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Integration of Building Information Modeling with Sport and Facility: Current Status and Future Directions

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Abstract: Currently, sport is considered an entertainment and leisure industry and includes activities such as athletics, water, and skiing. The influence of a sport event exceeds the event itself, which indicates the importance of a sport facility to the building and construction. A sport facility refers to a facility related to the sport industry, mainly including not only stadiums, swimming pools, and sport centers, but also water parks, ski resorts, and other amusement facilities. At present, there is a lack of comprehensive exploration of integrated building information modeling (BIM) with sport and facilities and performance of applications to help identify potential opportunities to support sustainable development. Therefore, this paper aims to explore the integration of BIM, sport, and facility by revealing the current research status and hotspots in the field, which identifies the development lineage and emerging areas of the research and highlights the development trends and directions for future research towards sustainable development. This paper adopts a quantitative research method to investigate the current research status, hotspots, emerging areas, development trends, and important directions in the integration of BIM, sport, and facilities from macro-quantitative perspectives via bibliometric tools, i.e., VOSviewer and CiteSpace software packages. The main findings of this paper are that the hot keywords on the integration of BIM, sport, and facilities are mainly focused on BIM, facility management, framework, management, sport, construction, and design. Moreover, over the past 26 years (year 1997 to 2022), hot keywords for each year have been revealed through keyword co-occurrence overlay visualization analysis and identified in five schemes, i.e., life cycle assessment, emerging technology, behavior and sport, health and wellbeing, and sustainable built environment. Furthermore, the application of deep learning, IoT, and immersive experience technologies are current hot topics which could provide more innovative breakthroughs for the integration of BIM, sport, and facilities in the future for sustainable development.

Keywords: building information modeling (BIM); sport; facility; sustainable building; sustainable development; bibliometric; facility management; life cycle; deep learning; Internet of Things (IoT); immersive experience

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1. Introduction

Sport is considered an entertainment and leisure industry and includes activities such as athletics, water, and skiing. As a means of modernization, diplomacy, and soft power [1], a sport event has an impact far beyond the event itself [2]. Sport facilities for a sporting event and activity is gaining attention now. Studies have shown that the application of building information modeling (BIM) in sport facilities is important to construction [3–5]. Sport facilities refers to facilities related to the sport industry, mainly including not only stadiums, swimming pools, and sport centers, but also water parks, ski resorts, and other amusement facilities. Sport facilities are representative of facility buildings, which are considered

one of the most complex buildings in the world [6]. Unlike other facility building types (e.g., commercial, residential), sport facilities have a variety of areas with different use of scenarios (e.g., offices, swimming pools, etc.) and dissimilar occupancy patterns (e.g., low, medium, high) [7]. Therefore, it is challenging to meet users' comfort, health, and safety while using functions such as lighting, broadcasting, air conditioning, and monitoring in sport facilities [8].

The Intergovernmental Panel on Climate Change (IPCC) currently highlights carbon emissions from building operations need to be cut by more than half by year 2030 in its Global Warming 1.5 °C Special Report [9]; this requires a huge effort to overcome the challenges in achieving the Sustainable Development Goals (SDGs). Meanwhile, the building sector accounts for 30% of global energy consumption and the global building market is expected to grow by more than 70% by year 2025 [10,11], of which sport and recreation facilities account for about 10% of Europe's energy consumption [12]. Moreover, the energy consumed by a 90-min soccer game can be used by more than a dozen households for an entire year [13]. A sport facility is a particular type of building with an extremely high energy consumption, with open and enclosed areas of spacious space with different functional zoning [14,15]. Therefore, reduction in the energy consumption of sport facilities is of great importance for environmental protection and sustainable development.

The use of digital technologies in sport facilities is currently evolving at the breakthrough phase to support the SDGs [16]. Building information modeling (BIM) technology has been used widely for sport facilities. For complex buildings, building automation and management system (BAMS) enhanced sport facilities have made rapid progress, supported by the integration of cutting-edge technologies such as artificial intelligence, machine learning, and internet of things (IoT) [7]. In addition, the integration of BIM and IoT has greatly improved the efficiency of the construction and operation of sport facilities [17]. Deep learning has the potential to optimize energy efficiency and propose predictive solutions in sport facilities [7,18,19]. Further, BIM-based immersive experience technology also plays an important role in sport facilities. However, despite the support provided by BIM in processes and working methods, the digitization of sport facilities is still too slow, with particular reluctance to use new technology and inefficiency in sustainable development [20].

At present, there is a lack of comprehensive exploration of integration BIM with sport and facilities and performance of applications to help identify potential opportunities to support sustainable development. Therefore, this paper aims to explore the integration of BIM, sport, and facilities by revealing the current research status and hotspots in the field, which identifies the development lineage and emerging areas of the research and highlights the development trends and directions for future research on sustainable development.

2. Materials and Methods

Since the multidisciplinary and interdisciplinary integration of BIM, sport, and facilities, and unclear directions and trends in the theme, a quantitative research method has been adopted for this investigation, which includes a quantitative analysis via bibliometric tools. Bibliometric analysis is a quantitative analysis method that uses various external characteristics of scientific and technical literature as a data source and applies mathematical and statistical methods to objectively and directly describe, evaluate and predict the current status and development trends of the field [21], which can provide references and insights for potential future in-depth work [22]. Hence, this paper employs a bibliometric analysis method to explore current studies in terms of time, sources, disciplines, keywords, research methods, research themes, research hotspots, application areas, and future trends from a quantitative perspective.

In the quantitative analysis, data have been obtained from the Web of Science (WoS), which is one of the world's most used scientific citation indexing databases, with keywords including "BIM", "CIM", "sport", and "facility", and only "Article" and "Review" were screened out. The rigorous indexing process of the Web of Science Core Collection

(WoSCC) ensures that the database content is of high quality and has a significant scientific impact [23]. First, the data volume, journal source, and disciplinary classification of research on the integration of BIM, sport, and facilities have been explored through charts and graphs using the Analytical Search Results tool in the WoS database to provide statistics on the current status. Secondly, the keyword co-occurrence network visualization and overlay visualization, and the burst word analysis have been conducted to visualize and analyze the first 99 hot keywords of the current studies to obtain the hot areas and development trends via bibliometric visualization software VOSviewer and CiteSpace software, respectively. VOSviewer is a free software tool that is focused specifically on the pictorial representation of bibliometric mappings and used to create and visualize bibliometric networks of scientific publications, authors, journals, countries, institutions, and keywords [24]. CiteSpace software is an information visualization software developed by Dr. Chao-Mei Chen of Drexel University, mainly for the measurement and analysis of scientific knowledge data [25]. In addition, the data visualization function of Scimago Graphica software plays another important role [26].

As shown in Figure 1, the research method flowchart contains four objective phases of approach and technique for the quantitative analysis process via bibliometric analysis: (1) to provide statistics on studies on the integration of BIM, sport, and facility in the WoSCC database, from which "Article" and "Review" article types have been screened out with keywords including "BIM", "CIM", "sport", and "facility" to obtain results for analyzing in terms of the number of published articles each year, exponential trend lines in published articles, journal sources of published articles, and subject areas of published articles; (2) to analyze the current research status and hot spots on the integration of BIM, sport, and facilities, in which the network visualization of keyword co-occurrence analysis is performed by VOSviewer software, and the keyword co-occurrence for data visualization is conducted by Scimago Graphica, followed by a table of high-frequency keywords via VOSviewer; (3) to reveal the development lineage and emerging areas on the integration of BIM, sport, and facilities, in which the over visualization of keyword co-occurrence analysis has been illustrated by VOSviewer, the time zone diagram of keyword co-occurrence analysis has been created via VOSviewer, and the keywords of hot research in VOSviewer per year have been listed in a table; and (4) to explore the development trends and important directions for future research, from which the keyword co-occurrence analysis and burst word analysis have been conducted using CiteSpace software; the keywords appeared in VOSviewer keyword co-occurrence analysis but missing in the CiteSpace keyword co-occurrence analysis have been tabulated; the important nodes in the network visualization of keyword co-occurrence analysis via VOSviewer have been highlighted.

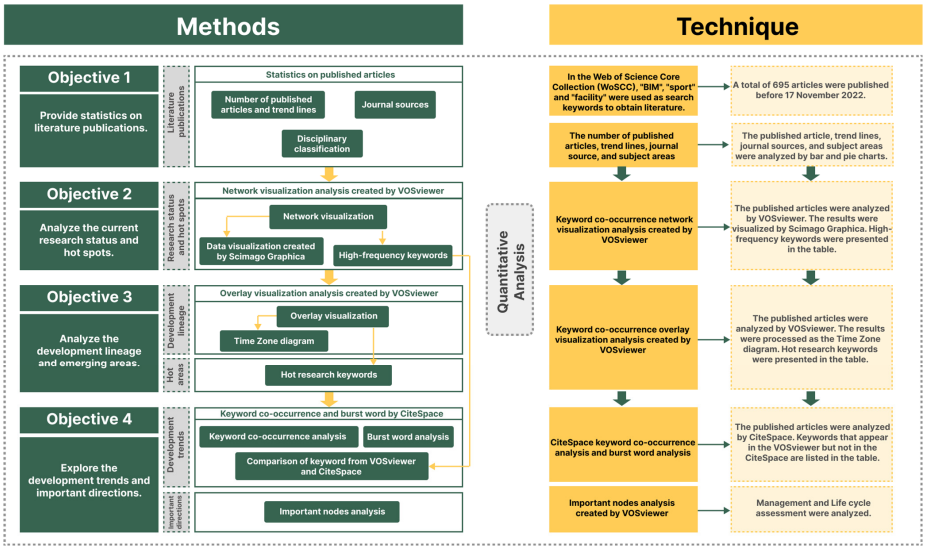

Figure 1. Research methodology flowchart (generated by authors).

3. Results

3.1. Background of Publications

The data have been obtained from the WoSCC database by searching the keywords "BIM", "facility", and "sport" resulting in a total of 695 articles, as shown in Table 1. Among them, the first research on the integration of BIM with sport and facilities in the WoSCC database was conducted in the year 1997 which is about 26 years ago [27].

Table 1. Process and results of data collection from the Web of Science Core Collection (WoSCC) database (generated by authors).

Source	Web of Science Core Collection
Citation	SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH, CCR-EXPANDED, IC
Search Steps	#1 = (TS = ((“facility”) AND (“sport”))) #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 (“sport”))) #4 = #1 OR #2 OR #3
Timespan	1997.07.01–2022.11.17
Document Type	Article and Review
Qualified records	695

As shown in Figure 2, the publication on the integration of BIM, sport, and facilities from year 1997 to 2022 (26 years) can be divided into the following three stages:

(1) Stage I: from 1997 to 2008 (12 years), it has a slow increase with 39 published articles (5.6% of all the articles).
(2) Stage II: from 2009 to 2017 (9 years), a significant increase is shown with 214 articles accounting for 30.8% of all the published articles.
(3) Stage III: in the recent five years (2018 to 2022), a high rate of increase appears with 442 articles, accounting for 63.6% of all the published articles, of which the highest number is 108 articles in 2021.

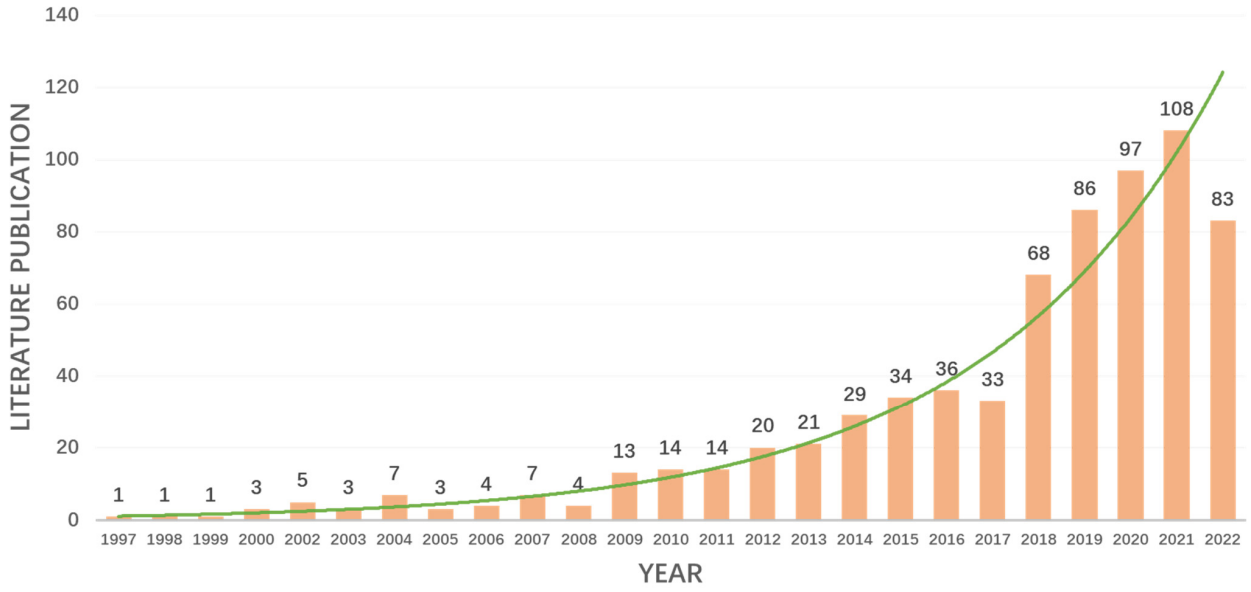

Figure 2. Number of published articles each year and exponential trend lines for research on the integration of BIM, sport, and facilities in the WoSCC database from 1997 to 2022 (26 years) (generated by authors).

The exponential trend line (green line in the Figure 2) has been generated with the publication per year for 26 years from 1997 to 2022, of which the average annual growth rate of cumulative publications is 20.08%, via the formula:

$$y = 0.9276e^{0.1959x}, R^2 = 0.9091 \quad (1)$$

These data indicate that research on the integration of BIM, sport, and facilities is developing at a high rate, becoming a hot topic in the AEC industry.

The sources of the publication per year related to the integration of BIM, sport, and facilities are shown in Figure 3. A total of 695 articles have been published in 267 journals, with 34% of the articles published in the top eight journals that are *Automation in Construction* (13.81%) followed by *Applied Sciences-Base* (4.60%), *Buildings* (3.45%), *Sustainability* (3.17%), *Journal of Computing in Civil Engineering* (2.59%), *Sport Management Review* (2.16%), *Journal of Athletic Training* (2.01%), and *Journal of Construction Engineering and Management* (2.01%).

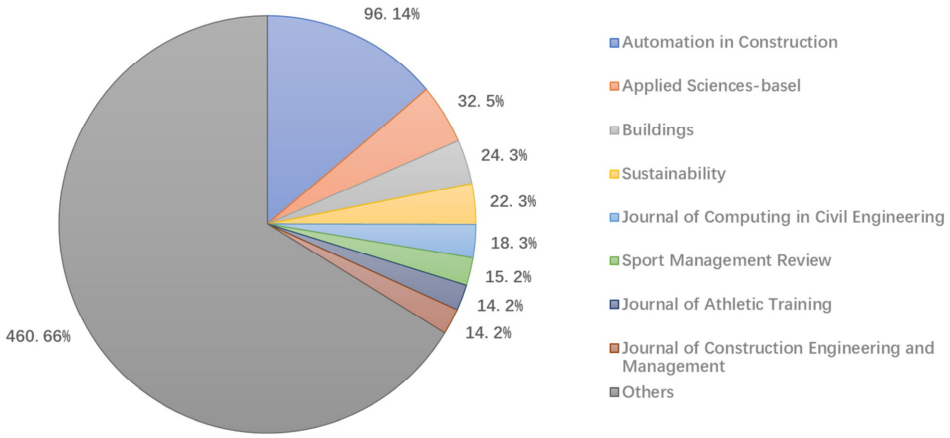

Figure 3. Journal sources of published articles in the WoSCC database on the integration of BIM, sport, and facility from year 1997 to 2022 (26 years) (generated by authors).

By using the "Analyze Search Results" tool in the WoSCC database to explore hot subject areas on the integration of BIM, sport, and facilities, as shown in Figure 4, with a minimum number of records of forty, there are a total of six hot subject areas, i.e., Engineering Civil (240 articles), Construction Building Technology (194 articles), Sport Sciences (71 articles), Hospitality Leisure Sport Tourism (67 articles), Engineering Multidisciplinary (56 articles), and Environmental Sciences (45 articles).

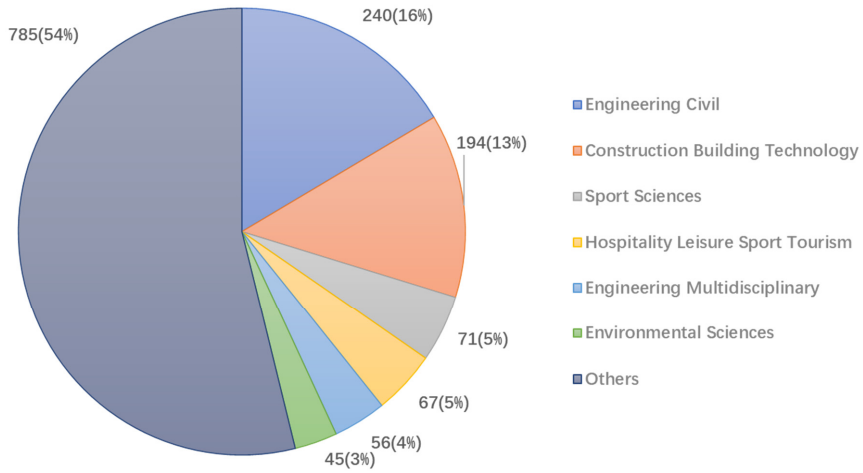

Figure 4. Number of published articles in the WoSCC database from 1997 to 2022 (26 years) in different subject areas on the integration of BIM, sport, and facilities (generated by authors).

3.2. Research Status and Hot Spots

3.2.1. Network Visualization of Keyword Co-Occurrence

The obtained 695 articles (as shown in Table 1) have been imported into the software VOSviewer (version 1.6.17) for keyword co-occurrence analysis. As shown in Figure 5, the text labels, color nodes, and connecting lines are illustrated in the keyword co-occurrence network visualization, in which items are represented by text labels and nodes that indicate the frequency of keyword occurrences by size, the larger the node, and the more frequently the keyword appears. The distance between positions of two keywords and the length of the connecting line suggests the similarity and relevance between topics represented by the words, and the thickness of the line indicates the strength of the connection [28]. In addition, the more connecting lines, the more co-occurrence between the keywords. Further, different colored areas represent different clusters, which allows the viewing of each cluster [29]. When the keyword co-occurrence analysis has been performed with a set of threshold values with the unit of analysis as "All keywords", the counting method as "Fractional counting", and the threshold values of keyword occurrence frequency was "8", a total of 99 keywords meet the set threshold value, forming four color clusters in red, green, blue, and orange, as shown in Figure 5. The keyword "BIM" occupies the largest node, with 314 occurrences, and the node is located in the center of Figure 5, followed by "facility management" and "model", with 164 and 74 occurrences, respectively, which indicates that the closest link with BIM on the theme is facility management, while the model is a part of the BIM process.

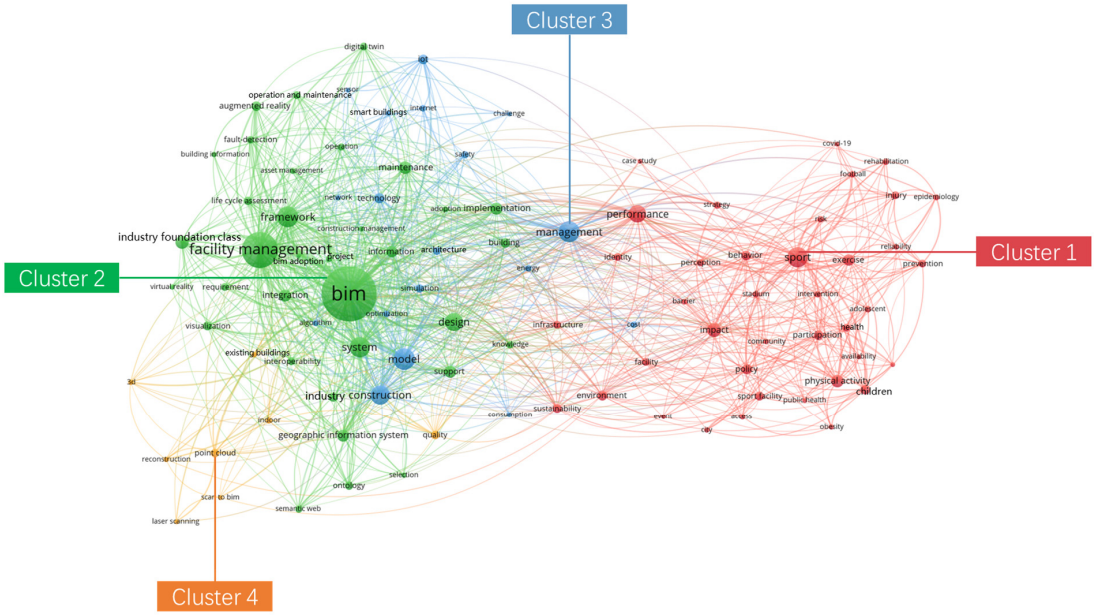

Figure 5. Network visualization of keyword co-occurrence on the integration of BIM, sport, and facilities from 1997 to 2022 (26 years) created with VOSviewer software (generated by authors).

The results of the keyword co-occurrence analysis (Figure 5) have been further visualized by Convex Hull Chart of Scimago Graphica with four colored clusters in clear boundaries of red, green, blue, and orange, as shown in Figure 6, in which the keyword nodes belonging to the same cluster and the distribution of the nodes in space can be easily identified. Scimago Graphica (version 1.0.25) is a software that creates complex visual charts without programming code using imported file formats in VOSviewer (e.g., GML format) [26]. Cluster 1 (red) is based on the theme of sport development and sport performance, which emphasizes sport facilities research and experimental sport exploration, including "sport", "performance", "impact", physical activity", "exercise", "sport facility", and other 39 keywords. Cluster 2 (green) is an important cluster that focuses on the application of BIM in facility management and the application of emerging technologies in buildings during design, operation, and

maintenance stages of the building life cycle, including a total of 34 keywords such as "BIM", "facility management", "industry foundation class", "geographic information system", "augmented reality", "digital twin", and "virtual reality". Cluster 3 (blue) associates with the construction stage, which has a total of 18 keywords including "management", "construction", "IoT", and "smart buildings". Cluster 4 (orange) is related to 3D scanning technology for buildings with eight keywords, such as "point cloud", "scan to bim", and "laser scanning".

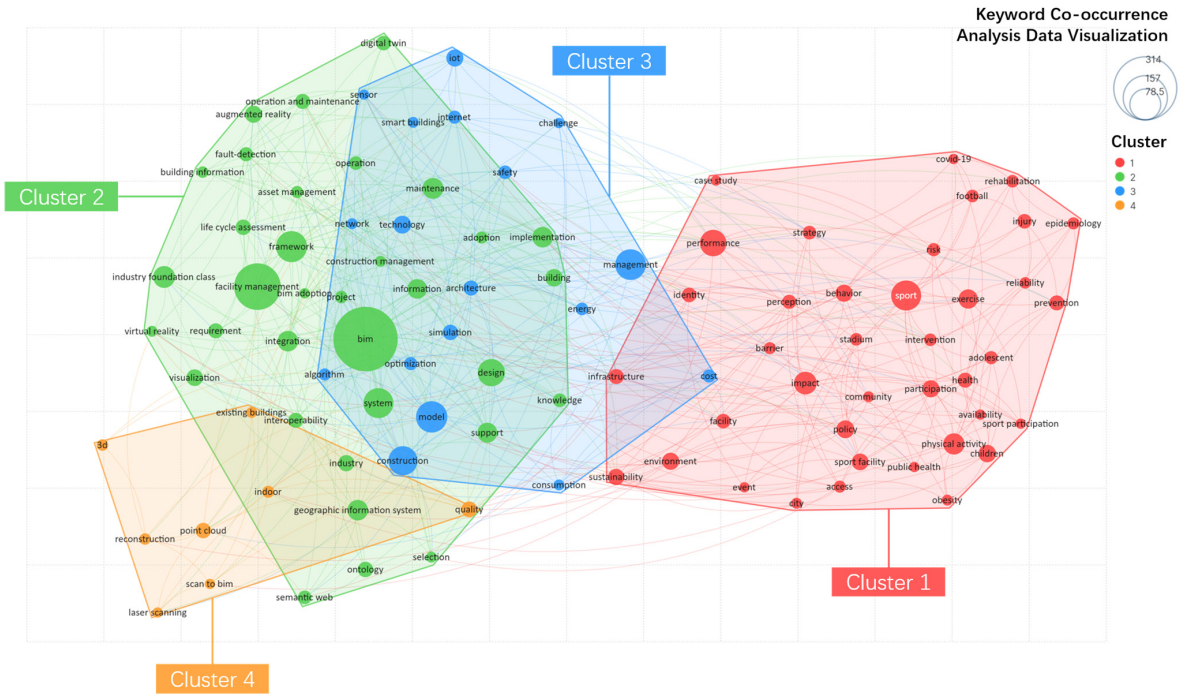

Figure 6. Data visualization of keyword co-occurrence analysis on the integration of BIM, sport, and facilities created with Scimago Graphica from 1997 to 2022 (26 years) in line with Figure 5 (generated by authors).

In addition, the boundary of the clusters and the spatial distribution of keyword nodes are shown in Figure 6, in which a farther distance between two clusters indicates a greater difference and a larger overlapping area of two clusters suggests a higher correlation and similarity. Cluster 1 (red) "sport development and sport performance" only overlaps with Cluster 3 (blue) "construction stage of the building lifecycle stages" with the keywords "infrastructure" and "cost", which is less related to Cluster 2 (green) "BIM in facility management" and Cluster 4 (orange) "building 3D scanning technology". Cluster 2 (green) "BIM in facility management" and Cluster 3 (blue) "construction stage of the building lifecycle stages" is heavily related with all stages of the building life cycle with emerging technologies such as "augmented reality", "digital twin", and "IoT". Cluster 4 (orange) "building 3D scanning technology" is also highly correlated with Cluster 2 (green) "BIM in facility management", with overlapping keywords, i.e., "quality", "industry", "geographic information system", "indoor", and "existing buildings".

3.2.2. High-Frequency Keywords

Table 2 lists the 10 most frequent keywords in the keyword co-occurrence analysis created with VOSviewer software from 1997 to 2022 (26 years), which includes represented color, cluster number, keyword, occurrence frequency, total link strength, and links. Keywords with higher total link strength and occurrence frequency have a greater impact including "bim", "facility management", "model", "framework", "management", "sport", "system", "construction", "design", and "performance", of which "facility management"

and "management" are ranked the second and fifth, respectively, indicating that the application of BIM in facility management is a popular research subject currently. The "design" and "construction" are stages in the building life cycle, suggesting that the current focus on the integration of BIM, sport, and facilities is on the first two stages of the life cycle, i.e., design and construction.

Table 2. High-frequency keywords on the integration of BIM, sport, and facilities created with VOSviewer software from 1997 to 2022 (26 years) (generated by authors).

Color *	Cluster	Keyword	Occurrences	Total Link Strength	Links
	2	bim	314	297	78
	2	facility management	164	162	76
	3	model	74	71	72
	2	framework	73	73	71
	3	management	71	70	77
	1	sport	68	60	49
	2	system	68	67	69
	3	construction	64	64	72
	2	design	56	55	67
	1	performance	53	47	64

* The colors in the table are in line with the colors from Figure 5.

3.3. The Development Lineage and Emerging Areas

3.3.1. Time Overlay Visualization of Keyword Co-Occurrence

Time overlay visualization can reflect hot topics in the research field by year and help with revealing future research trends. Figure 7 shows the keyword co-occurrence overlay visualization on the integration of BIM, sport, and facilities from 1997 to 2022 (26 years), via colors ranging from dark blue and green to yellow, representing time from past to present. As shown in Figure 7, the overall appearance is light yellow-green on the left side (bim-centered) and dark blue-green on the right side (sport-centered), which highlights that the sport-centered keywords appear generally earlier than BIM-centered keywords.

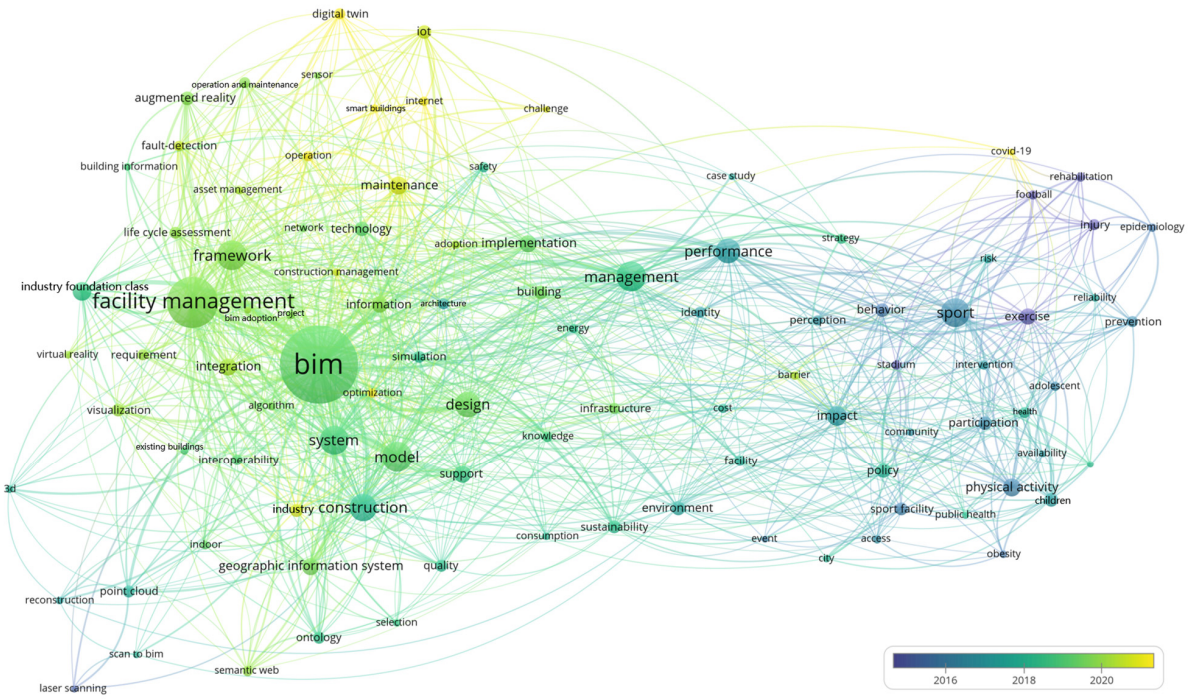

Figure 7. Time overlay visualization of keyword co-occurrence on the integration of BIM, sport, and facilities from 1997 to 2022 (26 years) created with VOSviewer software (generated by authors).

The data for the overlay visualization of keyword co-occurrence (Figure 7) has been further processed to obtain results of time zone analysis, as shown in Figure 8, in which the keywords listed in chronological order from past to present, clearly showing the evolution of keywords in the timeline. As shown in Figure 8, "exercise" and "injury" are the initial keywords, appearing in the year 2014. Most keywords came on stage since the year 2016, with a rapid growth in the field, of which a new keyword "digital twin" showcased since the year 2021. With the rise in facility management and the digital transformation in the building sector, sport facilities and BIM have become hot research areas to emerging technologies such as deep learning, HVAC system, motion planning, digital twin, IoT, fault detection, visualization, and augmented reality, of which the HVAC system, deep learning, and motion planning emerged in the year 2022.

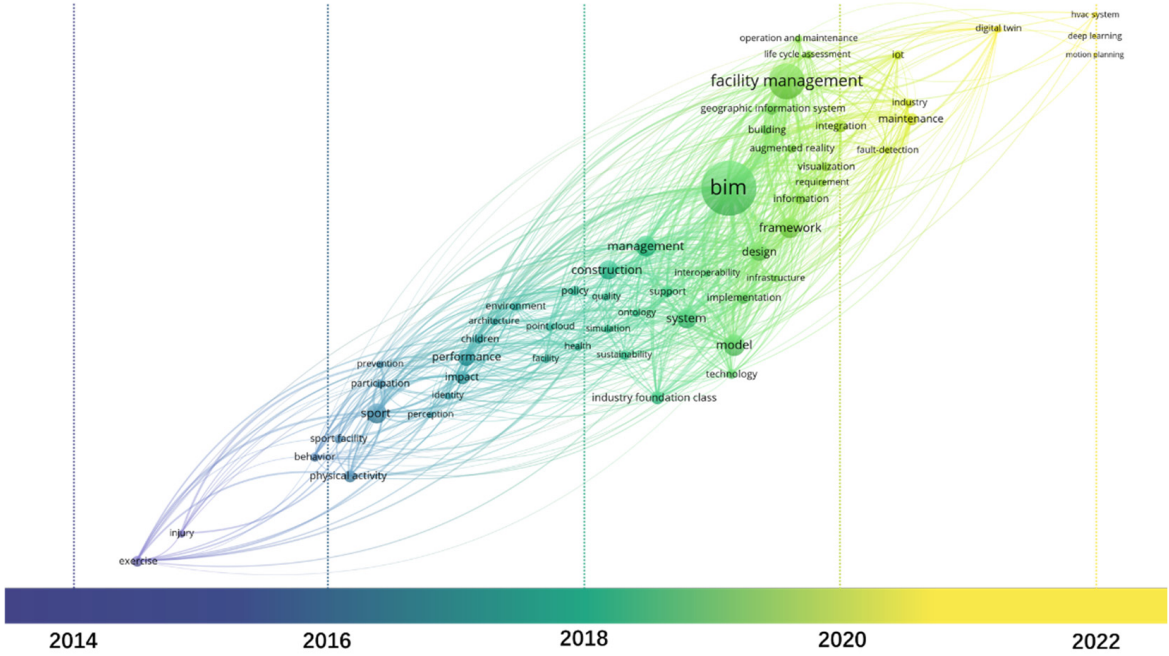

Figure 8. Time zone diagram of keywords on the integration of BIM, sport, and facilities from 1997 to 2022 (26 years) from time overlay visualization of keyword co-occurrence via VOSviewer software (generated by authors).

3.3.2. Hot Research Keywords

As shown in Table 3, the hot research keywords on the integration of BIM, sport, and facilities from 1997 to 2022 (26 years) are grouped into the following five main schemes:

(1) Life cycle assessment: maintenance, life cycle assessment, operation and maintenance, design, implementation, management, construction, and simulation.
(2) Emerging technology: deep learning, HVAC system, motion planning, digital twin, IoT, fault-detection, visualization, augmented reality, facility management, infrastructure, geographic information system, BIM, industry foundation class, and point cloud.
(3) Behavior and sport: performance, participation, sport, physical activity, sport facility, behavior, and exercise.
(4) Health and wellbeing: requirement, health, policy, children, perception, prevention, and injury.
(5) Sustainable built environment: building, sustainability, facility, environment, and architecture.

Table 3. Hot research keywords on the integration of BIM, sport, and facilities from keyword overlay visualization via VOSviewer software from 1997 to 2022 (26 years) (generated by authors).

Year	Color *	Keyword
2015 and earlier		Behavior, injury, exercise
2016		Identity, perception, prevention, participation, sport, physical activity, sport facility
2017		Health, policy, point cloud, facility, environment, architecture, children, performance, impact
2018		Interoperability, system, support, industry foundation class, management, ontology, sustainability, construction, simulation, quality
2019		Integration, visualization, requirement, life cycle assessment, information, operation and maintenance, augmented reality, framework, facility management, infrastructure, geographic information system, building, design, implementation, model, technology, bim
2020		Maintenance, industry, iot, fault-detection
2021		digital twin
2022		deep learning, hvac system, motion planning

* The color range in the table is in line with the color range in the Figure 7.

3.4. Trends and Directions

3.4.1. Comparison of Keyword Results from VOSviewer and CiteSpace Keyword Co-Occurrence Analysis

The general process of keyword co-occurrence analysis is to count the number of keyword occurrences and measure the affinity between them through a co-occurrence matrix. Currently, widely used keyword co-occurrence analysis tools are distance-based visualization of two-dimensional co-ordinates (i.e., VOSviewer software) and relationship-based network visualization (i.e., CiteSpace software). Although the fundamental concept of both tools is the same, in practice, keyword co-occurrence analysis sometimes does not exactly follow the general process. Therefore, the results of the keyword co-occurrence analysis through VOSviewer software sometimes differ from results via CiteSpace software. The results of keyword co-occurrence analysis from VOSviewer and CiteSpace have been compared in the following sections to minimize bias caused by using different software tools.

The obtained 695 articles listed in Table 1 have been imported into CiteSpace software (version 6.1.R6) for keyword co-occurrence analysis. As shown in Figure 9, the top 99 hot keywords have been obtained via CiteSpace on the theme of BIM, sport, and facilities. Compared with the keywords from results in Figure 5 generated with VOSviewer, there are 13 keywords that appear in the results from the VOSviewer keyword co-occurrences but not in the results via CiteSpace keyword co-occurrences, which include “ontology”, “interoperability”, “rehabilitation”, “epidemiology”, “reliability”, “reconstruction”, “consumption”, “city”, “community”, “obesity “, “sensor”, “COVID-19”, and “scan to BIM”, as listed in Table 4 that presents the number of connections, total link strength, and frequency of occurrence for the keyword co-occurrence analysis of VOSviewer software as well. The results of keyword co-occurrence analysis from VOSviewer and CiteSpace show differences, indicating that the influence and importance of the 13 keywords could cause bias, and as such the keywords will not be included in the subsequent analysis process.

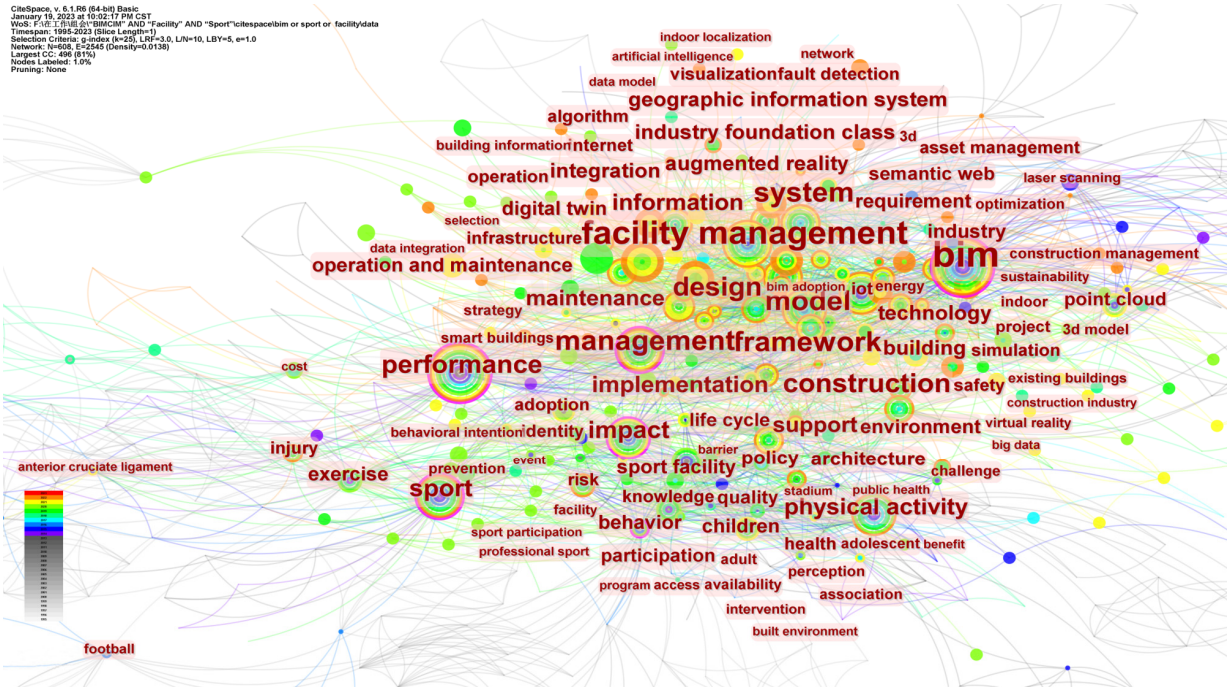

Figure 9. Keyword co-occurrence analysis on the integration of BIM, sport, and facilities created by CiteSpace software from 1997 to 2022 (26 years) (generated by authors).

Table 4. Keywords that are only in the VOSviewer keyword co-occurrence analysis rather than in the CiteSpace keyword co-occurrence analysis on the integration of BIM, sport, and facilities (generated by authors).

VOSviewer Keyword Co-Occurrence Analysis			
Keyword	**Weight <Links>**	**Weight <Total Link Strength>**	**Weight <Occurrences>**
ontology	59	18	18
interoperability	72	17	17
rehabilitation	57	12	12
epidemiology	47	11	11
reliability	45	10	10
reconstruction	44	10	10
consumption	55	9	9
city	53	9	9
community	47	9	9
obesity	39	9	9
sensor	47	8	8
COVID-19	30	8	8
scan to bim	29	8	8

3.4.2. Citespace Burst Word Analysis

Burst word analysis allows to explore the frontiers of research and the latest trends in an identified field. The burst word analysis in CiteSpace is mainly based on the Kleinberg algorithm, which flags the periods when the target trend is unusually frequent [30]. The burst words are keywords that have a sudden increase in the number of citations or occurrences within a certain period time. The detection of burst keywords helps to obtain research hotspots and predict future research trends. The top 20 burst words with the strongest citations have been obtained through the CiteSpace Software, as shown in Figure 10, in which "Year" represents the start year of the analysis, spanning between 1997 and 2022 (26 years); "Strength" suggests the intensity of the burst; and the red line indicates the duration of the burst [31].

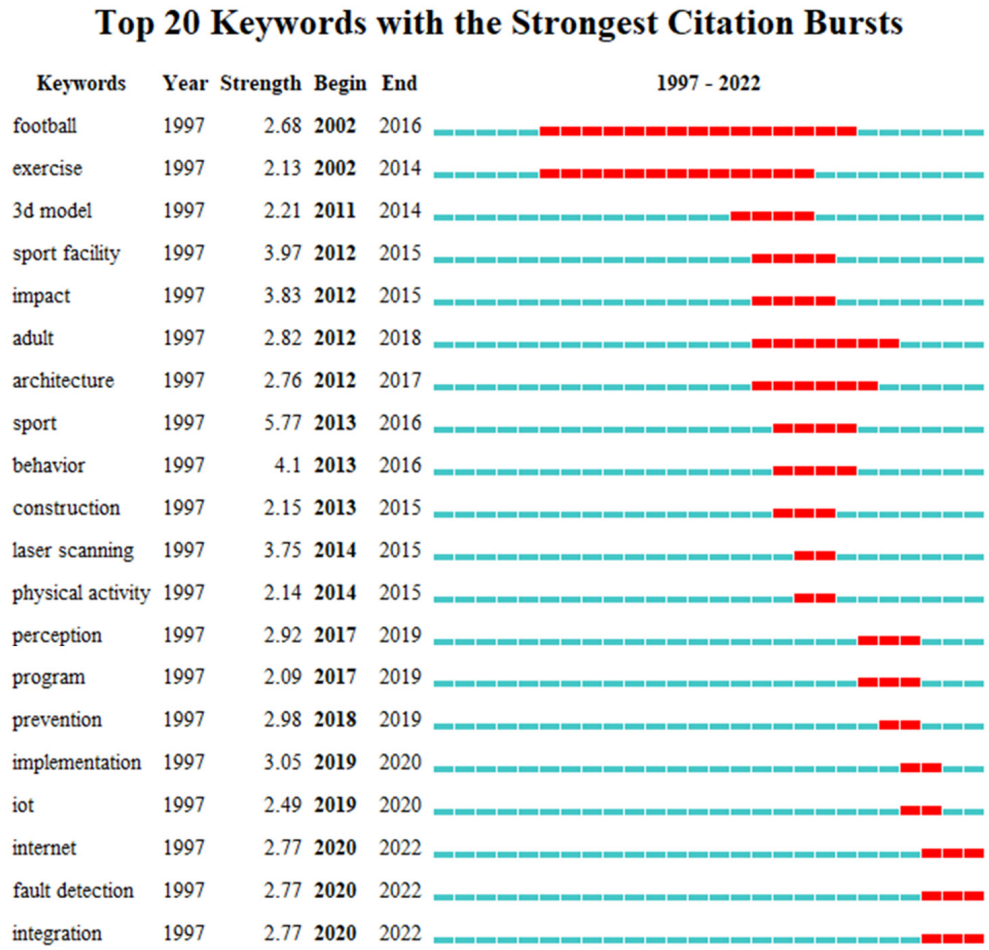

Figure 10. The top 20 keywords with the strongest citation bursts on the integration of BIM, sport, and facilities from year 1997 to 2022 (26 years) created with CiteSpace (generated by authors).

As shown in Figure 10, "football" became a research hotspot in the year 2002 lasting for 15 years (red line range), the longest duration in all the burst words. In addition, "sport" is a hot research term from the year 2013, with an intensity of 5.77, the strongest among all the burst words. "Internet", "fault detection", and "integration" are the three remaining strongest citation burst keywords related to the integration of BIM, sport, and facilities since the year 2022.

3.4.3. Important Nodes Analysis

As shown in Figure 5, "management" is an important node, which appears most frequently among the keywords that connect BIM and sport. The network visualization of the "management" in Figure 5 has been further highlighted, as shown in Figure 11, in which the keywords in the four clusters can be further subdivided into two categories. In the first category, the most prominent keywords are closely related to BIM and life cycle assessment, including design, construction, operation, and facility management. The second category has sport and performance as the main themes. While, management is also closely related to emerging technologies such as IoT, digital twins, virtual reality, and point cloud, which shows that management plays an important role in the development and application of emerging technologies for the integration of BIM, sport, and facilities.

Figure 11. Network visualization of keyword co-occurrence on the theme of "management" (further highlighted from Figure 5) in the WoSCC database created by VOSviewer (generated by authors).

In addition, life cycle assessment is an important topic in Figure 5, which has been further highlighted in Figure 12. The keywords "BIM", "facility management", "management", "system", "design", "performance", "construction", and "framework" are closely related to life cycle assessment, which indicates that life cycle assessment has been well integrated into the field of facility management and construction, and life cycle stages such as design, construction, and operations play an important role in the integration of BIM, sport, and facilities.

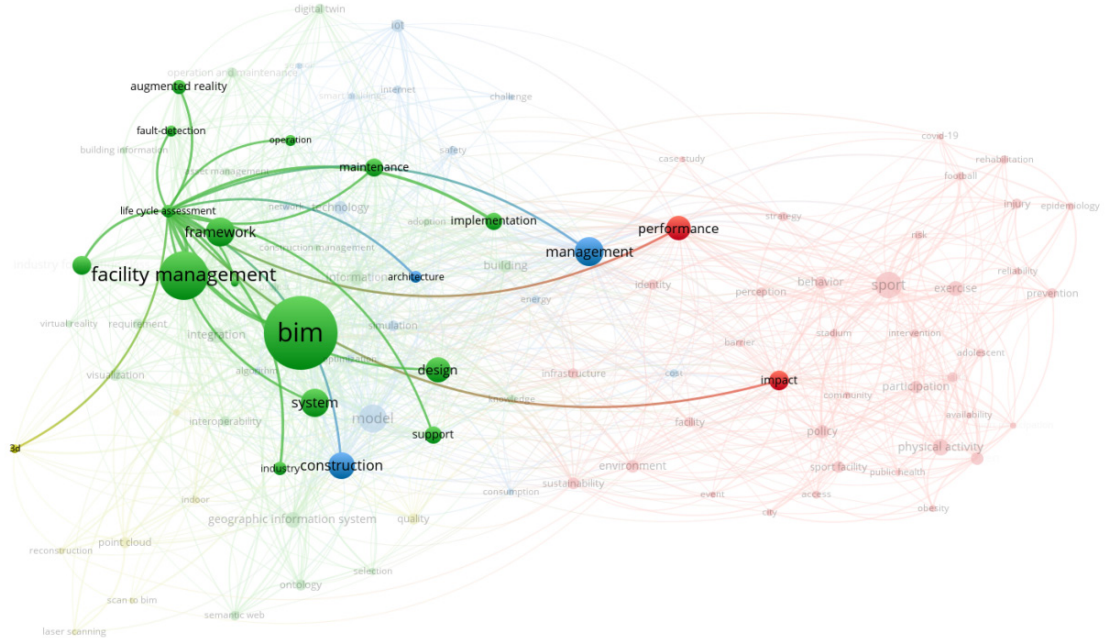

Figure 12. Network visualization of keyword co-occurrence on the theme of 'life cycle assessment' (further highlighted from Figure 5) in the WoSCC database created with VOSviewer (generated by authors).

4. Discussion

4.1. Emerging Technologies

The application of BIM technology to sport facilities, one of the most complex facility buildings, is considered to be a challenge. Therefore, a sport facility is a representative of a facility building, and on the one hand, there are few references on emerging BIM technology applied to sport and facilities. On the other hand, the studies involving other facilities tend to use sport facilities as a case study for results validation, which could be included within future research of BIM, sport, and facilities in terms of emerging technologies, such as deep learning, IoT, and immersive experience technology.

4.1.1. Deep Learning

As shown in Figure 8, HAVC system, deep learning, and motion planning are the emerging research hotspots to the integration of BIM, sport, and facilities in the year 2022. Deep learning generated interest in the sport facility sector in the year 2022. Deep learning is included in the field of machine learning and is a path to achieving artificial intelligence. In addition, neural networks based on artificial intelligence and machine learning algorithms have been deployed in BIM applications [18]. For example, the development of an intelligent management system for sport facilities to predict patronage helps to optimize the operational management [32]. Data-based intelligence techniques are capable of handling more complex models of sport facilities than traditional physical-based modeling approaches, attracting attention from the industry [33].

Further, the results of Figure 8 indicate that sport facilities that have been equipped with a sophisticated Building Automation and Management System (BAMS) that includes the emerging hotspot in HVAC system have achieved rapid growth by integrating with a number of cutting-edge technologies such as artificial intelligence, machine learning, and IoT [7]. However, interdisciplinary thinking and cross-disciplinary thinking are needed to better facilitate optimization methods of implementing BIM to sport facilities. Besides the BAMS, IoT plays a key role in improving the performance of sport facilities with the integration of BIM.

4.1.2. Internet of Things (IoT)

As shown in the results of Section 3.4.2, IoT is the only emerging term in the smart technology category of the integration of BIM, sport, and facilities. Interestingly, IoT lasted from 2019 to 2020, followed by the emergence of internet, which is closely related to IoT, lasting to the present. This indicates that the application of IoT in studies on the integration of BIM, sport, and facilities is in a rapid development period from 2019 to 2020, focusing on unique sport facilities, which is consistent with the results in Table 3. Currently, there is no a lack of widely accepted definition for IoT, including devices such as smart devices, sensors, and actuators [34], which is seen as an open and comprehensive global computer network that can automatically organize and share information, data, and resources [35]. In addition, the IoT has brought a huge change in social development, in which BIM has been integrated with IoT devices to enhance construction operations and monitoring [36,37], facility management [38–40], and health and safety management of sport facilities [41,42].

The use of BIM improves the speed and reliability of data collection and identification for a sport facility's management system [43]. With the support of BIM, project stakeholders can access various data needed to extract and analyze in order to make accurate decisions for a sport facility [44]. In addition, IoT is capable of capturing large amounts of data on sport facilities in real time. The integration of BIM and IoT enhances the strengths and addresses the limitations of capability of obtaining data, thereby improving the efficiency of construction and operation in sport facilities.

However, research on the integration of BIM and IoT in sport facilities is scarce and in the early stage of development, such as theory and concept proposal [17]. In the future, the integration of BIM and IoT has the potential to drive the digitalization development in sport facilities.

4.1.3. Immersive Experience Technology

Immersive technology is quickly becoming the medium of choice for various architectural, engineering, and construction applications, such as design visualization, construction planning, and safety training [45], for which immersive experience technologies such as virtual reality (VR), augmented reality (AR), and game engine-based mixed reality (MR) have being implemented widely in sport facilities [46,47]. The results of Figure 11 suggest that management and VR technology are correlated in the integration of BIM, sport, and facilities, which indicates that the integration of BIM and VR enhances the management of sport facilities based on the rich information contained in the BIM model. The VR technology provides fully virtualized 3D scenes and the ability to load 3D models in virtualized scenes [48], in which project managers can seamlessly transit data across the completion, takeover, and maintenance stages of sport facilities through the use of VR technology. In addition, AR was a hot research keyword in the year 2019, as shown in the results of Section 3.3.2, which is an advanced technology for superimposing information onto the real world [46]. Currently, a number of studies have applied AR to a wide range of applications in the architecture, engineering, construction, and facility management (AEC/FM) sector, as AR has demonstrated potential in addressing the lack of on-site construction information, program implementation errors, and communication barriers in sport facilities [47,49,50]. In the future, BIM-based immersive experience technology could potentially trigger a major paradigm shift in the sport facilities sector.

4.2. Challenges and Opportunities for Current Research

Sport facility refers to a facility related to the sports industry and mainly includes stadiums, swimming pools, and sport centers as well as water parks, ski resorts, and other amusement facilities according to the size, capacity, and type of sport activity [6], containing spacious indoor and outdoor spaces for various activities, such as offices, arenas, and swimming pools, which consumes extremely high energy for which the advanced BIM technology has been implemented [51]. Therefore, unlike other types of buildings, e.g., commercial, residential, and industrial, it is challenging to apply advanced technologies to maintain minimum energy consumption and realize the wellbeing of users while meeting the requirements of related activities, i.e., lighting, ventilation and air conditioning, and other services [8]. The application of BIM technology in the building sector is not a new concept [52]. However, as a collaborative working method for creating and managing construction projects, BIM allows for better handling of a large amounts of information, which enhances sport facility projects [53]. In addition, the BIM is seen as a database that needs to be continuously expanded and improved during the sport facility's life cycle [54].

The results in Section 3.1 suggest that the research on the integration of BIM, sport, and facility is growing at a high rate in recent years after more than a decade of dormancy. Although, the results in Section 3.2 show that BIM and facility management are the two keywords that appear most frequently and are most closely related, little research concerns sport facilities in relation with BIM enhanced FM. Moreover, BIM creates a collaborative environment that hosts all disciplines and project stages of sport facility projects, including design, construction, service, and maintenance management [55]. In the future, BIM could facilitate more effective multidisciplinary research on sport facilities from the perspective of life cycle stages and supply chain integration, which will become a new trend in sustainable construction. Furthermore, as shown in the results of Figure 12, life cycle assessment is an important research hotspot that is closely associated with keywords such as design and construction, which indicates that the life cycle has been well integrated into the design and construction regarding the integration of BIM, sport, and facilities, which contributes to the knowledge, as a review of current BIM research and its possible applications throughout the building life cycle in sport facilities [3–5]. Further, BIM not only helps to provide unique opportunities for energy efficiency decisions throughout all the life cycle stages and supply chains of a sport facility [11], but also contributes significantly to the achievement of carbon emission targets by integrating sport facilities with the achievements of the Sustainable

Development Goals [4]. Currently, BIM as a technology and approach used in developed countries is being gradually implemented in sport facilities in developing countries where the usage of BIM is increasing, which will play a key role in sport facilities across world in the future.

4.3. Building Life Cycle Stages

As shown in the results of Section 3.2.2, the integration of BIM, sport, and facilities currently concerns design, construction, operation and maintenance stages, of which the operation and maintenance stage receives the most attention.

The operation and maintenance stage is of most concern to current studies that focus on addressing the energy efficiency optimization in sport facilities [18,56,57]. Similarly, BIM has achieved great success in the architecture, engineering and construction (AEC) sector [58–60]. However, the AEC sector suffers from significant waste and inefficiencies in energy use currently [18], in which energy optimization and operation management of sport facilities is always a hot topic. In the context of sustainable architecture and building, proposing and optimizing smart and effective solutions during the operation and maintenance stage is essential to addressing the sustainability and efficiency of sport facilities. Moreover, the use of BIM enhances design and manages sport facility projects throughout all stages of the building life cycle, allowing to manage and reduce operational costs [61]. In the future, research could focus on integrating BIM technologies to improve and enhance sport facilities in the operation and maintenance stage.

In the design stage of the building life cycle, the application of BIM technology has helped to address design challenges and improve design efficiency [62–64]. The integration of BIM models with decision-making tools solves the problem of difficult decisions in the design process [3]. In addition, BIM is a technology that can improve efficiency, collaboration, and performance in the building sector [65]. BIM tools facilitate the creation of superior designs that most traditional methods cannot achieve [66], in which efficient design tools assist the improvement of communication between team members during the design stage of a sport facility, thereby reducing the cost of design changes during on-site construction [53]. Further, cost estimation, one of the key processes in the design stage, particularly benefits from BIM in sport facility projects [67]. In the future, advanced BIM technology will enable better design decisions across disciplines.

As shown in Section 3.3.2, life cycle assessment is summarized as a scheme, which indicates the importance of life cycle assessment on the integration of BIM, sport, and facilities. In the life cycle assessment, although the application of waste water heat exchangers (WWHX) in sport facilities significantly improves heat utilization and reduces the environmental impact, economically unsustainable approaches are due to the high cost of implementing BIM across all the life cycle stages [68]. In addition, the benefit assessment of sport facilities is still a challenge for BIM worldwide. A subjective benefits assessment model for immature BIM stakeholders allows benefits assessment throughout all the life cycle stages for a sport facility project, in which the model provides a benchmark for assessing the benefits of BIM [69].

4.4. Sustainable Built Environment

As shown in Section 3.3.2, health and wellbeing and sustainable built environment are summarized as the two main schemes, which need to be focused on. The development of sport facilities is important to improve the physical activity and social wellbeing of people [70], as such the BIM-based criteria for site selection and urban structure must be of concern [71]. While the benefits of BIM implementation for sport facilities are well recognized [72], objectively measuring the benefits to stakeholders is complex and challenging. Currently, "low level of consultant experience", "low level of contractor experience", "shortage of construction materials", and "difficulty for contractors to finance projects " are the most critical delay factors to a sport facility project [73]. Although the absence of maintenance policy (AMP), ignorance of maintenance responsibility (IMR), and poor

infrastructure design (PID) limit the maintenance and management of sport facilities [74], the information integration, visualization, and positioning introduced by BAS-to-BIM integration technology effectively improves the quality and efficiency of operation and maintenance in sport facilities [54].

In addition, facility safety is an essential issue in sport facilities, for which the BIM-supported integrated safety-maintenance performance framework is a key tool for advanced maintenance and safety management of sport facilities, allowing collaborative safety-maintenance monitoring, control, and management of sport facilities [75]. Further, in the post-epidemic COVID-19 era, a BIM-based FM system collects and registers information through a digital format, avoiding contact between users or managers of the sport facility [55]. Moreover, intelligent renovation of sport facilities during design enhanced by BIM disassembly effectively improves green performance [76]. Interestingly, heritage building information modeling (HBIM) has been used in renovation and demolition, during which structural analysis and health monitoring (SHM) of heritage buildings and sport facilities cannot be done without the HBIM [77].

5. Conclusions

This paper adopts a quantitative research method to investigate the current research status, hotspots, emerging areas, development trends, and important directions on the integration of BIM, sport, and facilities from a quantitative perspective. This paper explores the integration of BIM, sport, and facilities from 1997 to 2022 (26 years), which conducts bibliometric analysis via keyword co-occurrence network visualization to analyze the current research status and hotspots using keyword co-occurrence overlay visualization to analyze the research development correlation and emerging technology areas; it explores the future research trends and important directions towards sustainable development through CiteSpace keyword and burst word analysis.

This paper has four main contributions: (1) In terms of research method, this paper is the first to employ a quantitative analysis via visual bibliometric tools, i.e., VOSviewer and CiteSpace software packages, for keyword co-occurrence analysis and to produce in-depth insight into the integration of BIM, sport, and facilities systematically through keyword network visualization mapping, which provides a reliable research method for future research. (2) In terms of research content, this paper attempts to explore the 26-year history (from 1997 to 2022) of the integration of BIM, sport, and facilities based on the WoSCC database via a quantitative analysis. (3) In terms of research technique, this paper compared the results of keyword co-occurrence analysis from bibliometric analysis tools, i.e., VOSviewer software and CiteSpace software, to ensure credibility of the research findings by cross-corroboration checking between the above two software packages.

The main findings of this paper are that the hot keywords on the integration of BIM, sport, and facilities are mainly focused on BIM, facility management, framework, management, sport, construction, and design. Moreover, over the past 26 years (from 1997 to 2022), hot keywords for each year have been revealed through keyword co-occurrence overlay visualization analysis and identified in five schemes, i.e., life cycle assessment, emerging technology, behavior and sport, health and wellbeing, and sustainable built environment. Furthermore, the application of deep learning, IoT, and immersive experience technologies are current hot topics, which could provide more innovative breakthroughs to the integration of BIM, sport, and facilities in the future. However, the efficiency of the digitalization process of sport facilities in a low level, and high energy consumption and high occupancy rate of sport facilities need to be addressed. Hence, sustainable development research (e.g., health and wellbeing) on the integration of BIM, sport, and facilities has great research potential.

This paper has limitations, as "BIM" has various terms (e.g., building information model, and building information modeling) in different sectors and fields, resulting in a shortage of keyword terms in the search. Additionally, the bibliometric tools VOSviewer and CiteSpace software require manual merging of synonymous keywords for more accu-

rate results when performing keyword co-occurrence analysis, which may lead to slight bias in data analysis. Further, this paper employed the WoS database for the data collection rather than other databases that may obtain other relevant studies, such as the Engineering Index Compendex (EI) [78]. As such, future research could consider the use of other databases such as EI, Scopus, and Science Direct to extend the scope of research on the integration of BIM, sport, and facilities, and to check the value and potential of advanced BIM technologies in addressing challenges in practical applications through empirical research. In the future, it is necessary to accelerate the process of BIM technology application in sport facilities to enhance efficiency, collaboration, and performance. Meanwhile, the sport facility energy efficiency needs to be improved to achieve environmental protection and sustainable development. Moreover, future research could have a more comprehensive, multidisciplinary, and interdisciplinary mindset that delves into the future of the metaverse and Web 3.0, which incorporates the promotion of health and wellbeing consistent with the world Sustainable Development Goals.

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