings13061488

[9] Matarneh, S. T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., & Matarneh, R. (2019). Building information modeling for facilities management: A literature review and future research directions. Journal of Building Engineering, 24, 100755. https://doi.org/10.1016/j.jobe.2019.100755

[10] Ebiloma, D. O., Aigbavboa, C. O., & Anumba, C. (2023). Towards digital twin maintenance management of health facilities in Nigeria: the need for maintenance documentation. Buildings, 13(5), 1339. https://doi.org/10.3390/buildings13051339

[11] Hou, H., Lai, J. H., Wu, H., & Wang, T. (2024). Digital twin application in heritage facilities management: Systematic literature review and future development directions. Engineering, Construction and Architectural Management, 31(8), 3193-3221. https://doi.org/10.1108/ECAM-06-2022-0596

[12] Siccardi, S., & Villa, V. (2022). Trends in adopting BIM, IoT and DT for facility management: A scientometric analysis and keyword co-occurrence network review. Buildings, 13(1), 15. https://doi.org/10.3390/buildings13010015

[13] Baghalzadeh Shishehgarkhaneh, M., Keivani, A., Moehler, R. C., Jelodari, N., & Roshdi Laleh, S. (2022). Internet of Things (IoT), Building Information Modeling (BIM), and Digital Twin (DT) in construction industry: A review, bibliometric, and network analysis. Buildings, 12(10), 1503. https://doi.org/10.3390/buildings12101503

[14] Bhandal, R., Meriton, R., Kavanagh, R. E., & Brown, A. (2022). The application of digital twin technology in operations and supply chain management: a bibliometric review. Supply Chain Management: An International Journal, 27(2), 182-206. https://doi.org/10.1108/SCM-01-2021-0053

[15] van Raan, T. (2010). Bibliometrics: measure for measure. https://doi.org/10.1038/468763a

[16] Ioannidis, J. P., Boyack, K. W., Small, H., Sorensen, A. A., & Klavans, R. (2014). Bibliometrics: Is your most cited work your best?. Nature, 514(7524), 561-562. https://doi.org/10.1038/514561a

[17] Van Noorden, R. (2013). Formula predicts research papers' future citations. News, Nature, 3. https://doi.org/10.1038/nature.2013.13881

[18] Hicks, D., Wouters, P., Waltman, L., De Rijcke, S., & Rafols, I. (2015). Bibliometrics: the Leiden Manifesto for research metrics. Nature, 520(7548), 429-431. https://doi.org/10.1038/520429a

[19] Holbrook, J. B., Barr, K. R., & Brown, K. W. (2013). We need negative metrics too. Nature, 497(7450), 439-439. https://doi.org/10.1038/497439a

[20] Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. Profesional de la Información, 29(1). https://doi.org/10.3145/epi.2020.ene.03

[21] Hassan, W., & Duarte, A. E. (2024). Bibliometric Analysis: A Few Suggestions. Current Problems in Cardiology, 102640. https://doi.org/10.1016/j.cpcardiol.2024.102640

[22] Lyu, P., Liu, X., & Yao, T. (2023). A bibliometric analysis of literature on bibliometrics in recent half-century. Journal of Information Science, 01655515231191233. https://doi.org/10.1177/01655515231191233

[23] Arruda, H., Silva, E. R., Lessa, M., Proença Jr, D., & Bartholo, R. (2022). VOSviewer and bibliometrix. Journal of the Medical Library Association: JMLA, 110(3), 392. https://doi.org/10.5195/jmla.2022.1434

[24] Petrovich, E., Verhaegh, S., Bös, G., Cristalli, C., Dewulf, F., van Gemert, T., & IJdens, N. (2024). Bibliometrics beyond citations: introducing mention extraction and analysis. Scientometrics, 129(9), 5731-5768. https://doi.org/10.1007/s11192-024-05116-x

[25] Heersmink, R., van den Hoven, J., van Eck, N. J., & van den Berg, J. (2011). Bibliometric mapping of computer and information ethics. Ethics and information technology, 13, 241-249. https://doi.org/10.1007/s10676-011-9273-7

[26] Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of informetrics, 11(4), 959-975. https://doi.org/10.1016/j.joi.2017.08.007

[27] Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., & Herrera, F. (2011). Science mapping software tools: Review, analysis, and cooperative study among tools. Journal of the American Society for information Science and Technology, 62(7), 1382-1402. https://doi.org/10.1002/asi.21525

[28] 16(18), 8245. https://doi.org/10.3390/su16188245

[29] Siccardi, S., & Villa, V. (2022). Trends in adopting BIM, IoT and DT for facility management: A scientometric analysis and keyword co-occurrence network review. Buildings, 13(1), 15. https://doi.org/10.3390/buildings13010015

[30] Zhang, J., Cheng, J. C., Chen, W., & Chen, K. (2022). Digital twins for construction sites: Concepts, LoD definition, and applications. Journal of Management in Engineering, 38(2), 04021094. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000948

[31] Yu, W., Patros, P., Young, B., Klinac, E., & Walmsley, T. G. (2022). Energy digital twin technology for industrial energy management: Classification, challenges and future. Renewable and Sustainable Energy Reviews, 161, 112407. https://doi.org/10.1016/j.rser.2022.112407

[32] Zhao, J., Feng, H., Chen, Q., & de Soto, B. G. (2022). Developing a conceptual framework for the application of digital twin technologies to revamp building operation and maintenance processes. Journal of Building Engineering, 49, 104028. https://doi.org/10.1016/j.jobe.2022.104028

[33] Motlagh, N. H., Zaidan, M. A., Lovén, L., Fung, P. L., Hänninen, T., Morabito, R., ... & Tarkoma, S. (2023). Digital twins for smart spaces—beyond IoT analytics. IEEE internet of things journal, 11(1), 573-583. https://doi.org/10.1109/JIOT.2023.3287032

[34] Bortolini, R., Rodrigues, R., Alavi, H., Vecchia, L. F. D., & Forcada, N. (2022). Digital twins' applications for building energy efficiency: A review. Energies, 15(19), 7002. https://doi.org/10.3390/en15197002

[35] Jiao, Z., Du, X., Liu, Z., Liu, L., Sun, Z., & Shi, G. (2023). Sustainable operation and maintenance modeling and application of building infrastructures combined with digital twin framework. Sensors, 23(9), 4182. https://doi.org/10.3390/s23094182

[36] Ghansah, F. A., & Lu, W. (2024). Major opportunities of digital twins for smart buildings: a scientometric and content analysis. Smart and Sustainable Built Environment, 13(1), 63-84. https://doi.org/10.1108/SASBE-09-2022-0192