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Article

Integration of Building Information Modeling (BIM) with Transportation and Facilities: Recent Applications and Future Perspectives

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Abstract: At present, increased modes of transport have facilitated daily life. Building information modeling (BIM) integration has become a key strategy to foster efficiency, collaboration, and sustainability in the fields of buildings, transport, and facilities. Currently, there is a scarcity of comprehensive examinations of the performance of integrated BIM with transport facilities and applications to help identify potential prospects for sustainable development. Hence, this research paper attempts to scrutinize the integration of BIM, transportation, and facilities (T and Fs) by highlighting future directions and trends, revealing the existing status and hotspots of research in the field, and clarifying the developmental pulse of research as well as emerging areas in the future. A quantitative research technique is utilized in this study, using VOSviewer and CiteSpace software, and the Web of Science Core Collection (WoSCC) database. The study findings suggest that the hot keywords for the integration of BIM and T and Fs are predominantly concentrated on construction, framework, system, design, and management. In addition, over the previous 34 years (years 1989 to 2023), the applications of point cloud, digital twin, and life cycle assessment have been the current hot topics, and these emerging technologies can offer more innovative breakthroughs for the future. Furthermore, the integration of BIM and T and Fs represents an important trend that is essential for improving the efficiency, sustainability, and intelligence of buildings and infrastructure, from which the three domains can create synergies that contribute to the better planning, construction, and management of building and infrastructure projects.

Keywords: building information modeling (BIM); transportation; digital twins; point cloud; bibliometric; life cycle assessment (LCA)

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1. Introduction

Owing to the continuous acceleration of global urbanization, the populace is gradually gathering in cities, where urban spatial patterns are changing, and the mode of transport is becoming more diversified [1]. Meanwhile, the rapid development of the transportation-in-construction industry has made construction projects in transportation infrastructure increasingly large, difficult, and technically complex [2]. As a result, modern cities have to cope with the challenges of a continuously growing population, traffic congestion, limited resources, and environmental sustainability. Furthermore, the trend of the integration of building information modeling (BIM) and transportation and facilities (T and Fs) forms the forefront as a key factor in shaping the future of urban development. Consistent with this, BIM technology is based on various types of information data to do with engineering projects, the establishment of three-dimensional models, and related applications, which have six characteristics, i.e., visualization, parameterization, coordination, simulation, optimization, and information completeness, to meet the requirements of transportation infrastructure construction projects throughout the life cycle of the collaborative operation, the information storage, information transfer, data sharing, and other aspects of their requirements [3]. Noticeably, a comprehensive transportation hub represents a crucial aspect of the national or regional transportation system, is the intersection of several modes of transportation network, and is by several kinds of transportation connected to the fixed and mobile equipment that comprise the whole [4], in which the productive activity of transportation is to achieve the displacement of people, goods, and information transmission, mainly including that of highway, rail transit, maritime, and air transport. Besides this, the advancement of transportation infrastructure plays a crucial role in enhancing people's quality of life, stimulating economic progress, upholding social welfare, and bolstering national security [5]. Further, transportation accessibility represents and influences regional socio-economic development to a large extent.

Recently, given the innovative changes in terms of digital technologies (including Artificial Intelligence (AI), big data, cloud computing, and the internet of things (IoTs) during the COVID-19 pandemic, cutting-edge investigations into BIM and transportation and facilities integration has been advancing. In the same vein, a disciplinary crossover has been expanding, whereas there exists a further urgent need for systematic analyses and reviews of the extant literature and to recapitulate the approach and structure of the future development of the integration of BIM and T and Fs in light of technological changes.

In the modern age, the erection of basic transportation facilities has undergone radical changes, and public transportation systems such as air and rail transportation have been gradually improved, providing residents with more diversified and convenient travel services [6]. Certainly, transportation is the lifeblood of economic, social, political, and population mobility, which follows the development of various fields and sectors. In addition to this, transportation contributes to economic development and the economy's progress toward a new stage of stable and sustainable growth [7]. For instance, International Energy Agency (IEA) energy statistics show that from the year 1971 to 2001, energy consumption in the transportation sector grew at an annual rate of 9.3% [8]. Worldwide, transportation is an energy-consuming industry, for which governments, transportation authorities, experts, and scholars have attached great importance to energy conservation and environmental protection in the transportation sector [9]. Although the transportation industry is required to focus on the use of resources and environmental protection in the design of development policies [10], and the key affecting factors associated with the changes in transportation energy consumption, it is important to minimize the energy consumption of transportation to achieve the goal of sustainably developing the transportation industry.

This research article attempts to analyze the integration of BIM and T and Fs by highlighting future directions and trends, revealing the present status and hotspots of research in the field, and clarifying the developmental pulse of research, as well as emerging areas in the future.

2. Materials and Methods

Since BIM, and transportation and facilities are a fusion between multiple disciplines and interdisciplinarity, and the direction and trend of the subject matter are currently unclear, a quantitative methodology has been incorporated in this research paper. Therefore, this paper investigates the research in the field via bibliometric methods, and quantitatively demonstrates research hotspots, development paths, and evolutionary trends in this research area from a quantitative point of view using bibliometrics and makes a more in-depth compendium and investigation of this field's discipline through mapping.

2.1. Research Methods

In specific, bibliometrics represents an estimation technique employed to define and explore the dynamics and progress of a field or discipline of study, for which, through modern IT, it is possible to envisage the outcomes of bibliometric analysis (BA) with clear and concise knowledge graphs [11]. In particular, studies in the field of bibliometrics have pointed out that visual co-citation analysis (VCCA) facilitates data interpretation while leading to more in-depth results, thereby enabling researchers to unearth the intrinsic linkages in this information [12]. Explicitly, it enables researchers to unravel the evolutionary nuances of a particular field while highlighting emerging areas in the field. Further, visualization allows the researchers to unearth the intrinsic associations between information, including the research priorities of various institutions, and new theories from existing institutions. This understanding becomes pivotal as BA is then employed to delve into current research quantitatively that involves exploring aspects such as keywords, sources, time, disciplines, countries, research themes, application fields, research hotspots, research approaches, and future trends.

However, relying solely on econometric analysis may have some limitations, as quantitative information, while presenting an overview of the development's state of a field and being highly reliable, makes it challenging to gain a deeper insight into the research field, in order to uncover the potential notions and narratives of the cited literature, and hence fails to explore the research's kernel. As such, in this study, the visualization software is also combined with thoroughly exploring the study field/discipline, showing the development status, frontiers, and paths of the discipline in the form of mapping, and selecting the core literature in the field to analyze and synthesize.

2.2. Research Tools

Reportedly, knowledge mapping was performed using two software programs, i.e., VOSviewer (version 1.6.18) and Citespace (version 6.1.R6), which have their own characteristics and play complementary roles. On the one hand, VOSviewer adopts a probabilistic-oriented data-standardization approach and extends several visualization views of keywords, co-authors, and co-institutions including Overlay Visualization, Network Visualization, and Density Visualization, which have the outstanding characteristics of clear mapping [13]. On the other hand, CiteSpace software(version 6.1.R6) was developed by Dr. Chao-Mei Chen, a Chinese American from the School of Computing and Information at Drexel University, which is based on the Java language and the theory of citation analysis and information visualization, emphasizing the analysis of the possible knowledge embedded in scientific literature and developed from the standpoint of research data, information visualization, and scientometrics [14].

2.3. Source of Data

To confirm the quality of the gathered data, the Web of Science Core Collection (WoSCC) database was taken as the data source. Correspondingly, Web of Science (WOS) includes the numerous most influential core research journals in diverse research disciplines, which ensures a high quality of the content of the database with significant scientific impact [15] and has already been accepted by many studies as the most appropriate database for BA. From the viewpoint of quantitative analysis, research data were derived from the WOS, with "City Information Modeling (CIM)", "transportation", "BIM", and "facility", whereas only "Articles" as well as "Review Articles" were filtered out. Firstly, data volumes, journal sources, and discipline classifications of BIM, transportation hubs, and facility integration research was obtained through graphical illustrations and charts using advanced search tools in the WOS database, in order to offer relevant statistics on the existing state. Second, with the help of bibliometric visualization software tools, i.e., CiteSpace and VOSviewer, a number of scientific knowledge maps have been generated, respectively, using the hot keywords of current research in network visualization for keyword co-occurrence analysis (KCOA) and superposition visualization, time-zone-map analysis, and burst word analysis to establish currently popular areas, development trends, and future directions.

2.4. Research Methodology Flow

Notably, a flowchart of the research methodology outlines the four stages of the methods/techniques used to quantitatively analyze the collected data (Figure 1): (1) primarily, to retrieve data regarding the amalgamation of BIM and transportation and facilities from the WoSCC database, articles have been filtered by types "Article" and "Review" using keywords such as "BIM", "CIM", and "facility", and analyzed annual paper publication counts, trends in article indexes, journal sources, and disciplinary fields of the published papers; (2) subsequent to this, to examine the present research landscape and key areas of focus within the integration of BIM and T and Fs, we utilized VOSviewer (version 1.6.18) software for network visualization on KCOA, followed by the generation of a high-frequency keyword list; (3) building upon this, to uncover the evolution and emerging trends in the integration of BIM and T and Fs, VOSviewer has been used to visually represent keyword co-occurrence analysis that included a time-zone map and a tabular list showcasing noteworthy research for each year; and (4) ultimately, to investigate the development trends and necessary directions of future studies, CiteSpace software has been used for KCOA and emergent word analysis, and a table of the keywords has been made for comparing terms that appeared in the VOSviewer KCOA and were missing in the CiteSpace KCOA, and focused on the important KCOA in the VOSviewer KCOA network visualization nodes.

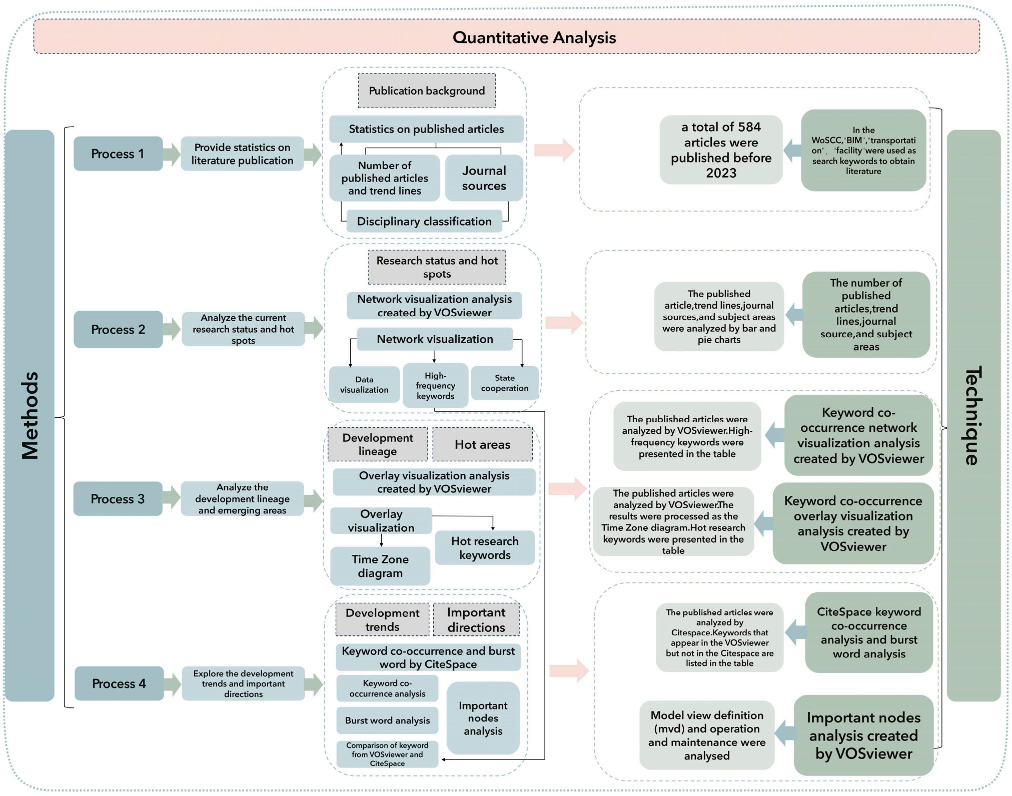


Figure 1. Flowchart of the research methodology.

3. Results

3.1. Publications' Backgrounds

In this paper, the WoSCC was taken as the data source to confirm that the retrieved data are comprehensive, credible, and persuasive. In order to completely encompass the core literature in the research field of this study, after several search attempts, the final search strategy of this paper was to search for the keywords "BIM", "transportation", and "facility" in the WoSCC database through an advanced search in the WoSCC database for the time span from the year 1989 to 2023, since the first studied the integration of BIM and T and Fs was in 1989, about 34 years ago, with the indexes of SSCI, CPCI-S, CCR-EXPANDED, Sci-expanded, IC, and CPCI-SSH. As a consequence, a total of 722 documents were obtained. Subsequent to screening and filtering the retrieved literature and eliminating the papers with less relevance, the refinement eventually yielded a total of 584 literature records as the objects of this study, which were exported to include full record inscription information such as the title, author, journal, abstract, keywords, references, and source journal. In the meantime, the search process and results are populated in Table 1.

Table 1. The process and results of data assortment.

Category	Specific Standard Requirements
Research database	Web of Science Core Collection (WoSCC)
Citation indexes	SSCI, Sci-expanded, CPCI-S, CCR-EXPANDED, CPCI-SSH, IC
Search Steps	#1=(TS=((“facility”) AND (“transportation”)) #2=(TS=((“building information modeling”OR“BIM”OR“city information modeling”OR“CIM”) AND (“facility”))) #3=(TS=((“building information modeling”OR“BIM”OR“city information modeling”OR“CIM”) AND (“transportation”))) #4=#1 OR #2 OR #3
Timespan	January 1989 to August 2023
Document Type	Articles and Reviews
Data extraction	Export with full records and cited references in plain text format
Language	English
Qualified records	584

In the light of the theory of bibliometrics, the distribution of the number of documents in a particular discipline according to the chronology can roughly reflect the development of the era of the related disciplines [16,17]. Accordingly, the articles’ publications on the integration of BIM and T and Fs from 1989 to 2023 (34 years) are categorized into the below three periods (Figure 2):

(1) The embryonic phase: it was in the initial development phase (years 1989 to 2010) when research in this field was kept to fewer than 10 articles per year, with a slow start and slow growth, resulting in a total of 51 articles being published (8.7% of all the obtained articles);
(2) The germination period: the fluctuating and rising stage (the years 2011 to 2018) shows a significant uplift in the number of published articles compared to the previous stage, and research studies have paid more concentration to the field, though the quantity of articles published varies on yearly basis, but the overall fluctuating and rising trend is shown, with a total of 158 articles, which accounts for 27% of all the articles;
(3) The continuous climbing period: the last five years (years 2019 to 2023) show a high growth rate, with an increasing trend from year to year, and a total of 375 articles (64.2% of all articles published), of which the largest number of study articles published was in the year 2021 (126 articles).

The annual number of publications serves as an important value for assessing the development of scientific research, and the trend in the number of publications reflects changes in knowledge in the field; as such, the amount of literature is one of the most important measures of the amount of knowledge [18]. Specifically, the trend line of the number of articles (green line in Figure 2) shows the trend of the overall change in articles regarding the integration of BIM and T and Fs. In general, the number of publications in the field has been rising, especially since the year 2011. Further, the publications’ number has seen a rapid surge, and the number of publications has stabilized at more than 80 between the years 2019 and 2022, which indicates that the amount of knowledge in the field of study has shown steady growth in recent years, and has received more attention.

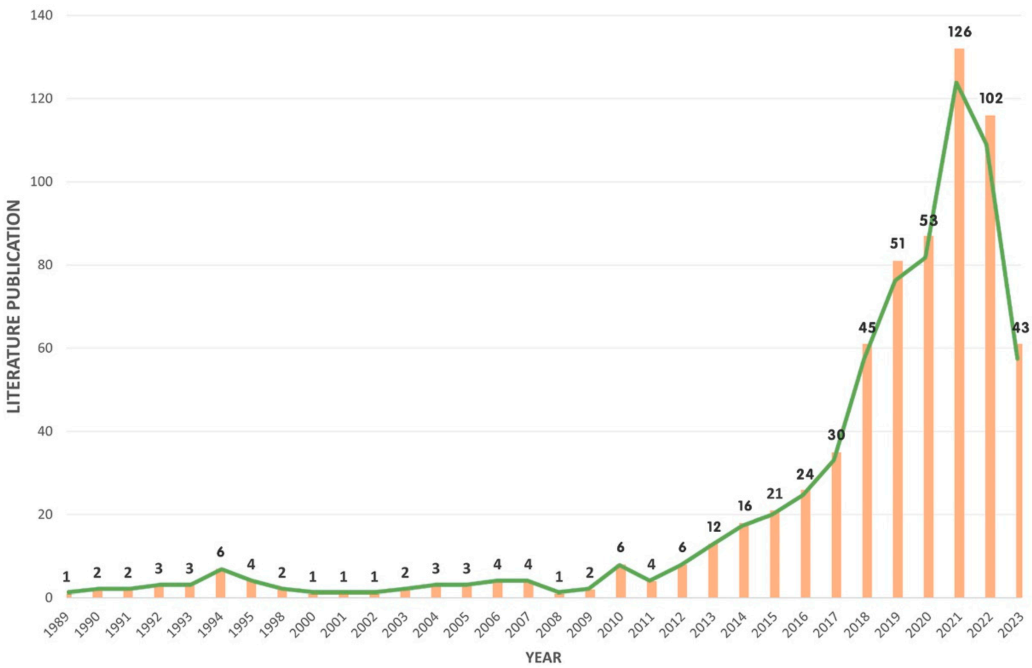


Figure 2. Number of research articles published per year and exponential trend lines for research on the integration of building information modeling (BIM) and transportation and facilities (T and Fs) in the Web of Science Core Collection (WoSCC) database from the year 1989 to 2023 (34 years).

The sources of publications relevant to the field of BIM and T and Fs integration each year are shown in Figure 3. Noticeably, the 584 articles included in the WoSCC database originated from 228 journals, and the top 8 journals and the number of papers in different research directions were screened to map the distribution of publications and research directions (Figure 3). Moreover, the research articles published in the top eight journals accounted for 40.6% of all the obtained articles, with the highest published journal, Automation in Construction (15.8%), followed by Buildings (5.8%), Sustainability (4.3%), Applied Sciences-Basel (5.2%), Engineering Construction and Architectural Management (1.9%), Journal of Computing in Civil Engineering (2.9%), Journal of Advances in Civil Engineering (2.2%), and Advanced Engineering informatics (2.3%). The journal Automation in Construction had the highest number of published articles because it is a well-established and respected journal with a large collection of research papers and a wide readership in the construction and automation fields [19]. However, it is evident that the research focus is more diverse and lacks a clear direction and a central theoretical framework.

By utilizing the "Analyze Search Results" instrument in the WoSCC database, the hot subject areas of the integration of BIM and T and Fs were screened (Figure 4), with a minimum of 50 records and a total of 6 hot subject fields, that is, Civil Engineering (327 research articles), Construction Building Technology (256 research articles), Engineering Multidisciplinary (70 articles), Environmental Sciences (63 articles), Engineering Industrial (61 articles), and Green Sustainable Science Technology (60 articles). Evidently, the significant difference in the number of publications between the top three disciplinary directions and those behind them indicates that the research scope on the integration of BIM and T and Fs is more limited. Though, there are still unexplored or immature areas of research, but research in the fields of architecture, civil engineering, and engineering is more mature.

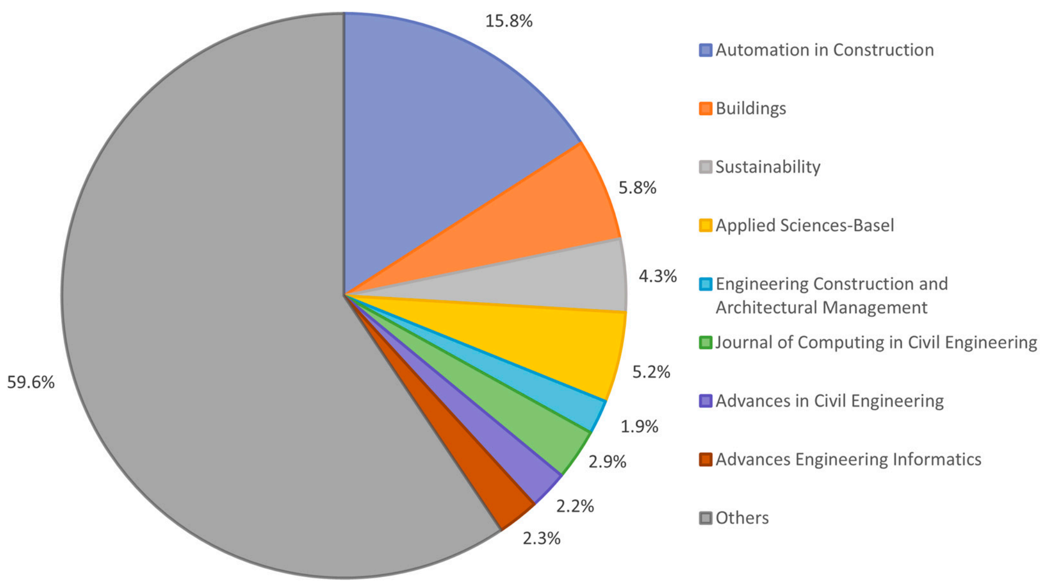


Figure 3. Journal sources of published research articles in the WoSCC database on the integration of BIM and T and Fs from 1989 to 2023 (34 years).

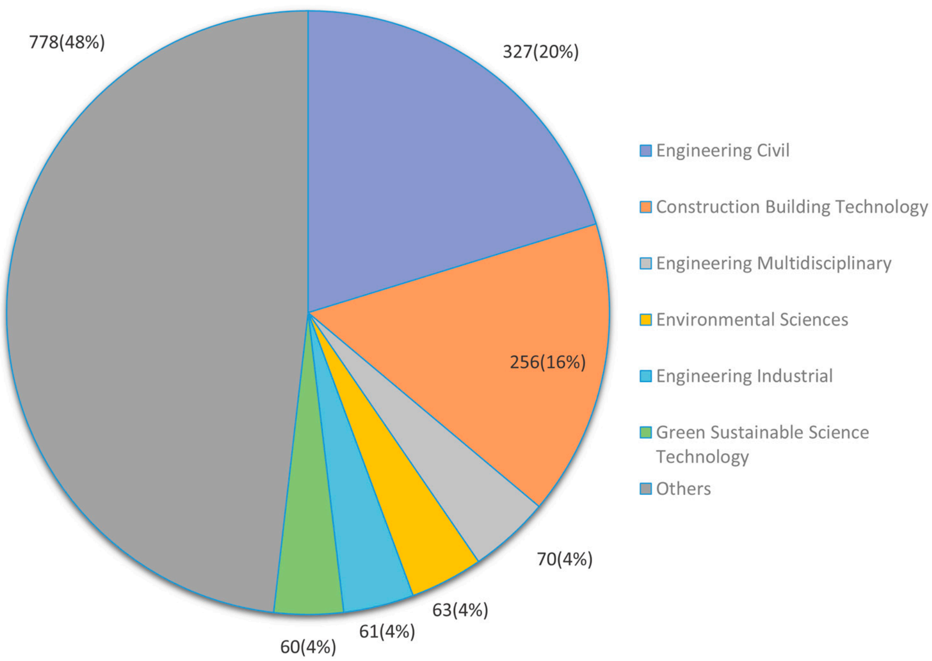


Figure 4. Number of published research articles in the WoSCC database from 1989 to 2023 (34 years) in different subject fields/disciplines on the integration of BIM and T and Fs.

3.2. Research Status and Hot Spots

3.2.1. Keyword Co-Occurrence Visualization Network

In general, keywords mirror both the focus and theme of a study and condense the core and essence of the study in a prompt and accurate fashion, which is a high-level summary of the research theme [20]. In addition to this, keywords can express the research direction of the literature, of which the high and low distribution of frequency can assist in studying the development trends and research hotspots in the field [21]. As a result, KCOA helps to identify research hotspots in a particular scientific area. By setting the type of analysis as Co-occurrence, and Unity of analysis by All Keywords in VOSviewer software (version 1.6.18), a keyword-co-occurrence-network view is performed on the obtained 584 articles from the data collection (Figure 1), in which the threshold for the frequency of occurrence is selected to be greater than or equal to "8" keywords to generate a total of 111 keywords that are visualized to form six color clusters of red, yellow, green, purple, blue, and lake blue (Figure 5), with different color areas representing different clusters [22]. Meanwhile, the text labels, the color nodes, and the connecting lines are depicted in the network visualization of keyword co-occurrence, where the entries are presented by text labels and nodes, which reveal the keyword occurrences' frequency according to their size and are represented by circles, with higher weights and larger nodes representing higher importance [23] and higher frequencies of keyword occurrences. In Figure 5, the larger the circular nodes, the more times the keywords appear and the more representative of the domain hotspots they are. In particular, the node-connecting lines represent the strength of the association, and the thickness of the connecting lines indicates the strength of the connection [24]; node colors represent different clusters, i.e., research themes. Prominently, the keyword "BIM" occupies the most nodes, with 229 occurrences, situated in the middle of Figure 5, succeeded by "facility management" and "framework", with 150 and 104 occurrences, respectively, which suggests that facility management is the closest thematic connection to BIM, and that framework serves as a portion of the BIM process. In terms of layout, these high-frequency keywords are also key pivot nodes, and the other nodes surrounding them form the popular research themes in the field in recent years.

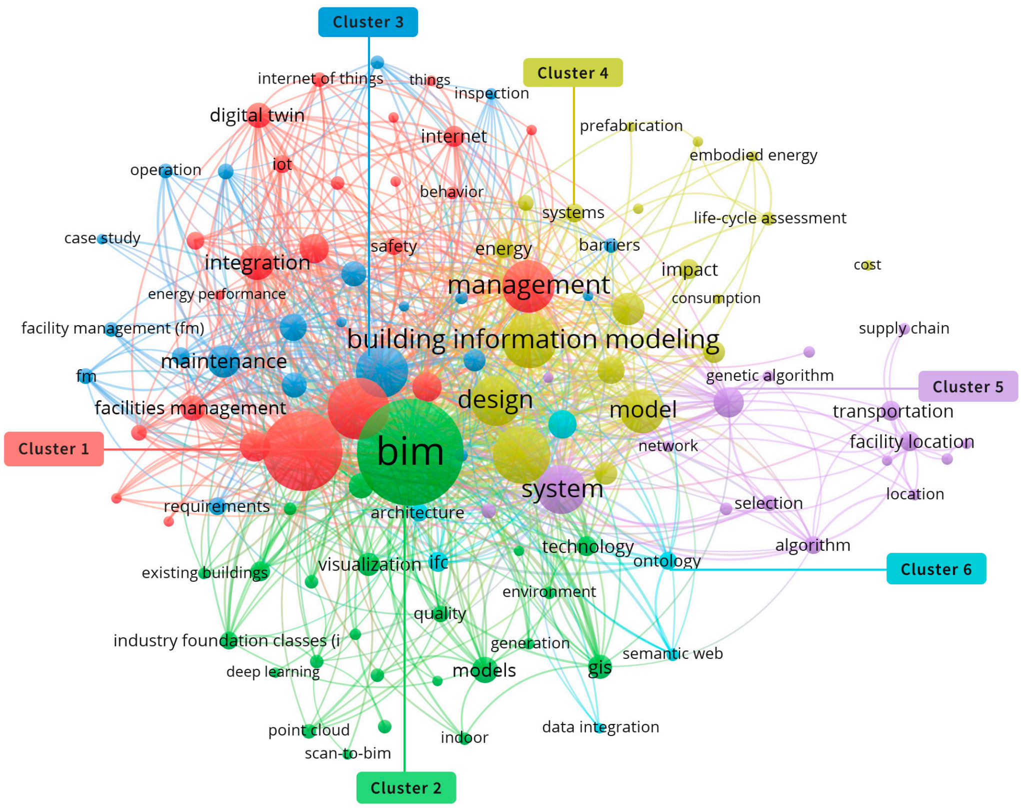


Figure 5. Network visualization of keyword co-occurrence analysis (KCOA) in the integration of BIM and T and Fs, generated using VOSviewer software, from the years 1989 to 2023 (34 years).

In addition, Figure 6 further highlights Figure 5 by displaying a network graph that shows the co-occurrence of keywords, with "transportation" as the central node, where the term "BIM" is strongly linked to "transportation" as a significant node, indicating a close relationship between the two nodes. Additionally, Figure 6 illustrates the correlation between transportation and related terms such as "facility location", "logistics", "supply chain", and "algorithm". These terms exemplify the diverse utilization of BIM in transportation hub projects, encompassing tasks such as site selection, logistics and supply chain optimization, and data analysis through algorithmic methods. This correlation is crucial for comprehending the range and extent of BIM applications, as it demonstrates the intersection and interaction between BIM and several disciplines associated with transportation and hub buildings. Furthermore, it emphasizes the capacity of BIM as both a technology and an approach to facilitate interdisciplinary integration in transportation and building projects. This integration is crucial for the strategic coordination and seamless execution of activities related to the planning, designing, construction, and operation of transportation- and hub-building infrastructure.

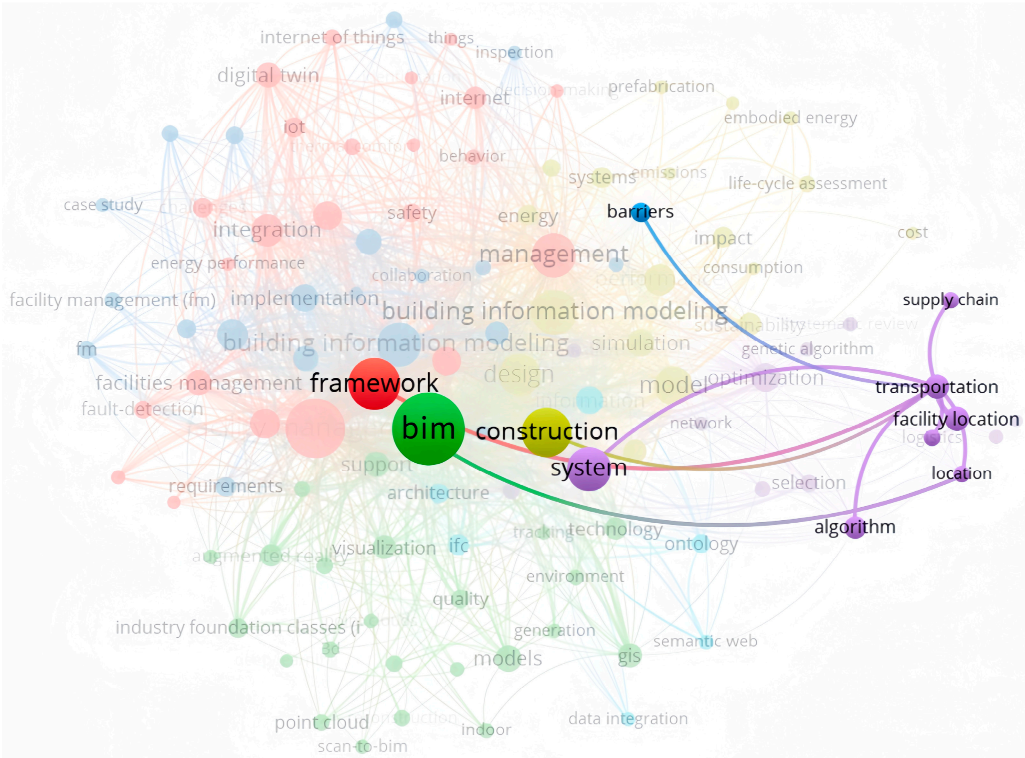


Figure 6. Network visualization of KCOA on the theme of "transportation" (further highlighted in Figure 5) in the WoSCC database via the VOSviewer tool.

Further, to acquire an explicit view of the specifics of the keywords, the outcomes of the KCOA (Figure 5) were further visualized into six well-defined colored clusters in red, green, blue, yellow, purple, and lake blue. Consistent with Figure 7, the keyword nodes relevant to the same cluster and the spatial distribution of the nodes can be easily identified based on the color blocks. Primarily, Cluster 1 (red) emphasizes the exploration between transportation facility research and facility management with the themes of facility management and framework, including a total of 24 keywords such as "internet of things", "digital twin", and "management". Subsequently, Cluster 2 (green) presents a substantial cluster that asserts the use of BIM in visualization [25], as well as in industry foundation classes (IFC), including "BIM", "technology", "existing buildings", "support buildings", and "point cloud". Thereafter, Cluster 3 (blue) is related to BIM that contains the following keywords: "implementation", "life-cycle", "maintenance", "building", and "construction". Afterwards, Cluster 4 (yellow) is related to building design aspects, including "construction", "design", and "life-cycle assessment". Further, Cluster 5 (purple) is related to the optimization phase, and includes "algorithm", "transportation", and "supply chain management". Lastly, Cluster 6 (blue) features "data integration", "IFC", and "semantic web". Additionally, the boundary of the cluster and the spatial distribution map of the keyword nodes are depicted in Figure 7, in which the further distance between two clusters establishes the more significant variance between the clusters, and the closer the distance indicates the smaller the difference of the clusters, and the larger the overlap area of two clusters indicates the higher the correlation and resemblance between them. At the same time, "operation and maintenance", and "maintenance management" in Cluster 1 (red) do not overlap with Cluster 3 (blue), which means that they are less relevant to Cluster 3 (blue). Simultaneously, Cluster 2 (green) and Cluster 6 (blue) are highly correlated with overlapping keywords. Additionally, Clusters 4 (yellow) and 5 (purple) are also closely related.

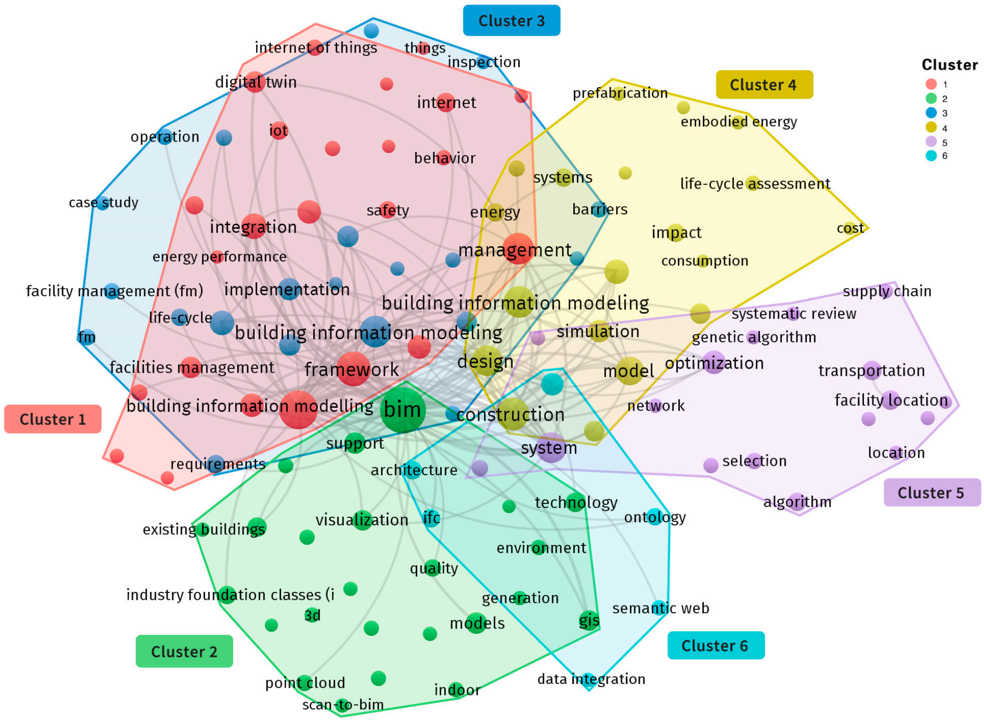


Figure 7. Further visualization of the integration of BIM and T and Fs; KCOA data from Figure 5.

3.2.2. Distribution and Analysis of Cooperation Networks

By analyzing the number of studies published in different countries in a number of research areas, it is possible to reflect the depth of research in the field in each country. Reportedly, a total of 76 nation states were involved in the co-authored analysis of the literature using VOSviewer software (version 1.6.18). Meanwhile, the top 10 nations were listed in accordance with their volume of publications. Furthermore, the volume of publications, citations, and collaborations of these countries was compared to investigate the scientific research strength of these countries in research on the integration of BIM and T and Fs as well as their international influence, as shown in Table 2. Notably, the statistical analysis of the publication trends of 584 studies reveals that BIM and T and Fs integration has grown rapidly over the past few years, of which China ranked first with 182 articles, followed by the United States with a total of 142 articles, and the United Kingdom (UK) (77 articles) and South Korea (55 articles), ranked third and forth, respectively. On the same note, the total number of articles issued by the US, China, and the UK account for 68.6% of the total number of articles, which indicates that studies from the UK, the US, and China have a great influence on research in the integration of BIM and T and Fs.

To comprehend which nations have made the most significant contributions in the field of BIM and transportation and facilities integration, a mapping of country collaborations was developed, as shown in Figure 8, in which the larger the round nodes are, the higher the number of research articles issued, the node connecting line presents the strength of association, and the thicker the connecting line, the higher the number of research articles issued by the two countries in collaboration, and the node color signifies diverse clusters. Evidently, the distribution of countries issuing articles in the field is very uneven, and studies in China not only have the highest volume of publications but also participate most actively in cooperation with other countries/regions and cooperate most closely with the

United States. In the same fashion, there is also cooperation among Canada, the UK, South Korea, Italy, and other countries, and studies in China cooperate with the United States closely, followed by the UK and South Korea. With the deepening and development of different fields, BIM and transportation and facilities convergence development promotes maturity among interdisciplinary disciplines. In interdisciplinary collaborations, the field of BIM and transportation and facilities convergence usually requires the expertise of multiple fields/disciplines, including computer sciences, architecture, urban planning, transportation engineering, and civil engineering, where experts from a variety of professional backgrounds converge in order to meet complex challenges. Thus, BIM serves as a critical tool that facilitates information sharing and integration between the fields of architecture and transportation and facilities, in which studies in each field should be better able to work collaboratively. Since the maturation of the area of BIM and transportation and facilities integration is a by-product of interdisciplinary cooperation, which means that communication and cooperation between research entities [26–28], such as different countries and relevant research institutions, have become closer, which helps to solve increasingly complex urban planning and facility management challenges and will further contribute to sustainable urban development and more efficient traffic-management systems.

Table 2. Top 10 countries listed by number of papers issued.

Number	Country	Documents	Citations	Average Citation/Publication
1	People's Republic China	182	5023	27.00
2	USA	142	8471	47.32
3	United Kingdom	77	3506	45.53
4	South Korea	55	2265	41.18
5	Australia	50	2126	42.52
6	Canada	42	2152	43.91
7	Italy	40	756	17.58
8	Spain	25	779	25.96
9	Iran	18	802	40.1
10	Germany	13	1349	74.9

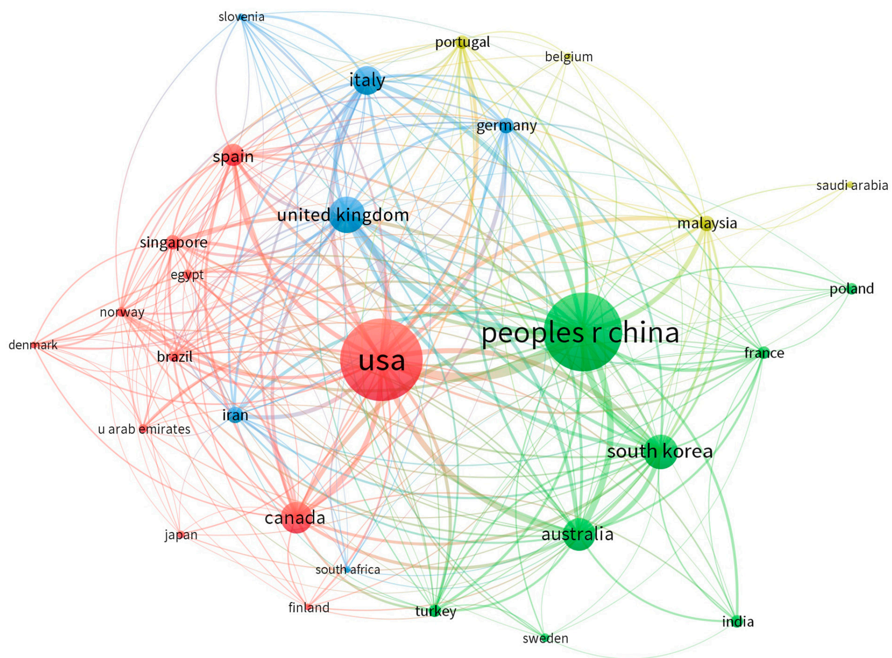


Figure 8. Visualization of a national cooperative data network with KCOA for BIM and T and Fs' integration, developed with VOSviewer from 1989 to 2023 (34 years) (Note: the label 'the People's Republic of China' has been automatically shortened to 'Peoples R China' instead by the VOSviewer software due to display shortage of the software).

3.2.3. High-Frequency Keywords

Categorically, the top ten keywords with the highest occurrence as high-frequency keywords from the KCOA generated by the VOSviewer software from the year 1989 to 2023 (34 years) are presented in Table 3, which includes the color, clustering, total link strength, keywords, occurrence frequency, and links. Keywords with higher total link strength and frequency of occurrence have a higher impact on the current research area [29], and include "BIM", "framework", "facility management", "system", "construction", "management", "design", and "integration", where "BIM" is used for "integration" with "facility management", highlighting that BIM's application in facility management represents a widespread research topic at present. Apparently, "System" and "Design" are two keywords in BIM, which indicates that the existing research on the integration of BIM and T and Fs is focused on design and systems.

Table 3. High-frequency keywords on the integration of BIM and T and Fs via VOSviewer from the year 1989 to 2023 (34 years).

Color *	Cluster	Keyword	Occurrences	Total Link Strength	Links
	2	bim	229	933	107
	1	facility management	150	805	94
	1	framework	104	613	100
	4	construction	94	509	98
	5	system	76	453	101
	4	design	77	416	91
	1	management	83	382	94
	4	building information modeling	87	335	90
	3	building information modeling(bim)	82	334	87
	1	integration	46	304	74

* The table's colors are aligned with the colors from Figure 5.

3.3. The Development Lineage and Emerging Areas

3.3.1. The Time Overlay Visualization of Keyword Co-Occurrence Analysis (KCOA)

In order to intuitively and effectively distill the research themes in the field, the keyword co-occurrence clustering results were visualized using VOSviewer's unique clustering density view as shown in Figure 9. Remarkably, temporal overlay visualization is able to illuminate hot topics in the research area by year and facilitate in revealing prospective research trends [30]. Consistently, a KCOA overlay visualization of BIM and T and Fs integration from the year 1989 to 2023 (34 years) is shown in Figure 9, with the color box in the lower right corner ranging from dark blue to green to yellow, expressing the time from the past to the present. Meanwhile, the magnitude of an element's density depends on the number of surrounding elements and the magnitude of their weights, with brighter to warmer shades representing the increasing density of clustering and the increasing heat of related research topics. As is evident in Figure 9, the overall appearance is in the dark blue–green area on the right side (construction-focused) and light yellow–green on the left side (BIM-focused), which establishes the fact that framework-focused keywords usually appear earlier compared to the BIM-focused keywords.

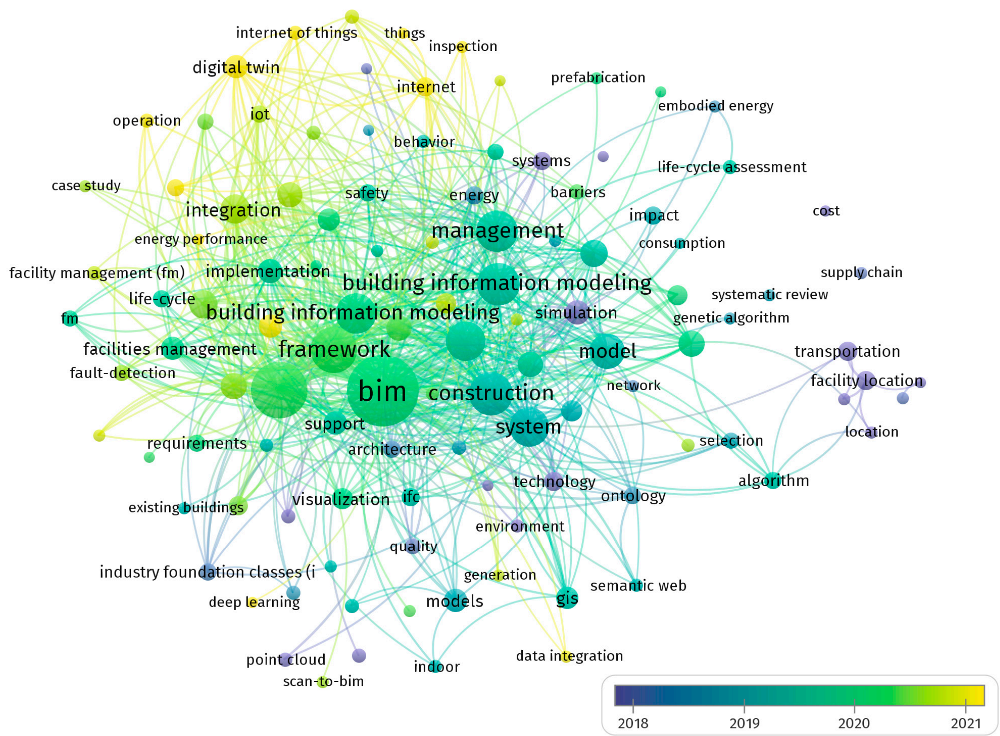


Figure 9. Time overlay visualization of KCOA on the integration of BIM and T and Fs from the year 1989 to 2023 (34 years) via VOSviewer.

Moreover, Figure 10 is further highlighted from Figure 9, with the central node being "transportation", in which the time overlay visualization of the keyword terms such as "construction", "system", "sustainability", "facility location", and "algorithm" plays a crucial role in the transportation industry and its potential implications for future research directions that demonstrates the increasing importance of BIM in the transportation sector.

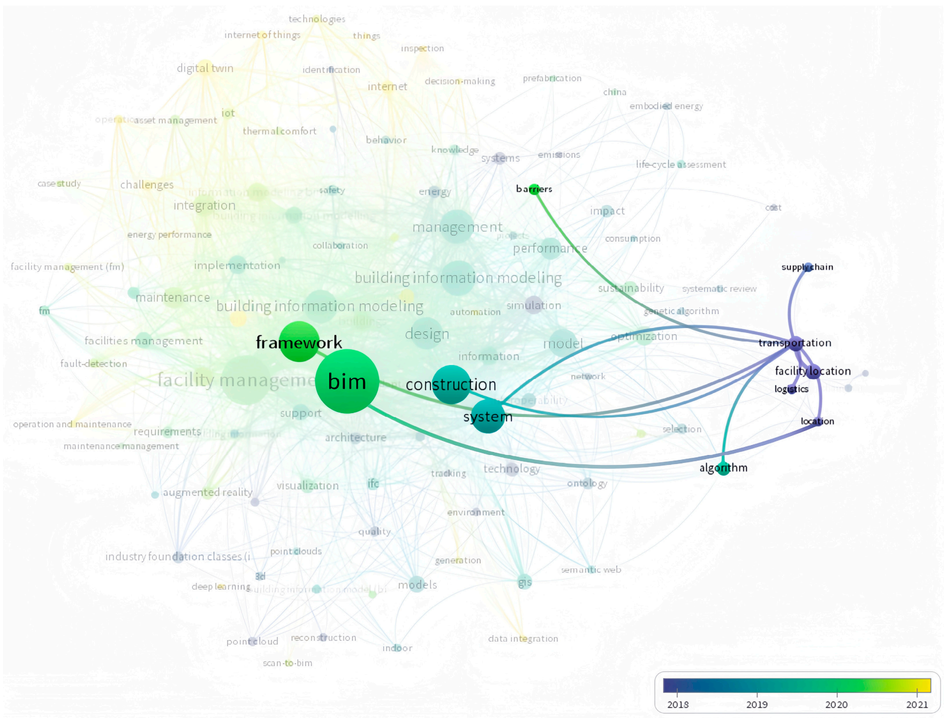


Figure 10. Time overlay visualization of KCOA on the theme of "transportation" (further highlighted from Figure 9) on the integration of BIM and T and Fs from the year 1989 to 2023 (34 years) via VOSviewer.

3.3.2. Citespace-Based Keyword Co-Occurrence Time-Zone-Mapping Analysis

In general, keywords can be clustered and analyzed to derive the basic status of each research topic within the research area. To explicitly pinpoint the temporal patterns of inflection points as well as frontiers in the development of the field, the keyword-co-occurrence mapping can be arranged according to the time series, hence showing the research hotspots' distribution in each time period. Consistent with this, the data for the KCOA overlay visualization (Figure 11) was further processed with the help of Citespace software to obtain the outcomes of the keyword time-zone analysis. Aligned with Figure 11, the keywords are listed chronologically from the past to the present in keyword-co-occurrence time-zone mapping, which clearly shows the evolution of the keywords on the time axis (year 1989 to 2023). Parallel to this, each time period corresponds to a vertical time period, the keyword on the timeline represents the first occurrence of the keyword during that time, the size of the node points out the keyword's high or low occurrence, and the connecting line reflects co-occurrence.

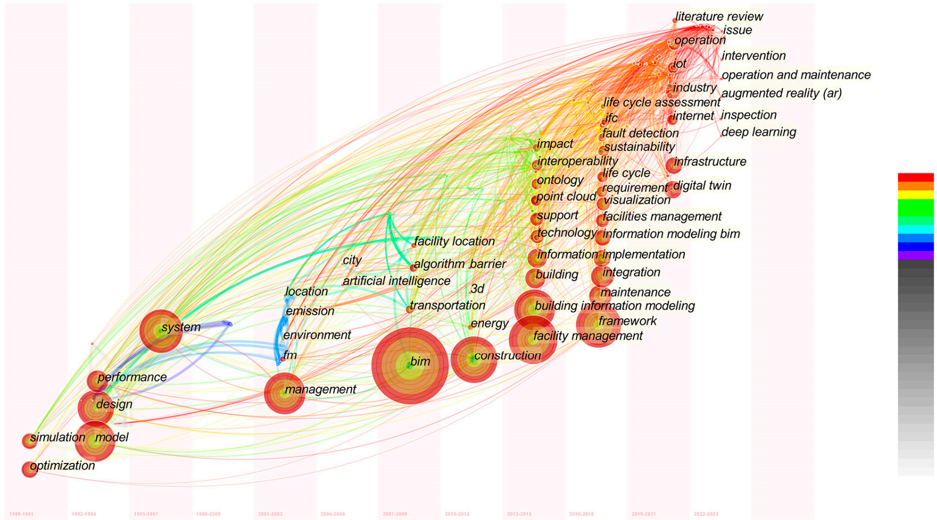


Figure 11. Time-zone diagram of keywords on the integration of BIM and T and Fs from 1989 to 2023 (34 years) from time overlay visualization of KCOA via Citespace.

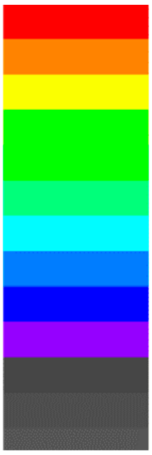
In Figure 11, the research theme of BIM and transportation and facilities integration is evolving, with "simulation" and "optimization" as the initial keywords being displayed in 1991, and most keywords having only been on the scene since 2001 and have grown rapidly in the field since then, which can be divided into three phases: (1) initially, in years 1991 to 2001, studies mainly focused on the BIM and transportation and facilities integration of the initial development, at the level of theoretical inquiry, including keywords such as "simulation", "optimization", "design", "model", "system", and "performance"; (2) subsequently, during years 2002 to 2014, research topics were more dispersed and the frequency of keywords in the research was low; and (3) afterward, from years 2015 to the present, research themes have continued to expand and the number of research hotspots continues to increase, showing that BIM and transportation and facilities integration has a diffuse expansion in research themes that incorporates emerging technologies, including the emergence of high-frequency theme words such as ontology, point cloud, IFC, visualization, augmented reality, digital twin, and internet. There are also high-frequency words such as asset management, integration, pollution, and primary energy, which represent a convergence of studies from different disciplinary backgrounds, and the overall trend of research is diversified and deepened into a number of fields.

3.3.3. Hot Research Keywords

Systematically, the hot research keywords for the integration of BIM and T and Fs from the year 1989 to 2023 (34 years) are divided into three phases through the time period and summarized into three themes (Table 4):

(1) Transportation and facilities: barrier, architecture, tracking, shared bicycle, and construction industry;
(2) Life cycle assessment (LCA): design, management, system, coronary heart disease, life cycle demand, carbon emission, carbon footprint, and allocation model;
(3) Emerging technology: 3D, digital design model, data visualization, internet of things (IoTs), smart building, deep learning, algorithm, strategic planning, network design model, big data, facility management, augmented reality, fault detection, and motion planning.

Table 4. Hot research keywords on the integration of BIM and T and Fs from keyword overlay visualization via VOSviewer from 1989 to 2023 (34 years).

Year	Color *	Keyword
Before 2001		optimization, design, system, model, simulation, performance
2002–2014		management, fm, facility location, emission, environment, facility location, data model, algorithm, bim, construction, 3d, barrier, artificial intelligence
2015–2017		facility management, building, technology, point cloud, ontology, impact
2018–2019		life cycle assessment, visualization, maintenance, framework, integration
2020		infrastructure, digital twin, industry, iot, operation, literature
2021		data visualization, COVID-19, carbon footprint
2022		smart building, inspection, augmented reality, issue
2023		deep learning, inspection, operation and maintenance, augmented reality

* The Table's color range is aligned with the color range in Figure 11.

3.4. Development Trends and Directions

3.4.1. Comparison of VOSviewer and Citespace KCOA Results

Commonly, the typical approach for KCOA involves tallying keyword occurrences and assessing their connection through a co-occurrence matrix, for which commonly employed tools include distance-based 2D coordinate visualization (e.g., VOSviewer tool) and affiliation-based network visualization (such as the Citespace tool). While both tools share essential concepts, those of the procedural steps in the keyword co-occurrence analysis may vary in practice. As such, the outcomes of VOSviewer and Citespace analyses sometimes may be inconsistent. Hence, bias has been reduced in the data by comparing the outcomes of keyword co-occurrence analyses generated by the two tools.

The obtained literature with 584 research articles (Table 1) was imported into Citespace software (version 6.1.R6) for KCOA. Thereafter, the hot keywords with the theme of "BIM, transportation, and facilities" were counted by Citespace and compared with the keywords in the result of Figure 5 produced using VOSviewer (Figure 12). Evidently, there exist eleven keywords that have been appeared in the VOSviewer KCOA results, which do not appear in the Citespace KCOA results, including "algorithm", "case study", "emissions", "prefabrication", "tracking", and "things". The proposed keywords have been listed as shown in Table 5, along with the total link strength and frequency of occurrence of these keywords in the VOSviewer KCOA. Thus, differences in the results of the KCOA between CiteSpace and VOSviewer suggest that the impact and significance of these 11 keywords may be biased and will, therefore, not be included in subsequent analyses.

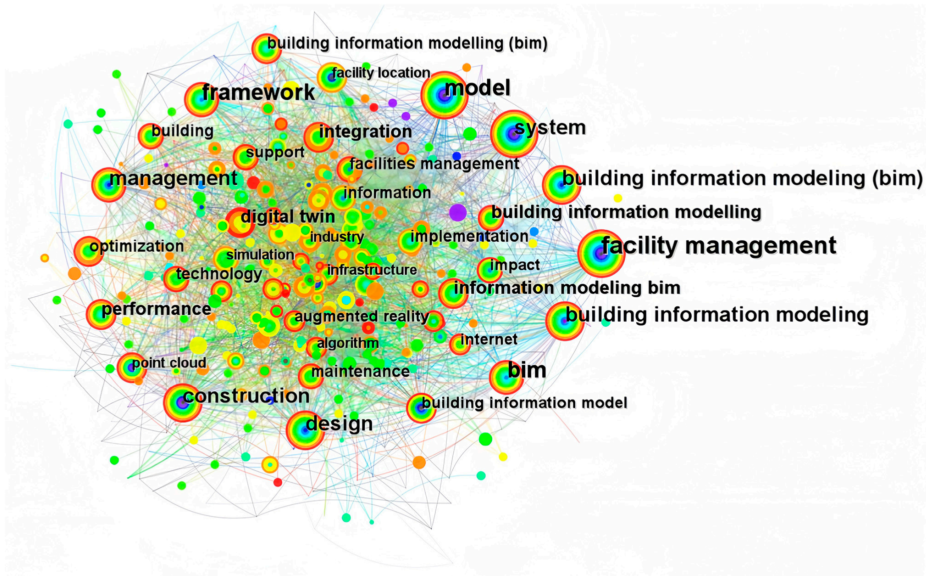


Figure 12. KCOA on the integration of BIM and T and Fs via the CiteSpace tool from the year 1989 to 2023 (34 years).

Table 5. Keywords that are only in the results of VOSviewer KCOA instead of in the results of CiteSpace KCOA on the integration of BIM and T and Fs.

VOSviewer KCOA			
Keyword	**Links**	**Total Link Strength**	**Occurrences**
algorithm	39	79	18
case study	27	42	9
emissions	25	32	8
identification	26	38	8
prefabrication	36	54	9
projects	31	45	9
things	27	45	8
tracking	29	41	8
virtual reality	27	39	9
scan-to-bim	29	37	9
operation and maintenance	37	66	9

3.4.2. Citespace

Burst Word Analysis

The cutting-edge direction of a field can be reflected by the degree of emergence of emergent words, which refers to certain terms that have been used with a sudden increase in frequency or have suddenly become a hot topic during a certain period of time [31]. In specific, Citation Burst, i.e., an emergent analysis function, can detect emergent dynamic concepts and potential research directions in the research field, reflecting emerging trends and mutations in the development of the discipline [32]. In the emergent bar, the blue color represents the duration of the mutant word and the red color represents the keyword burst's duration [33]. In order to have a clearer understanding of the abrupt outbreak of research hotspots in the field of BIM and transportation and facility integration, the bursts of words analysis function in Citespace was further used to set r [0, 1] = 0.5 and Minimum Duration = 1 to generate the first 20 keyword bursts of analysis graphs, as shown in Figure 13.

Based on Figure 13, most of the strongest citation bursts' keywords in the integration of BIM and T and Fs were found to be focused on the period of years 2013 to 2021, with "facility location" becoming a 10–year research hotspot since 2005 (red line range) which is the most extended duration of all the strongest citation bursts' keywords. In addition, "implementation" has been a hot research keyword since the year 2017, with an intensity of 3.91, which is the strongest among all the emerging keywords. Since the year 2020, "internet", "construction management", and "fault detection" are the three most cited keywords associated with the integration of BIM and T and Fs. "Internet" stands for the emerging technologies and network resources associated with the internet, which play an essential role in the management of modern buildings and transportation hubs and can be used to share data, remotely monitor and manage transportation, and collaborate with various departments. In addition, "fault detection" refers to the ability to identify faults and correct problems in transportation facilities and equipment via BIM technology, which is a key concept found in the previous section, where BIM can help to monitor the condition of a transportation facility in real-time and detect problems in the facility. Further, "construction management" means the planning, monitoring, and execution of a transportation construction project. Effective construction management is critical to the integration of BIM and T and Fs to ensure that the project stays on schedule. Thus, these three words have had the most citation bursts in recent years.

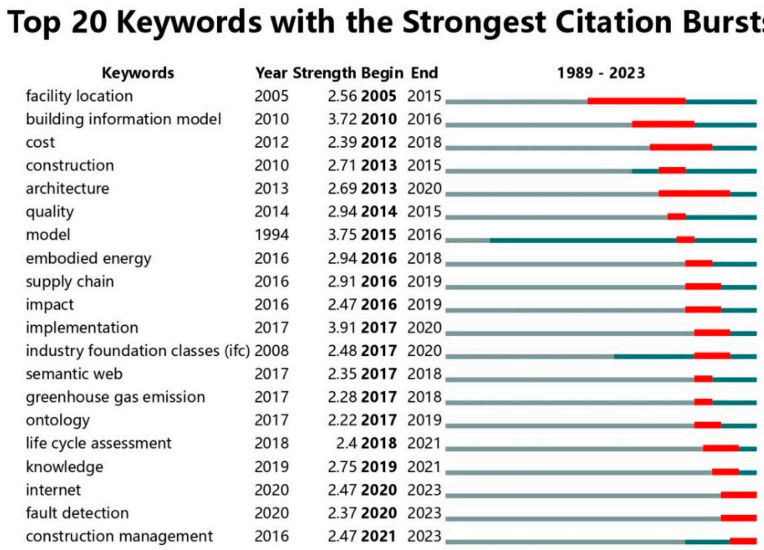


Figure 13. The top twenty keywords with the strongest citation bursts on the integration of BIM and T and Fs from the year 1989 to 2023 (34 years) via the CiteSpace tool.

3.4.3. Analysis of Imperative Nodes

"Framework" serves as a substantial node with a high frequency of keywords related to BIM and transportation (Figure 14). Consistently, the network visualization of the "framework" in Figure 5 is further illuminated (Figure 14). "Framework" plays a significant role in the integration of BIM and T and Fs, which is an organized methodology or structure. Since the integration of BIM and T and Fs is a highly complex domain involving multiple domains and stakeholders and relies on a large amount of data, an effective framework can help to integrate different aspects of information, data, processes, and standards for efficient planning, facilities, construction, and operations. Concurrently, the "framework" can also provide data-management strategies, including data collection, storage, and analysis, to support decision making and operations. Among the keywords closely related to "framework" are keywords from the life cycle theme, such as design, construction, and facility management. Further, "framework" is closely associated with emerging digital technologies including point cloud, the IoTs, and digital twin, which suggests that frameworks play a defining role in the application and development of the aforesaid technologies in areas for the integration of BIM and T and Fs.

In addition, "management" is another important node, which is further emphasized, (Figure 15). Particularly, the keywords "BIM", "design", "visualization", "construction", "facility management", and "internet" are closely associated with management, which suggests that management systems are involved in all aspects of the effective construction, visualization, design, internet, and management of projects and facilities. In the area of resource optimization, including human resources, materials, and time, it is critical in planning, designing, constructing, and operating projects and facilities, which helps to reduce costs and increase efficiency. The application of project management in BIM can help to plan and control all phases of the project to make sure that the project is executed on time and with quality, introducing advanced methods and techniques to control processes and waste as well as to deal with changes in customer needs [34]. Since management involves collaborative work between multiple stakeholders, including designers, engineers, and builders, coordination and communication are vital aspects of management. Effective management helps to realize the success of projects and facilities and ensures that they operate efficiently throughout their lifecycle. Hence, it indicates that management is effectively integrated into the areas of facilities management and construction and plays an imperative role in the integration of BIM and T and Fs.

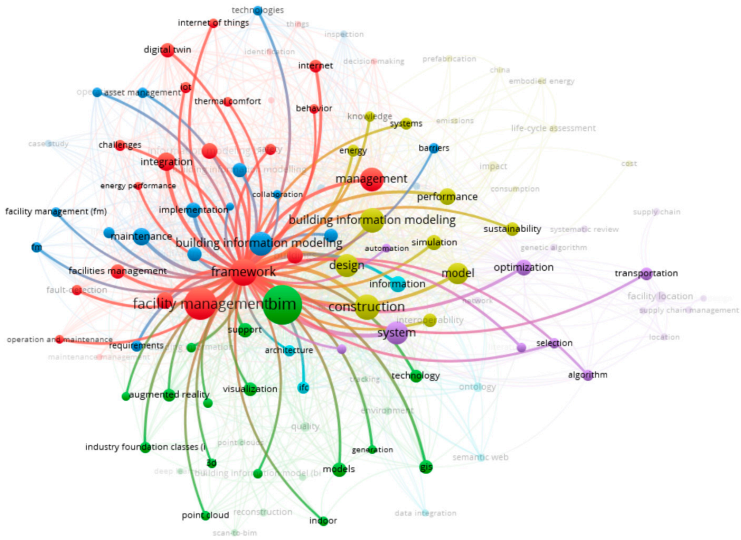


Figure 14. Network visualization of KCOA on the theme of "framework" (further illuminated from Figure 5) in the WoSCC database through the VOSviewer tool.

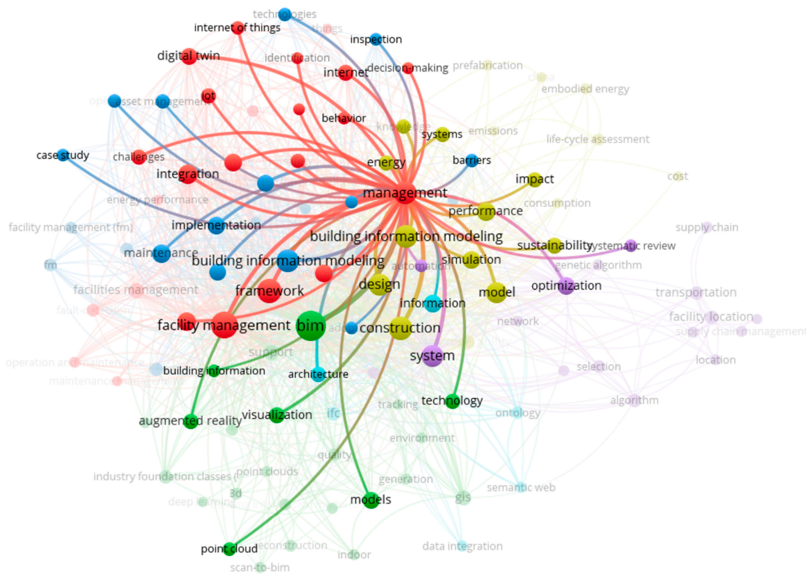


Figure 15. Network visualization of KCOA on the theme of "framework" (further illuminated from Figure 5) in the WoSCC database via the VOSviewer tool.

4. Discussion

4.1. Transportation and Building Facilities in BIM

The results of Figures 6 and 10 suggest that the cluster centered on "transportation" includes 10 keywords such as "facility location", "logistics", "supply chain", and "algorithm" in addition to "BIM". The application of BIM is becoming increasingly crucial in the field of transportation architecture [35]. In terms of facility location, BIM facilitates the optimization of transportation hub selection by integrating the Geographic Information System (GIS) [36] and conducting terrain analysis throughout the conceptualization and planning phases of a project, where BIM has the capability to replicate the transportation route of products and equipment for the purpose of managing logistics, and assists in strategizing their expected time of arrival and overseeing inventories. This aids in minimizing delays, preventing shortages of materials, and guaranteeing efficiency and cost optimization. In addition, BIM enables real-time supply chain management in the pre-construction phase [37] and construction process of transportation and buildings, ensuring the timely delivery of materials and projects while minimizing costs and hazards. Further, BIM algorithms process data throughout the design and construction stages, enabling accurate problem prediction, which can lead to enhanced efficiency, cost reduction, and improved sustainability in transportation and buildings [38]. As such, the keywords encapsulate the fundamental function of BIM in transportation and buildings, showcasing its utilization across all stages of a transportation- and hub-building project, encompassing their design, construction, and operations. Interestingly, as technology continues to progress and interdisciplinary collaboration deepens, the significance of transportation in the integration of BIM and facilities keeps increasing.

4.2. Cutting-Edge Technology

Transportation hub projects are large in volume, high in standard, multi-disciplinary, complex in coordination and organization, and tight in schedule [39] and are usually one of many complex building facilities. The conventional transportation project management approach exhibits organizational complexity, inefficiency in information conveyance, and challenges in management [40]. At present, the information on transportation-infrastructure-construction projects in multiple phases of decision making, such as design, construction, and operation, is managed by each participant, and the information transfer mostly adopts paper documents, which results in poor information synergy, insufficient accuracy, and low transfer efficiency [41]. Thus, emerging technologies have a key role in the integration of BIM and T and Fs. However, there is less literature on emerging BIM technologies applied to transportation. Conversely, emerging technologies improve the accuracy and efficiency of integration, collaborative work, and the information sharing of future BIM, transportation, and facilities, such as point cloud, digital twins, 3D, and IoT. Integrating BIM technology with other new technologies, such as virtual reality and augmented reality, enables a more user-friendly and interactive design and construction process, resulting in enhanced design quality. The conventional transportation-project-management approach exhibits organizational complexity, inefficiency in information conveyance, and challenges in management [42]. At the same time, emerging technologies improve construction efficiency, visualization, data-driven decision-making, and sustainability, contributing to smarter, more efficient, and sustainable buildings and infrastructure. In the future, these emerging technologies will continue to shape the future of cities to meet the growing demand for transportation hubs and facilities.

4.2.1. Point Cloud

As shown in Figure 11, point cloud technology is gradually being widely used, which shows the importance of point cloud for the integration of BIM and T and Fs. Meanwhile, the promotion of BIM technology's application in the area of transportation design is strongly correlated with the policy environment, technological advancement, and market demand [43]. Indeed, point cloud technology captures real-world objects and environmental information with high accuracy, which is important for BIM modeling, facility management, and transportation-infrastructure planning. For instance, the application of 3D laser scanning assists the real scenario at various phases of the on-site building construction, achieving the natural integration of BIM and laser point clouds [44]. The utilization of point clouds and BIM technology exhibits both practicality and significant potential for implementation in real-world, expansive, and intricate spatial constructions [45]. Aligning the BIM model with the point cloud enhances convenience in building construction, enables the monitoring of construction progress, and offers potential for the construction sector to achieve intelligence and precision. The utilization of point cloud and BIM technologies is both feasible and holds significant potential for application in real-world large-span complicated-space structures [46]. Point clouds can also function as crucial data infrastructure for digital advancements in the building industry [47]. Integrating BIM technology, point cloud technology, and digital technology, for carrying out relevant technical research from the perspective of improving the level of fine management, facilitates the existing technology implementation or application cases to achieve methodological innovation.

Further, point cloud technology will continue to evolve in the future, integrating more closely with BIM and transportation and facilities, which may include automated data processing and analytics tools, as well as integration with IoTs devices and Artificial Intelligence (AI) visualization for more innovative, efficient facility management and transportation planning that is replicable and scalable.

4.2.2. Digital Twins

As shown in Figure 15, digital twin is an emerging technology term in the smart technology category of the integration of BIM and T and Fs. Parallel to this, the digital twin is the integration of multidisciplinary and multiscale simulation processes using massive real multi-source multidimensional data [48]. With the advancement of digital reform in the construction industry, the industry is gradually entering the digital twin era and the real realization of the intelligent construction of digital twins of buildings, for which the basic premise is to build objects, and the construction process is highly digitalized. Simultaneously, to accomplish such a process is to rely on BIM to establish a digital model to achieve real intelligent construction or intelligent operation and maintenance.

In addition to this, the swift advancement of the IoTs has enabled the transportation industry to adopt digital twin technology to a greater extent [49]; digital twins have made a huge difference in the development of society. Besides, digital twins provide a more comprehensive management and optimization tool for transportation hubs, allowing for the more forward-thinking management of facilities that can better meet the growing demand for urban transportation. The integration of BIM and digital twin technology optimizes the operation and monitoring of transportation construction [50,51] and facility management [52–54]. Digital twins will offer comprehensive modeling and data management insights for the future of operations and maintenance [55]. Shared across different sectors and stakeholders to promote better collaboration and synergistic decision making, the incorporation of real-world augmented reality (AR) technology will enhance the capabilities of the new technology [56], contributing to synergistic work between urban planning, facilities management, and urban transportation management. The new technology will incorporate BIM, the IoTs, and other technologies to create a digital twin that enables comprehensive facility information management and intelligent operation and maintenance across its entire life cycle. Additionally, real-world AR technology will be integrated to enhance the system [57]. Nonetheless, the extensive literature on the integration of BIM and digital twin technologies in transportation facilities is rare and is still in the development phase of theoretical and conceptual proposals [58]. The convergence of BIM and digital twin technologies has the potential to force the digitization of transportation facilities in the future.

4.2.3. Life Cycle Assessment

Prominently, the results of Section 3.4.2 suggest that LCA has been of continuous interest to studies since it became a hot keyword in the year 2018. The primary focus of LCA research is on pre-planning, design, coordinated construction, operation and maintenance, and cost management, which presents development recommendations [59,60]. In common with this, the LCA techniques are used to assess the environmental influences of building materials (e.g., during the manufacturing and operational phases) and to assist in the evaluation of the potential for environmental improvements in building construction [61,62]. In current building construction, the utilization of BIM technology extends beyond just the design phase and is applied throughout the entire engineering construction process [63]. There is a close correlation between LCA and BIM, which can work in tandem to support the construction, design, and management of sustainable infrastructure. The construction phase of the application primarily focuses on many elements, such as cost management, building progress, quality and safety, and risk identification [64–67]. Additionally, the process of constructing supply chains entails the involvement of numerous stakeholders such as contractors, suppliers, developers, and government, so that diverse goals and conflicts of interest should be possessed. Based on this, key players must undertake decisions based on the notion of mutual benefit and SD (sustainable development) [68]. Hence, the BIM and LCA's integration assists in authenticating the construction of design concepts and extending optimal procedures for not only realizing sustainable buildings/structures but also optimizing the decision-making process in the construction sector [69], to reduce energy consumption and environmental impacts, and improve the sustainability of construction and transportation infrastructure projects. As a result, this integrated approach of LCA and BIM helps to create more sustainable and environmentally friendly buildings and transportation infrastructure.

4.3. Current Research Challenges and Opportunities

Transportation hub facilities serve as transportation interchanges in a city or region, usually including roads, highways, railroads, light rail, bus stations, and airports. The proposed facilities facilitate connections and transitions between different modes of transportation, of which each has specific functions and needs, and play a key role in urban and regional transportation systems by facilitating the movement of people and goods, improving transportation efficiency, reducing congestion, and supporting economic development. BIM is crucial in the Architecture, Engineering, Construction, and Operations (AECO) industry. Since the utilization of BIM is mostly attributed to the absence of organizational BIM capability (OBIMC), the lack of OBIMCs has hindered the realization of most of the benefits associated with BIM [70]. Indeed, the application of BIM in construction is not a novel notion [71]. Implementing BIM technology in the maintenance and administration of transportation facilities, including stations and tunnels, assist in enhancing operational precision, resulting in increased equipment lifespan, decreased equipment failure rates, and reduced maintenance expenses [72]. Although, as a collaborative working approach for developing and managing development projects, while BIM has developed in diverse aspects, the lack of organizational BIM capabilities remains a barrier to its implementation across the global AECO industry. Understanding these criteria can help researchers and industry practitioners to develop the optimal tool for assessing organizational BIM capabilities for the local industry [73]. Obviously, the results of Section 3.1 indicate that after more than a decade of silence, in recent years, studies on the integration of BIM and T and Fs have grown at a high rate. The widespread utilization of BIM improves the efficiency of construction and design, reduces waste, and thus cuts costs. Nevertheless, the construction strategy must prioritize safety factors. Construction safety is often neglected, although it is crucial to stress the integration of safety issues in the construction plan. Implementing BIM can effectively mitigate safety hazards faced by construction workers and efficiently coordinate concurrent construction tasks. BIM is an effective instrument for mitigating risk, promoting workplace safety, and ultimately enhancing project results [74]. To enhance the safety and efficiency of construction projects by implementing BIM in housing services, it is crucial to reinforce inter-organizational coordination among funding agencies, engineering and architectural firms, and other organizations involved in housing design and construction. This coordination is essential for ensuring the incorporation of appropriate technical design and construction practices [75]. Furthermore, a novel theoretical framework emerged, highlighting the pivotal importance of BIM in emergency management. Specifically, it emphasized the improvement of communication systems in times of crisis by utilizing ad hoc mobile networks to facilitate communication even in the absence of traditional infrastructure, which contributes by offering a significant enhancement to the discourse on the utilization of BIM in enhancing safety and efficiency in the construction industry [76]. In the process of augmenting the synergistic development of intelligent construction and building industrialization, it is indispensable to accelerate the comprehensive integration and penetration of a new generation of information technology into various industries enhanced by BIM, point cloud, digital twin, AI, big data, IoT, and blockchain, in which BIM technology has a fundamental role. In addition, the results in the analysis of the nodes in Section 3.4.3 suggest that the advent of digital twin technology facilitates the creation of virtual, real-time models that can be used for facility management and operations, which provides new opportunities to anticipate maintenance needs, supplement energy use, and enhance safety. Further, the results of the burst keywords analysis revealed that LCA presents a critical research hotspot that is strongly related to the keywords of design and construction. In the event of exploring the integration of BIM and T and Fs, the importance of sustainability and environmental protection cannot be ignored. The aforementioned two factors play a key role in these areas and are critical to improving efficiency, reducing costs, minimizing resource waste, and achieving global sustainability goals. Moreover, sustainability in BIM is about considering environmental and social factors throughout the building lifecycle, which helps to optimize the performance of the building, reduce energy consumption and emissions, and reduce dependence on natural resources. In addition to this, BIM helps in the selection of sustainable materials and methods of construction to reduce waste in the building process, and sustainability also includes the development of renewable energy sources and green transportation solutions to reduce the pressure on urban transportation, improve air quality, and reduce noise pollution. Hence, prioritizing sustainability and environmental protection are core principles.

As a matter of fact, the integration of BIM and transportation and facilities is full of opportunities but comes with complexity and challenges. Additionally, the successful implementation of emerging technologies and concepts requires interdisciplinary collaboration, technological innovation, and efficient management practices. Indeed, the field will continue to evolve as technology continues to develop and experience is gained, with point cloud technology, digital twins, and other digital technologies shaping the future direction of the field, providing more solutions and prospects for the future of urban infrastructure and transportation-hub construction.

4.3.1. Research Limitations

Despite extensive study on the integration of BIM and T and Fs, there are still significant gaps in the available literature that require further investigation. The study of BIM and transportation infrastructures has been relatively delayed in recent years, with a limited overall number of publications. The existing body of research on BIM and transportation infrastructure primarily focuses on theoretical aspects, with limited attention given to the practical use of these theoretical models in design practice. The research continues to prioritize the expansion of the theoretical framework into other domain situations in order to develop precise design methods. In the field of design, there has been a greater emphasis on qualitative research, yet there is a dearth of quantitative analysis. While several studies have evaluated BIM technology in terms of investment planning, construction organization, equipment operation and maintenance, technical research, and engineering application, there is a dearth of research from a bibliometric standpoint.

This paper offers a prompt and clear method for comprehending the current level of research in a swiftly developing new domain, which employs bibliometric analyses at both macro-quantitative and micro-qualitative levels to examine the current status and research frontiers of the integration of BIM and T and Fs, and investigates the research hotspots and future trends in sustainable buildings, aiming to assess the effectiveness of current integrations and propose viable solutions for providing a valuable contribution to enhanced comprehension and creative advancement in the realm of BIM and T and Fs.

4.3.2. Research Importance and Potential Future Directions

To demonstrate the necessity of incorporating developing technologies such as point clouds, digital twins, and LCA as "auxiliary plug-ins" into BIM and emphasize the value of studying and extracting valuable insights from extensive data in relation to the study's areas of practical importance, this paper offers practical recommendations for professionals in the transportation-planning industry to enhance data-management procedures and minimize the likelihood of errors. The utilization of BIM technology in the transportation industry will continue to innovate due to its integration with emerging technologies [42]. The integration of BIM and T and Fs can enhance the creation of digitally sustainable buildings [77] that optimize the utilization of building information and contribute to a more sustainable future.

This paper suggests a concise and clear approach, based on our knowledge, for comprehending the current state of research on a swiftly developing new topic, which utilizes bibliometric analysis to examine the current status and research boundaries of the integration of BIM and T and Fs. It also investigates the focal points of research and the emerging trends in the integration of BIM and T and Fs within sustainable buildings. The investigation utilized data from the WoSCC database, and knowledge mapping analysis was conducted using two visual bibliometric tools, VOSviewer and Citespace, to validate the acquired results, which establishes a theoretical foundation for in-depth research on the integration of BIM and T and Fs. Additionally, it offers significant references and lessons for research in other relevant domains.

In the future, the utilization of BIM technology in transportation infrastructure will become increasingly widespread, encompassing not only the pre-design and building phases but also the realms of operation and maintenance. In general, the implementation of BIM technology in the transportation sector holds significant potential, which may facilitate the digital transformation of the business and enhance the efficiency and quality of its design.

5. Conclusions

The aim of this paper is to examine the present state of the integration of BIM and T and Fs, using BIM technology as the focal point, and to objectively and thoroughly characterize the research focal points and trends in this domain. Hence, this paper not only contributes theoretical and empirical data for the comprehensive investigation of this domain, but also offers novel insights for the integration of BIM and T and Fs.

This paper employs a quantitative methodology to scrutinize the present research status, focal points, burgeoning areas, developmental trends, and future directions regarding the integration of BIM and T and Fs in the context of a quantitative view. The BA has been employed through the network visualization of KCOA to study the existing research status and hotspots, of which development relevance and emerging technology areas are explored through KCOA overlay visualization and analysis, and future research trends and significant directions for sustainability have been explored through burst keywords and CiteSpace keyword analysis. In terms of research methodology, the visual bibliometric tools, namely VOSviewer and CiteSpace, were used to quantitatively analyze KCOA and to systematically gain insight into the integration of BIM and T and Fs through keyword-network visual mapping, providing a reliable methodology for future studies. From the standpoint of research content, the 34-year history (years 1989 to 2023) of the integration of

BIM and T and Fs is examined through quantitative analysis based on the data from the WoSCC database. In terms of research techniques, this paper compares the results of the KCOA of the BA tools, namely VOSviewer and CiteSpace, to enhance the credibility of the study results through the cross-correlation test of the two software tools.

The prominent terms associated with the integration of BIM and T and Fs are principally focused on framework, system, design, construction, and management. In addition to this, over the past 34 years, the hot keywords of each year were discovered by KCOA overlay visualization, of which the applications of point cloud, digital twin, and life cycle assessment are the current hot topics, and these emerging technologies can offer more innovative breakthroughs for the future. Furthermore, the integration of BIM and T and Fs represents an important trend in the field for the future and is essential for improving the efficiency, sustainability, and intelligence of buildings and infrastructure, from which the three domains can create synergies that contribute to the better planning, construction, and management of building and infrastructure projects. Aided by BIM technology, the design and construction process becomes more accurate and visual, reducing errors, in which BIM can provide accurate data for transportation-hub planning, improving traffic flow management and safety.

In the same vein, digital twin and point cloud technologies add real-time monitoring and maintenance, making them more efficient and extending the life of the facility, and digital twin and point cloud technologies increase the efficiency of real-time monitoring and maintenance, making them more efficient and extending the life of the facility. In the future, the integration of these fields will be even closer, and digital twin technology and point cloud technology will be further popularized, providing more opportunities for real-time simulation and decision support. In addition, sustainability and environmental protection will continue to lead the way in these areas, driving the adoption of renewable energy and low-carbon solutions. As a result of this, sustainable development research that integrates BIM and transportation and facilities has great research potential, from which, through deeper collaboration, research, and innovation, the building industry and society can achieve smarter and more sustainable buildings and infrastructures to meet future needs, thereby improving transportation and improving quality of life.

The main limitation of this research is that the literature was collected using only the WoS database without considering other databases that may have access to other related research studies. Therefore, the results do not represent the full picture of research in the field. Future research should consider using other databases such as Scopus to expand the database search on the integration of BIM and T and Fs to obtain a more rigorous and comprehensive picture of existing knowledge.

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