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Article

Construction 4.0, Industry 4.0, and Building Information Modeling (BIM) for Sustainable Building Development within the Smart City

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Abstract: At present, the smart city offers the most desired state of urban development, encompassing, as it does, the concept of sustainable development. The creation of a smart city is closely associated with upgrading the construction industry to encompass many emerging concepts and technologies, such as Construction 4.0, with its roots in Industry 4.0, and the deployment of building information modeling (BIM) as an essential tool for the construction industry. Therefore, this paper aims to explore the current state of the art and development trajectory of the multidisciplinary integration of Construction 4.0, Industry 4.0, BIM, and sustainable construction in the context of the smart city. It is the first attempt in the literature to use both macro-quantitative analysis and micro-qualitative analysis methods to investigate this multidisciplinary research topic. By using the visual bibliometric tool, VOSviewer, and based on macro keyword co-occurrence, this paper is the first to reveal the five keyword-constructed schemes, research hotspots, and development trends of the smart city, Construction 4.0, Industry 4.0, BIM, and sustainable construction, from 2014 to 2021 (a period of eight years). Additionally, the top 11 productive subject areas have been identified with the help of VOSviewer software keyword-clustering analysis and application. Furthermore, the whole-building life cycle is considered as an aid to identifying research gaps and trends, providing suggestions for future research with the assistance of an upgraded version of BIM, namely, city information modeling (CIM) and the future integration of Industry 5.0 and Construction 5.0, or even of Industry Metaverse with Construction Metaverse.

Keywords: smart city; Construction 4.0; Industry 4.0; building information modeling (BIM); sustainable building; Construction Metaverse; life cycle stage; keyword co-occurrence; visualization; bibliometric; VOSviewer

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1. Introduction

With the move toward massive urbanization across the world, the smart city is widely studied as the next stage of urban development [1]. The concept of the "smart city" was first introduced in 1994, when the potential was recognized of digital servers to improve the development and management of cities [2]. Since the concept of the "smart city" was introduced, almost all forms of innovative and sustainable urban planning, development, operation, and management based on technology have been closely related to the concept of the smart city [3]. The concept of the smart city has continued to evolve, but scholars have defined it according to various aspects. Ramaprasad et al. [4] point out that most research in the field of information technology focuses on the definition of the smart city in terms of the electronic functions provided to citizens, wherein sustainability and quality of life are central. A common definition is that the smart city is a well-defined geographical area in which highly developed technologies, such as information and communications technologies, logistics, and energy production, collectively cooperate to create benefits for its citizens in terms of well-being, inclusion and participation, environmental quality, and intelligent development, which is governed by a "well-defined pool of subjects" who can establish the rules and policies for the city government and the area's development [5]. The smart city is the basis for sustainable development. The modern smart city is particularly concerned with sustainable and efficient solutions for energy management, transport, healthcare, and governance to meet people's needs for a good quality of life [6]. Most smart cities have four main attributes, namely, sustainability, quality of life, urbanization, and smartness [7]. However, studies have confirmed that the policies of a smart city are highly technocentric, but current smart-city practices fail to incorporate a progressive and authentic overall sustainable development goal [8].

Although the construction industry is changing its processes and working methods to meet the requirements of sustainability in the context of a smart city (e.g., energy saving, waste reduction, ensuring a quality building, and a smart indoor environment), construction is still considered to be a traditional industry that is reluctant to use new technologies and is inefficient [9]. However, recent advances in technology have enabled the construction industry to achieve rapid growth and higher profits, resulting in a new concept, "Construction 4.0" [10], a concept that is derived from the theoretical framework of a broader concept, "Industry 4.0", also known as the fourth industrial revolution. Industry 4.0, based on concepts and technologies that include cyber-physical systems, the Internet of Things (IoT), and the internet of services, is part of a high-tech strategy launched by Germany in 2011 [11]. It is also based on the perpetual communication of technology and people via the internet that allows a continuous interaction and exchange of information between humans, humans and machines, and the machines themselves [12]. In the year 2014, Industry 4.0 was first paired with construction in an article on three-dimensional (3D) printing prototypes [13]. Subsequently, the construction industry introduced the concept of Construction 4.0 in 2016 [14], hailing it as a new era for the sector, in line with Industry 4.0. In some studies [14,15], Construction 4.0 exists merely as a specific application of Industry 4.0. As the concept of Construction 4.0 is very new, there has not been a very clear definition and scope of application since then. Sacks et al. [16] further defined Construction 4.0 as a framework that includes the extensive use of building information modeling (BIM) for design and construction, the industrial production of prefabricated components and modules, the use of cyber-physical systems where possible, including in the field of robotics, digital monitoring of the supply chain and work on construction sites, and data analytics such as big data, artificial intelligence, cloud computing, and blockchain.

The value of technologies such as BIM, cyber-physical systems, sensors, the IoT, artificial intelligence, and big data for the Construction 4.0 and Industry 4.0 concepts have been studied to identify the goals of sustainable development [17–19]. BIM is the process of developing an intelligent model that links the architecture, engineering, and construction (AEC) industries to enable efficient data exchange throughout a project's life cycle [20]. The integration of BIM into processes related to building design/construction/operation is an approach that is consistent with sustainability characteristics in the built environment [21]. Integrated approaches to assessing the life cycle of a building using BIM have been developed in Asia and Europe [22]. Currently, BIM has been employed by the construction industry in many European countries, which facilitates the development of policies for the digital transformation of the built environment [23,24]. However, sustainable development practices via BIM remain relatively immature and inconsistent. The limited research published on the subject has focused on addressing the workflow barriers to green projects, with potential improvements using current BIM functionality [25]. Visualization-assisted functionalities, such as management, intelligent construction, simulation, and analysis are popular among BIM practitioners [26]. However, currently, independently functioning technology and weak approaches to information integration and management may limit the use of smart BIM environments [27]. The innovations of BIM mainly focus on the functionalities of BIM from a technical perspective, while the innovative capabilities of BIM remain under-researched and studies exhibit a scattered research focus [28].

Currently, there is the potential for Construction 4.0, Industry 4.0, and BIM to contribute to sustainable building development. However, a cross-disciplinary integration of Construction 4.0, Industry 4.0, and BIM is still in its infancy and few studies have focused on the impact of the integration for sustainable building in the context of the smart city. Therefore, this paper aims to explore the relationships between Construction 4.0, Industry 4.0, and BIM in terms of sustainable building in the context of a smart city, offering a way to move toward the goal of sustainable development. This research identifies the current state of research and the future trends of integration of Construction 4.0, Industry 4.0, and BIM regarding sustainable construction in the context of a smart city. In addition, this paper signposts the potential future directions in the field of sustainable building: the integration of sustainable construction with Industry 5.0 and Construction 5.0, and even with the Industry Metaverse and Construction Metaverse.

2. Method

The research method used in this paper is that of bibliometric analysis, which includes a macro-quantitative analysis and a follow-up micro-qualitative analysis of the literature article data, in terms of the year, sources, keywords, research directions, research methods, research themes, research contents, application areas, and future trends. Bibliometric analysis elicits objective and straightforward results and minimizes subjective judgments by authors [29]; it has been widely used to analyze published literature and assess research trends in specific fields [30]. It allows general conclusions to be drawn about the specific areas of research, thus avoiding the need for a thorough review of large volumes of literature studies [31]. Studies have investigated Industry 4.0, Construction 4.0, BIM, and sustainable building, using bibliometrics that contribute to the development of these areas [32,33]. Due to the multidisciplinary integration of Construction 4.0, Industry 4.0, BIM, and sustainable building in this study, the volume of relevant literature, and uncertainty regarding future directions and trends in the research fields, bibliometric analysis is the best method for our investigation.

For the macro-quantitative analysis of the literature, this paper obtained relevant articles from the Web of Science Core Collection (WoSCC) and imported them into VOSviewer software for keyword visualization. The Web of Science (WoS) is one of the world's most authoritative scientific citation indexing databases [34]. The WoSCC's rigorous indexing procedures ensure that the database content is of high quality and capable of producing significant scientific impact [35]. VOSviewer software is a commonly used tool in quantitative scientific analysis [36] and is based on the visualization of a similarity algorithm to easily visualize the relationships between data extracted from WoSCC [37]. As such, VOSviewer software is adopted to assist in achieving a comprehensive understanding of the current status and future emerging research hotspots regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city. In the micro-qualitative analysis, this paper presents a review regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, categorized by multidisciplinary orientation and building life-stages.

The flow diagram of the research method is shown in Figure 1, and is divided into five stages. The first is identifying the research target, searching for articles in the field of smart city, Industry 4.0, Construction 4.0, BIM, and sustainable building research, collecting and collating the relevant data. As the definition of Construction 4.0 is still in constant evolution and is influenced by its parent concept, Industry 4.0 [10], Industry 4.0 is included in the search. Since the concept of Construction 4.0 was introduced in the year 2016 [14], and the association between the construction industry and Industry 4.0 was made in 2014 [13], the publication-year range is from 2014 to 2021. The second stage is using bar charts and tables to record the number of publications per year and the top ten most productive sources of the relevant publications, while the third is performing a keyword co-occurrence analysis of articles through VOSviewer software, including network visualization, high-frequency keywords, overlay visualization, and hotspot research. The fourth stage is performing multi-disciplinary research, based on the classification of "research areas" in the WoS database, and selecting the most productive disciplines for keyword co-occurrence analysis, and the fifth is carrying out an analysis of building life-cycle stages and application areas in the context of Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city.

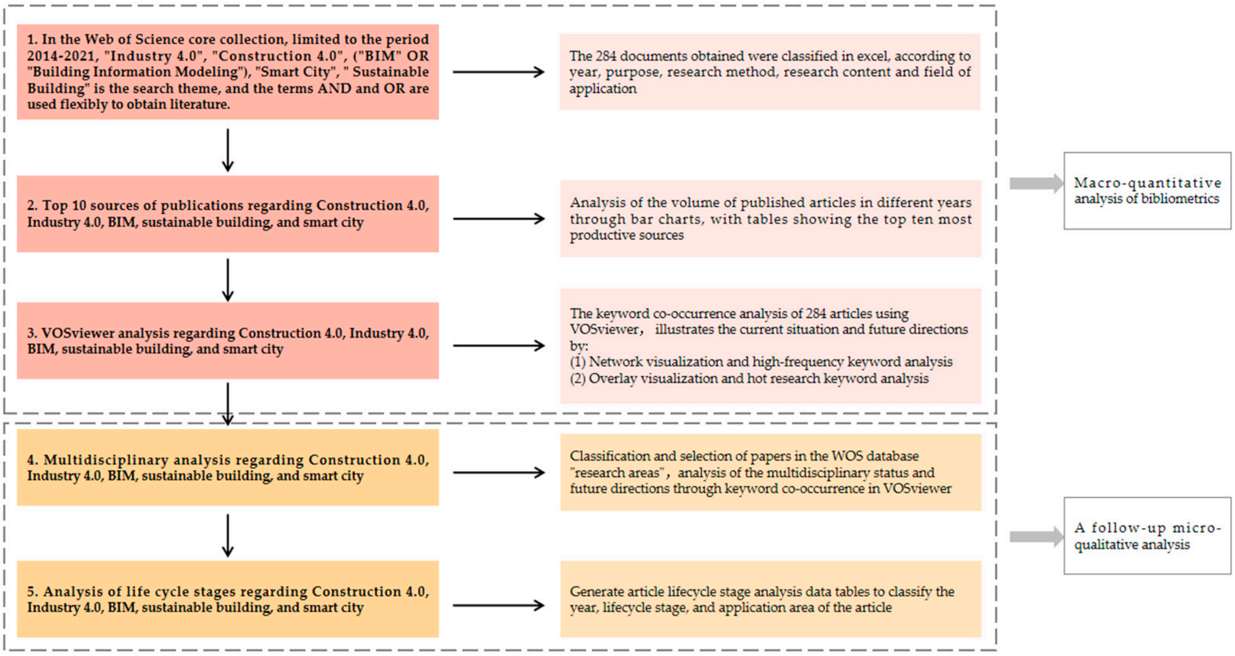


Figure 1. Flow diagram of the research methodology.

3. Results

The data collected for this paper is from the WoSCC database, from which this study has obtained the most relevant literature data by using the keywords: "Smart City", "Industry 4.0", "Construction 4.0", "BIM", "Building Information Modeling" and "Sustainable Building", as shown in Table 1. The keyword search led to a total of 284 articles within an eight-year period, i.e., from 2014 to 2021.

Table 1. Results of the data collection process for the most relevant literature data from the WoSCC database (generated by the authors).

Source	Web of Science Core Collection
Citation	SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH, CCR-EXPANDED, IC
Search steps	#1 = (TS = (("BIM" or "Building Information Modeling") and ("Industry 4.0 " or "Construction 4.0 ") and ("Smart City" or "Sustainable Building"))) #2 = (TS = (("Industry 4.0 "or "Construction 4.0 ") and ("Smart City" or "Sustainable Building"))) #3 = (TS = (("Industry 4.0 "or "Construction 4.0 ") and ("BIM" or "Building Information Modeling"))) #4 = (TS = (("Smart City" or "Sustainable Building") and ("BIM" or "Building Information Modeling"))) #5 = #4 OR #3 OR #2 OR #1
Timespan	Year 2014–2021
Qualified Records	284
Source	Web of Science Core Collection

3.1. Macro-Quantitative Analysis Regarding Construction 4.0, Industry 4.0, BIM, Sustainable Building, and Smart City

3.1.1. General Information

The number of publications is an important indicator of scientific research trends. As shown in Figure 2, published articles regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city have increased year by year. The earliest articles on the subject were published in the year 2014, with only three articles. This subject entered a period of development in subsequent years. The number of articles published in the year 2019 had doubled compared to 2018. In the three years thereafter, the number of articles remained above 60 per year, with 73 articles in the year 2021 setting an increasing trajectory for the near future.

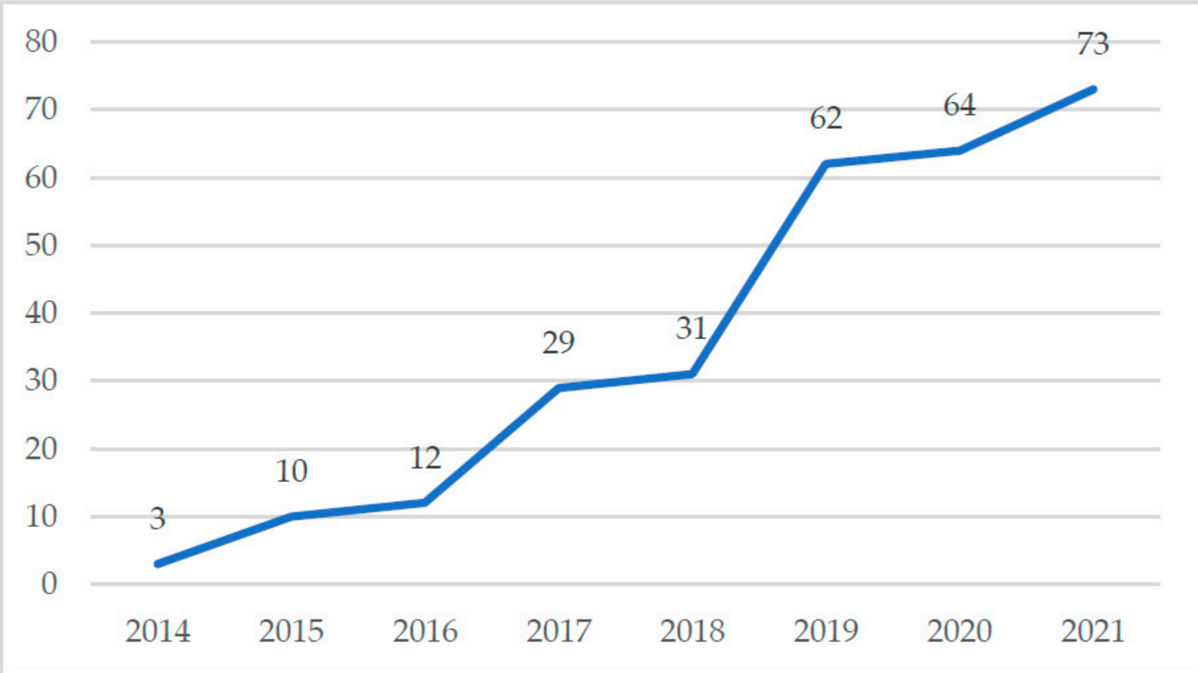


Figure 2. Number of articles published each year on Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city from the year 2014 to 2021 in the WoSCC database (generated by the authors).

In addition, the top 10 most productive sources for the subject are listed in Table 2. Among the sources, Sustainability is the most productive journal with 23 articles, followed by Automation in Construction, Buildings, IEEE Access, Applied Sciences Basel, IOP Conference Series Materials Science and Engineering, Advanced Engineering Informatics, the Journal of Building Engineering, the Journal of Cleaner Production, and Sensors. To be part of the top 10 most productive sources, they require at least five articles to have been published. The top 10 most productive sources play a leading role in establishing the foundation for research regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city. The year-on-year growth in the published literature indicates that academic efforts have been made to apply the concepts, technologies, and models of Construction 4.0, Industry 4.0, and BIM to the development of sustainable construction.

Table 2. Top 10 most productive sources regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and smart city articles from the year 2014 to 2021 in the WoSCC database (generated by the authors).

Ranking	Source Titles	Number of Publications
Top1	Sustainability	23
Top2	Automation in Construction	13
Top3	Buildings	11
Top4	IEEE Access	7
Top5	Applied Sciences Basel	6
Top6	IOP Conference Series Materials Science and Engineering	6
Top7	Advanced Engineering Informatics	5

Table 2. *Cont.*

Ranking	Source Titles	Number of Publications
Top8	Journal of Building Engineering	5
Top9	Journal of Cleaner Production	5
Top10	Sensors	5

3.1.2. VOSviewer Software Analysis

VOSviewer software has been used to conduct a macro-quantitative analysis for the 284 articles obtained in the data collection, as shown in Table 1, which includes a keyword co-occurrence network visualization, high-frequency keyword analysis, overlay visualization, and hot research keyword analysis.

1. Network Visualization

The 284 papers identified in the search were imported to conduct keyword co-occurrence analysis in the VOSviewer software (version 1.6.15) for network visualization, in which the threshold is set to 3 for keyword filtering and synonym merging. The result presents 113 keywords, forming eight different color clusters, i.e., green, dark blue, orange, light blue, purple, red, pink, and yellow, as shown in Figure 3. The size of the circular nodes indicates the number of keyword occurrences. The larger the node is, the more frequently that same keyword appears in different articles. The keyword "BIM" occupies the largest node and is at the center of Figure 3. The length of the line between two keywords indicates the similarity and relevance between the two topics, while the width of the line indicates the strength of the connection between them.

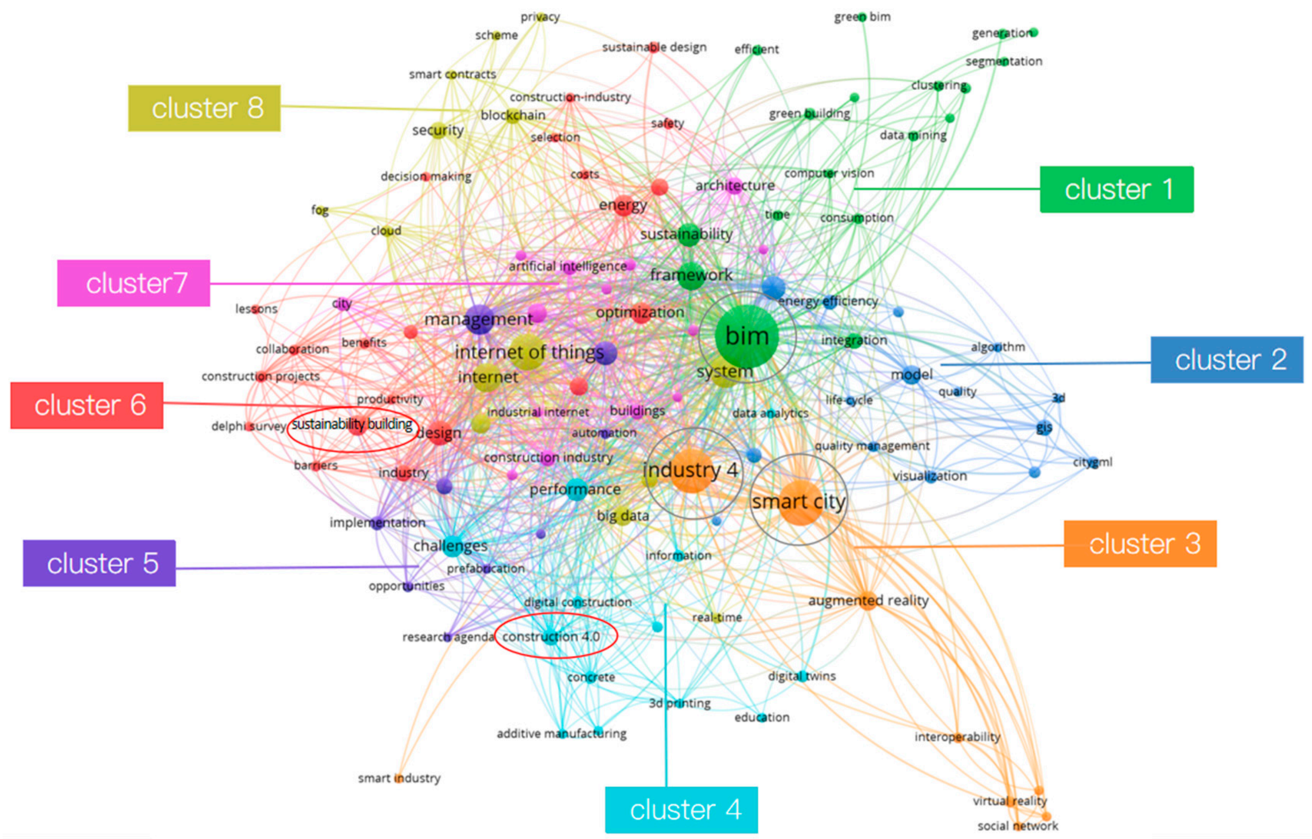


Figure 3. Keyword network visualization regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city from the year 2014 to 2021, created via VOSviewer software (generated by the authors).

Green Cluster 1, presenting 21 keywords, focuses on the application of BIM in sustainability, including the framework, integration, and green building. Dark Blue Cluster 2 (15 keywords) is mainly related to the topic of geoinformatics, including geographic information systems (GIS), CityGML, and sustainability management, including facilities management and quality management. Cluster 3, in orange (9 keywords), is associated with the smart city and Industry 4.0, including the technical requirements for achieving their goals via augmented reality, interoperability, virtual reality, cyber-physical systems, modularity, smart industry, and social networking. Cluster 4, in light blue (13 keywords), reflects the digital transformation of the construction industry, including concepts and technologies that are related to Construction 4.0, digital construction, digital twins (DTs), and 3D printing, which also emphasizes the impact of such technology on the environment and educational issues related to architecture. Purple Cluster 5 (9 keywords) concentrates on the management of the technical aspects while covering automation and prefabrication. Cluster 6 in red (21 keywords) focuses on building energy assessment, aiming at sustainable building design through life-cycle assessment (LCA) and addressing the challenge of energy optimization. Pink Cluster 7 (14 keywords) focuses on the future smart city and the sustainability of buildings, including artificial intelligence, along with the issues of human health and well-being. Cluster 8 (14 keywords), in yellow, features advanced technologies and systems, such as the IoT, blockchain, fog, and cloud, which are used to develop smart city projects and smart manufacturing.

As shown in Figure 3, the three keywords marked by grey circles, i.e., BIM, Industry 4.0, and the smart city, are highly associated with each other and appear frequently, occupying the center of Figure 3. The two keywords in red ovals, i.e., Construction 4.0 and sustainable building, are smaller nodes at the edge of the diagram without being closely related to the three grey-circled keywords. Therefore, keyword network visualizations on the themes of Construction 4.0 and sustainable building are worthy of attention and analysis.

Figure 4 depicts a keyword network visualization on the theme of Construction 4.0, which mainly includes digitalization, design, and management, as applied to sustainable development. Among these themes, links between Construction 4.0 and technologies, such as 3D printing, big data, the IoT, and augmented reality are apparent. However, Construction 4.0 fails to form effective links with the smart city. Figure 5 depicts keywords for interlinking sustainable building and other areas, focusing on energy, building performance optimization, and environmental impact. However, sustainable construction is only linked to BIM, and the field has established no links to the smart city, Construction 4.0, and Industry 4.0.

The clustering keywords that are most closely related to Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city are BIM, smart city, Industry 4.0, IoT, system, management, internet, framework, design, construction, sustainability, technologies, performance, challenges, energy, and optimization. Table 3 shows the high-frequency keywords identified from the VOSviewer software keyword co-occurrence analysis, which specifies at least 15 keyword occurrences, also including color representation, clusters, the frequency of occurrences, and the total link strengths to the keywords.

2. Overlay Visualization

The temporal overlay figure can reflect popular topics in the research according to year and can also help to reveal future research trends. Figure 6 shows the keyword co-occurrence overlay network diagram regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, with colors ranging from dark blue to yellow indicating the period from the year 2014 to 2021. The emergence years for the different keywords are associated with the color of the circle.

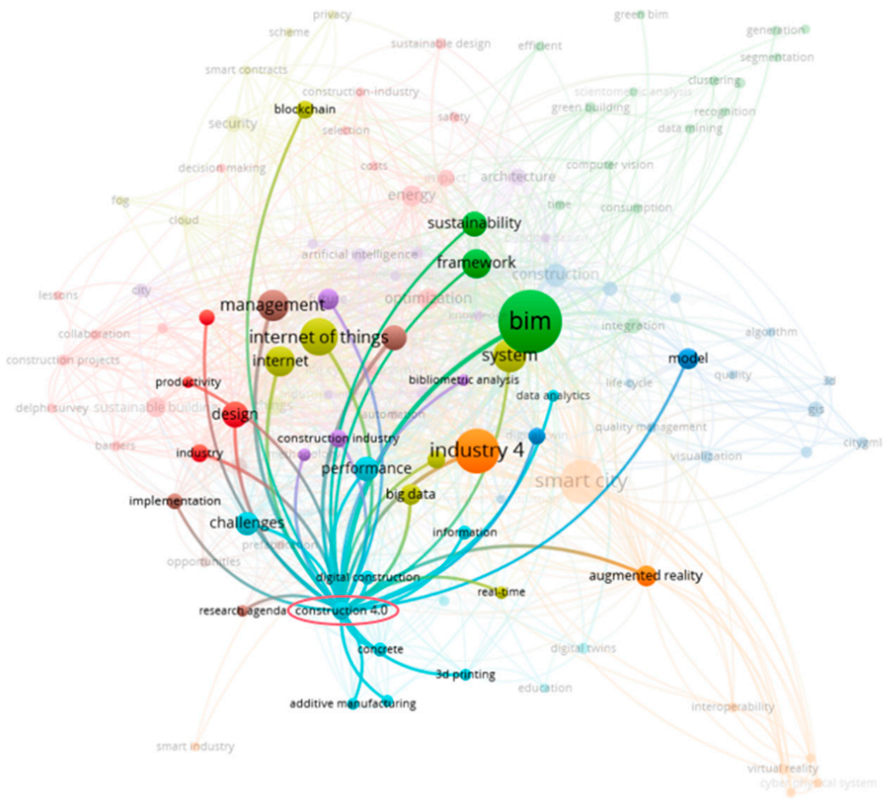


Figure 4. Keyword network visualization of Construction 4.0, created via VOSviewer software (generated by the authors).

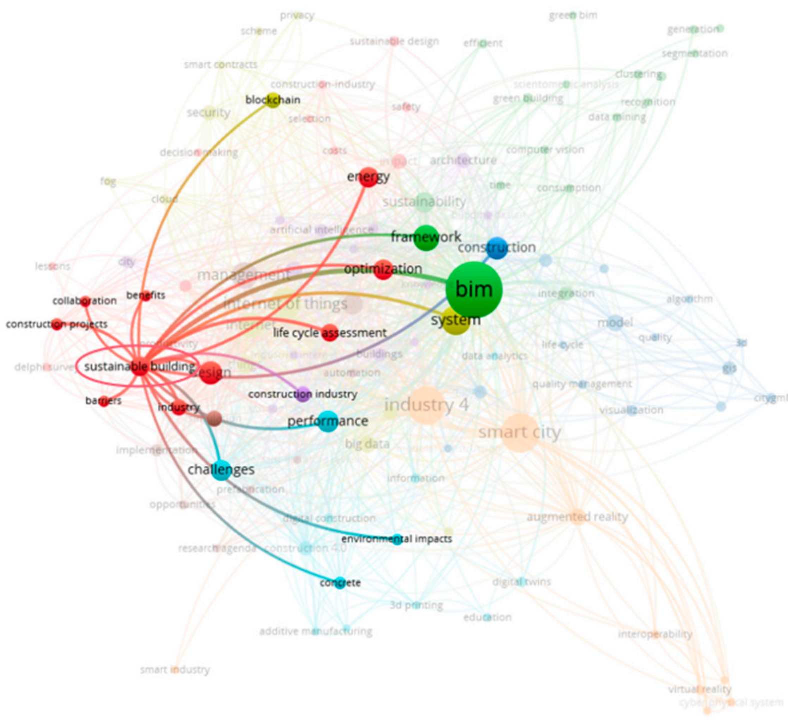


Figure 5. Keyword network visualization of sustainable building, created via VOSviewer software (generated by the authors).

Table 3. High-frequency keywords regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, via the VOSviewer software (generated by the authors).

Color [1]	Cluster	Keyword	Occurrences	Total Link Strength
	2	BIM	128	518
	7	smart city	65	244
	7	Industry 4.0	64	289
	4	Internet of Things	43	229
	4	system	34	185
	8	management	30	184
	4	internet	27	166
	2	framework	25	164
	1	design	20	130
	3	construction	18	104
	2	sustainability	18	92
	8	technologies	18	116
	6	performance	17	110
	6	challenges	15	109
	1	energy	15	78
	1	optimization	15	94

[1] The colors in the table are in line with the colors from Figure 3.

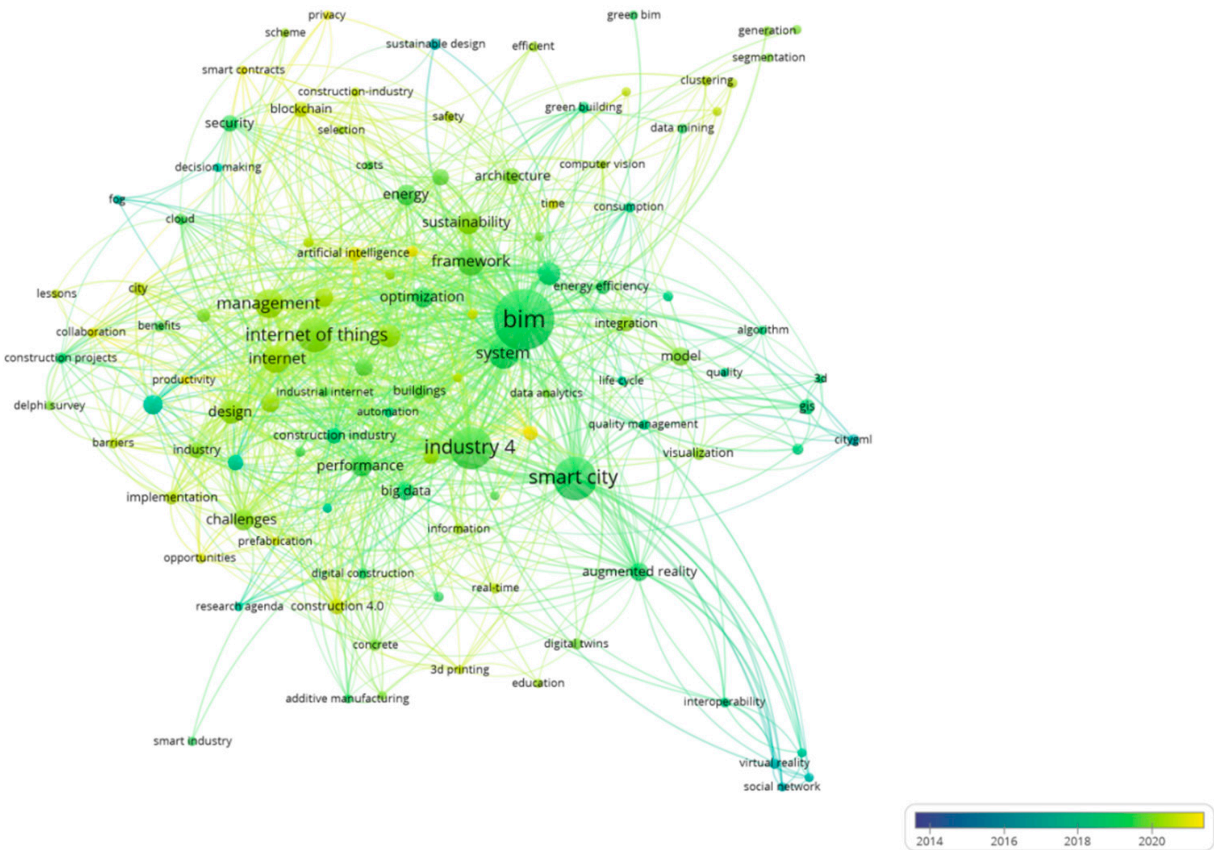


Figure 6. Keyword overlay visualization regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city from the year 2014 to 2021, created via VOSviewer software (generated by the authors).

As shown in Figure 6, the dark blue node representing 2014 to 2015 does not appear, indicating that the subject of Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city is in its infancy during these two years. The first keywords, such as "virtual 3D city modeling", and "sustainable design", appeared in the year 2016, indicating that the topic had begun to attract attention. Most of the nodes in Figure 6 are green and yellow-green, affirming that most of the keywords emerged from 2018 to 2020, a period of rapid development in the field. With the emergence of the smart city and the digital transformation of the construction industry, green building and sustainability have become hot topics in which big data, augmented reality, IoT, blockchain, cyber-physical systems, artificial intelligence, and other emerging technologies are widely implemented. The yellow part of Figure 6 reveals the two latest keywords in 2021, i.e., DTs and productivity, which indicates that the research on Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city has adopted digital twin technologies, while productivity remains important in the field.

As shown in Table 4, the research hotspots regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city from the year 2014 to 2021, have been summarized as the following five schemes:

(1) Cutting-edge concept: smart city, Industry 4.0, and Construction 4.0;
(2) Building sustainable development: sustainable design, sustainable building, green building, and sustainability;
(3) Factors influencing development: technologies, performance, and productivity;
(4) Activity for building the life cycle: simulation, decision-making, design, implementation, management, and consumption;
(5) Emerging technology and an integrated model: virtual reality, cyber-physical systems, fog, big data, augmented reality, automation, the Internet of Things, the internet, blockchain, artificial intelligence, DTs, things, BIM, CityGML, GIS, and industrial infrastructure classes.

Table 4. Popular research keywords regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city in the past eight years (the years 2014 to 2021) via overlay visualization using VOSviewer software (generated by the authors).

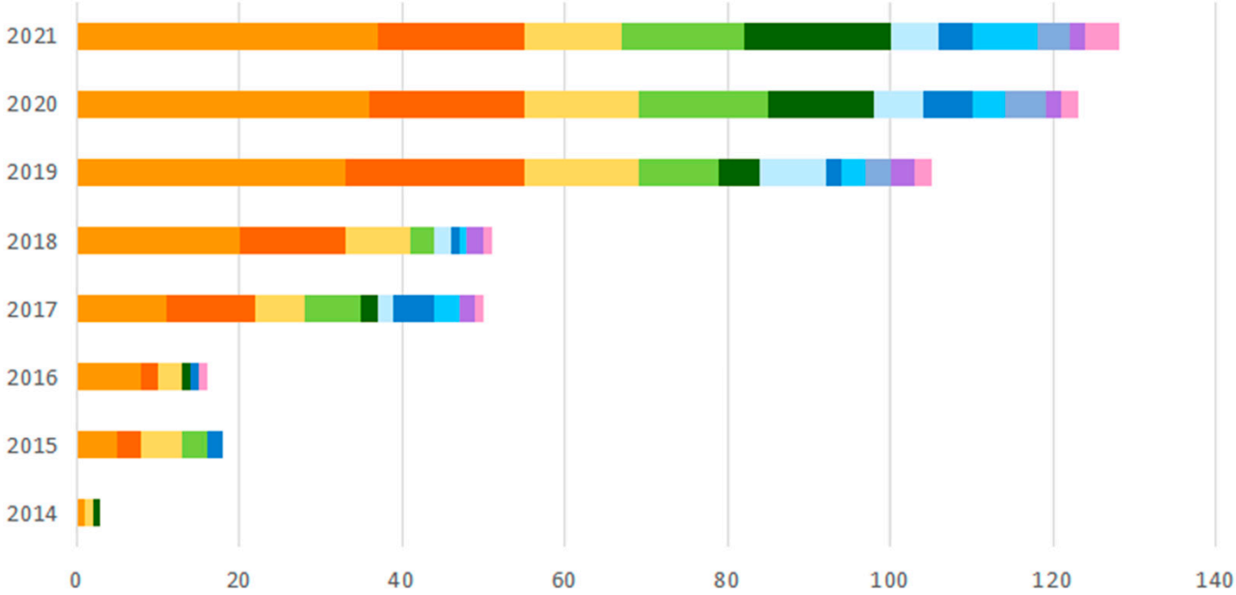
Year	Color [1]	Keyword
2016		CityGML, sustainable design, virtual reality, social network
2017		sustainable building, simulation, cyber-physical systems, decision-making, fog
2018		construction, big data, augmented reality, construction industry, GIS, construction projects, green building, industry foundation classes, automation, consumption
2019		BIM, smart city, Industry 4.0, Internet of Things, system, framework, design, sustainability, technologies, performance
2020		management, internet, future, things, blockchain, Construction 4.0, artificial intelligence, city, implementation
2021		DTs, productivity

[1] The color range in the table is in line with the color range used in Figure 6.

3.2. A Follow-Up Micro-Qualitative Analysis Regarding Construction 4.0, Industry 4.0, BIM, Sustainable Building, and Smart City

3.2.1. Classification and Selection of the Influential Subject Areas

The minimum number of records was set to 10, employing the WoS database classification of "research areas" to find influential research directions regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, resulting in 284 articles that were automatically divided into 11 subject areas to form valid keyword co-occurrences, namely, Engineering (151 articles), Computer Science (88 articles), Construction Building Technology (63 articles), Science Technology Other Topics (54 articles), Environmental Sciences Ecology (40 articles), Telecommunications (24 articles), Energy Fuels (21 articles), Business Economics (19 articles), Chemistry (12 articles), Automation Control Systems (11 articles), and Materials Science (11 articles), as shown in Figure 7. Engineering exhibits the highest number of publications and maintains the highest trend, followed by Computer Science, with its first article published in 2015. Chemistry is the latest area to be developed, starting in 2019, but this was faster than Automation Control Systems and Materials Science. Furthermore, this research imported articles from the 11 subject areas into the VOSviewer software, modeling the findings to reveal the current state of multidisciplinary research and to identify the gaps and trends across disciplines.



Color	Research areas	2014	2015	2016	2017	2018	2019	2020	2021
	Engineering	1	5	8	11	20	33	36	37
	Computer Science	0	3	2	11	13	22	19	18
	Construction Building Technology	1	5	3	6	8	14	14	12
	Science Technology Other TopicsS	0	3	0	7	3	10	16	15
	Environmental Sciences Ecology	1	0	1	2	0	5	13	18
	Telecommunications	0	0	0	2	2	8	6	6
	Energy Fuels	0	2	1	5	1	2	6	4
	Business Economics	0	0	0	3	1	3	4	8
	Chemistry	0	0	0	0	0	3	5	4
	Automation Control Systems	0	0	0	2	2	3	2	2
	Materials Science	0	0	1	1	1	2	2	4

Figure 7. The number of articles published between 2014 and 2021 in different years, divided into eleven subject areas (generated by the authors).

3.2.2. Research Overview of the 11 Subject Areas

1. Engineering

The articles in the Engineering area regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city were imported into the VOSviewer software. a threshold of 3 was set to generate a keyword co-occurrence map, as shown in Figure 8. BIM occupies the center of Figure 8, with other keywords closely linked to the center, such as smart city, technologies, health, optimization, IoT, management, and system, which are shown mainly in yellow, light blue, red, and dark blue areas that can be summarized as Smart City and Technology, BIM, Industry 4.0 and IoT, and Management and System.

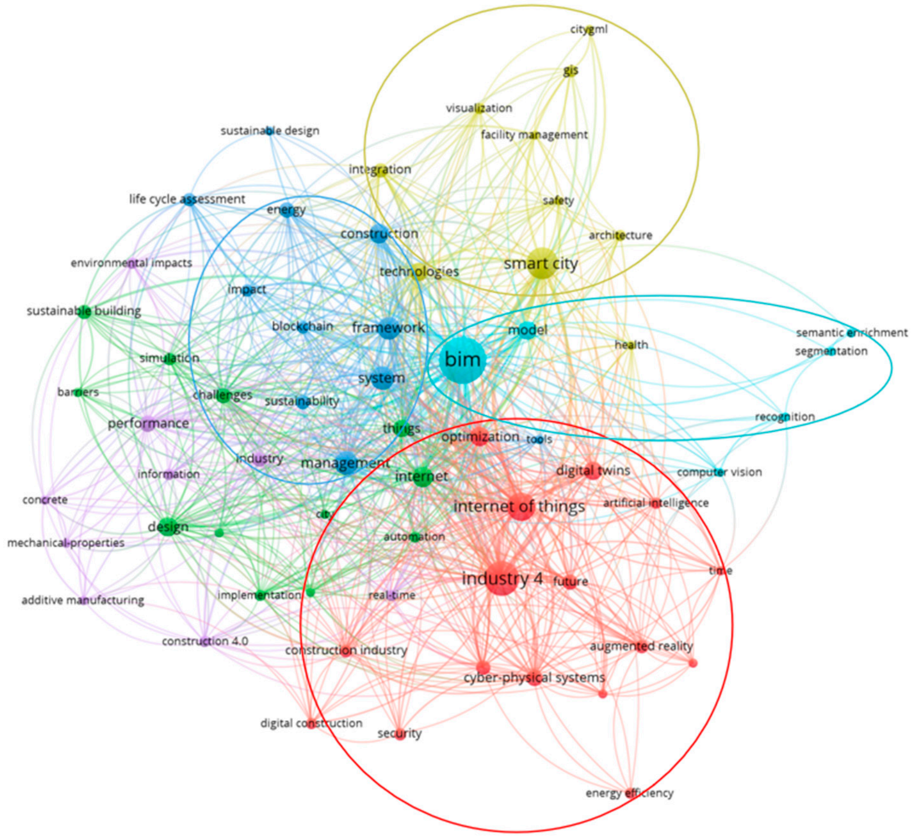


Figure 8. Keyword visualization of articles published between 2014 and 2021 in the field of Engineering in terms of Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

As shown in Figure 8, the keywords in the yellow area that are closely related to "Smart City and Technology" are health and safety. The smart city aims to improve the efficiency and safety of its urban infrastructure, as well as the quality of life of its citizens [38]. In terms of the quality of life of the city's citizens, a focus on the health and well-being of people who are living in buildings will lead to significant changes in the decision-making process for sustainable building design and operation. On the one hand, the use of wellbeing-centered LCAs for decision-making by designers and operators can improve energy efficiency regarding human well-being and its socioeconomic aspects [39]. On the other hand, occupational safety in construction activities also needs attention, to which end BIM has the potential to improve construction safety. However, more practical BIM applications are needed, especially focusing on safety training and education, the use of BIM to enhance the safety climate and resilience, and the development of quantitative risk analysis to better support safety management [40]. In terms of smart city security, data security is a necessary guarantee for many scenarios, such as a large number of nodes that share data across networks [41]. Furthermore, cybersecurity is one of the future research opportunities for digital supply chains and procurement in built environments [42].

In the light blue cluster, the connections among BIM, semantic enrichment, segmentation, and recognition are still developing, which may become new research directions in the future. A semantic 3D building model for construction solutions benefits smart city management [43]. As data sources, algorithms, and computing power continue to increase, BIM-based city information modeling (CIM) assists in exploring semantic enrichment [44]. On the one hand, the semantic alignment method-based multi-model optimization and architectural design knowledge improve the effectiveness of a 3D point cloud-reconstructed BIM [45]. This derivative-free optimization-based method automatically generates a semantically rich as-built BIM from complex scenes using 3D point clouds [46]. The dynamic logic-based method for clustering and identifying objects in laser-scanned point clouds aids in creating a theoretical basis for many new application algorithms and software for BIM and smart urban environments, which addresses various problems related to the extraction of semantically rich information from non-traditional types of digital data [47]. In addition, a reliance on BIM, data mining, and semantic data modeling enable researchers to create a performance-oriented design decision-supporting system, which will inform future design decisions [48].

In the red area of "Industry 4.0 and IoT", the keywords closely related to BIM are optimization, DTs, and artificial intelligence. The area focuses on the development of Industry 4.0 and its key technologies within the engineering discipline. "Smart city and smart infrastructure" comprises one of the five pillars of Industry 4.0 [49], in which field the IoT is widely used, and DTs and artificial intelligence are likewise emerging during its development. In terms of IoT applications, the use of 5G-assisted industrial IoT provides privacy protection and energy resource optimization for a smart city infrastructure [50]. IoT-based public lighting applications can improve public lighting management and provide big data platforms to help turn urban centers into smart cities [51]. However, the use of DTs in the smart city is not yet as popular a topic [52]. In the area of DTs for the architecture, engineering, construction, operations, and facilities management (AECO-FM) industries, topics such as "virtual-physical building integration", "building life-cycle management", and "information-integrated production" are widely studied, while "information-based predictive management" and "virtual-based information utilization" need to be explored at greater depth [53]. Interestingly, Metaverse, a virtual world that is parallel to reality, also uses DT technology, which is an important tool for building a smart city. The DT assists in digitally mapping the physical world and can comprehensively capture urban data, such as people, vehicles, objects, and space, to form a visible, controllable, and manageable DT city. It also facilitates improvement in the efficiency of resource utilization, optimizes urban management and services, and enriches the quality of life of its citizens [54]. The most widely used artificial intelligence methods in the AEC industry are genetic algorithms, neural networks, fuzzy logic, fuzzy sets, and machine learning [55]. An adaptive approach to mining the textual content of a corpus from literature studies related to the AEC and artificial intelligence industry has been developed to form an integrated artificial intelligence platform in the AEC industry (AEC—artificial intelligence Industry 4.0) [56]. Artificial intelligence is likewise one of the supporting technologies for Industry 5.0, in which the widespread implementation of Industry 4.0 lays down the fundamentals for the concept of Industry 5.0, which merges physical and virtual space to solve not only production problems but also social problems. The synergy between humans and autonomous machines means that artificial intelligence will permeate human life to enhance human capabilities in solving social problems [57].

In the dark blue area, frameworks, blockchain, sustainability, and "Management and System" are closely related. The keywords in this area are mentioned more often alongside the central term, BIM, focusing on the wide range of BIM applications in sustainable construction projects. In BIM applications, design optimization and the reduction of material requirements are important issues to consider in sustainable construction [58]. The extension component of BIM, SimulEICon, is specifically designed to help in the decision-making process during the design phase of sustainable construction projects, integrating economic and environmental impact analysis [59]. In addition, the integration of BIM with other methods/technologies can also support sustainable building projects. The implementation of BIM and blockchain can support information management [60]. BIM and LCA integration is the best procedure by which to achieve sustainable development and environmental protection [61]. In an integrated framework for mathematical optimization, BIM and LCA facilitate decision-making for energy-efficient buildings [62]. Furthermore, BIM is one of the most effective methods by which to determine the appropriate building orientation and envelope [63] by which south-facing buildings can reduce energy consumption, using double-glazing and low emissivity coated glass, while the installation of blinds is the best way to provide shading [64]. Interestingly, a BIM-based water conservation framework can optimize traditional water conservation measures in sustainable building design and construction management [65].

2. Computer Science

Figure 9 shows the keyword co-occurrence network for the Computer Science subject area regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city. The keyword Industry 4.0 is at the center of Figure 9, with the IoT, internet, smart city, and cyber-physical systems surrounding it, mainly in the purple, green and red clusters. In the purple cluster, keywords other than Industry 4.0 are located at the peripheries of Figure 9. Industry 4.0 is more closely related to the green cluster and serves as a bridge between the virtual reality technologies populating the red cluster and the other clusters.

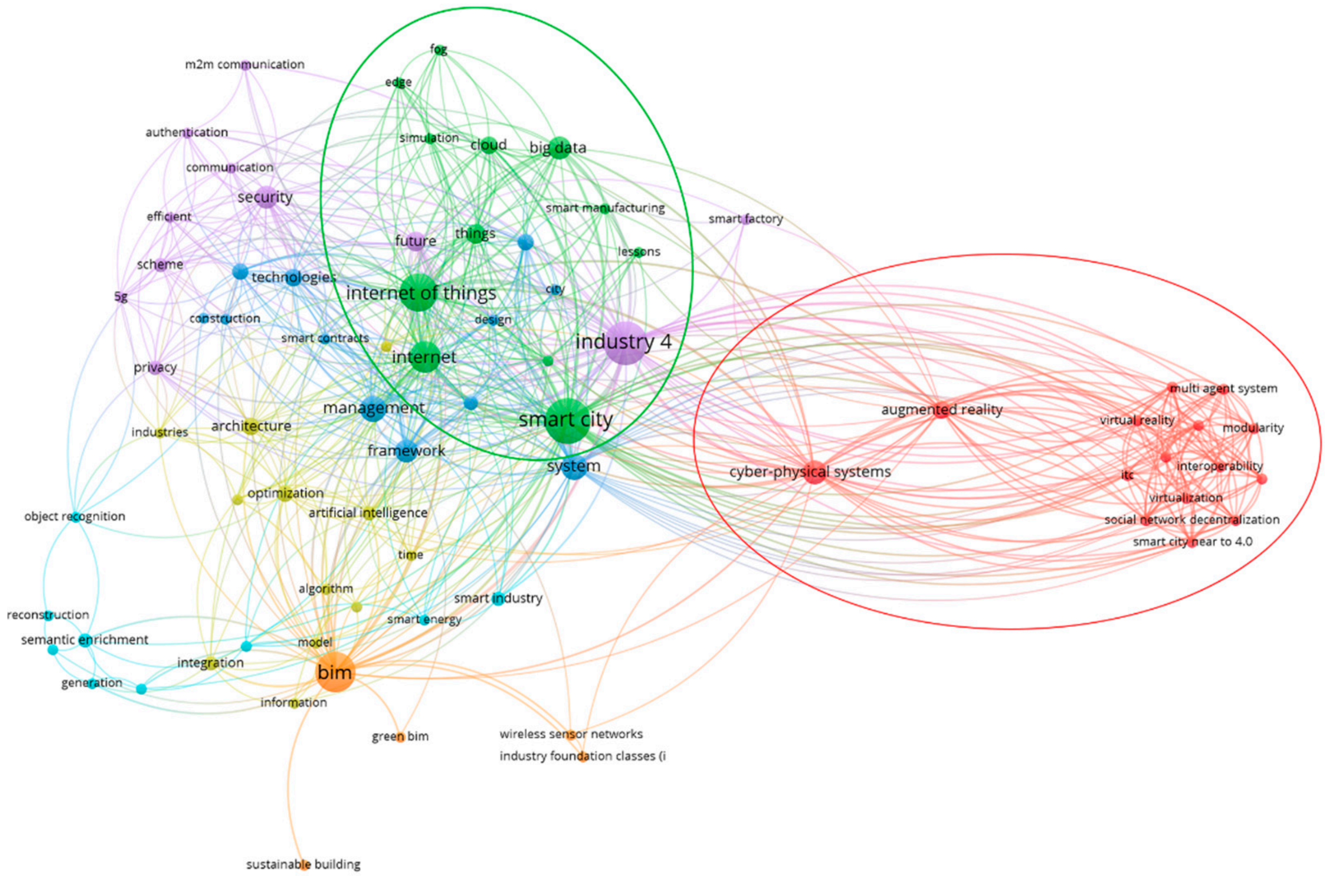


Figure 9. Keyword visualization of articles published between 2014 and 2021 in the field of computer science on Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

The green cluster where the smart city node is located has 12 keywords that include emerging technologies, such as the IoT, big data, and DTs. The cluster is also associated with the internet and smart manufacturing. The concept and model of the smart city are based on the new urbanization and technologies of Industry 4.0 (e.g., IoT, cloud computing, cyber-physical systems, and big data) for planning, building, managing, integrating industrialization, informatization, urban modernization, and sustainable development [66]. Among these, IoT, additive manufacturing, 3D printing, and big data occupy increasingly important positions in subsequent years [67]. In sustainable building design, sensors can be used to measure information about changes in the built environment, such as temperature, energy consumption, or building utilization. The IoT can increase the number of information sources from which data can be collected, which is a challenging task in terms of storing data from different sensor systems [68]. At the same time, if the continuity of data flow and communication between IoT devices and data-driven applications is interrupted or lost, this can lead to equipment or system failures or unexpected behaviors [69]. However, there is a possible method by which to fill in the values missing from the signals sent by IoT devices and keep the process automated, which needs to utilize an IoT device signal-processing algorithm based on the Shepard local approximation operator [70]. In addition to sensor-based living, the main focus of the projected future society comprises the wearable internet, big data analytics, and the implementation of a smart city [71]. Big data-centered architecture meta-modeling tools enable the collection of specifications from all the elements involved in the digital platform, such as data, resources, applications, and monitoring metrics, in which the tools automatically generate the necessary information for the configuration, deployment, and execution of applications, to be transmitted and executed accordingly on the platform's nodes [72]. Furthermore, the integration of technologies related to Industry 4.0, such as IoT, big data, artificial intelligence, and edge computing, enhances the effective planning and construction of the smart city, as well as finding ways to get ahead in terms of smart manufacturing [73]. For example, associating DTs with IoT data can complement financial progress, effectively manage resources, reduce environmental impacts, and enhance the full value of residents' lives [74].

The keywords that appear more frequently in the red cluster (15 keywords) are cyber-physical systems, augmented reality, virtual reality, and virtual city models. Most of the keywords in the red cluster are far from the center of the diagram, in which the smart city connects to them through cyber-physical systems and augmented reality. There may be more directions for the integration of the real and virtual worlds in the future. The smart city encompasses complex cyber-physical model systems with the integration of computational technologies that are embedded in all its domains [75]. Among all the areas, virtual environments, particularly mixed-reality technologies, can improve spatial awareness, increase the effectiveness of spatial conflicts, and support design collaboration [76]. Additionally, augmented reality provides context-aware interaction with the environment [77]. The Metaverse, based on a fusion of technologies (e.g., augmented reality and virtual reality) enables multisensory interaction with virtual environments, digital objects, and people, to integrate physical reality with digital virtualization [78]. In addition, BIM technology assists with virtual city models, in which BIM semantics-based virtual earth models are able to visualize more complete features in both the outdoor and indoor environment [79].

3. Construction Building Technology

Figure 10 shows the keyword co-occurrence network for the subject area of construction building technology in terms of Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city. BIM takes center stage in this network, with closely related keywords such as construction, framework, energy, system, performance, design, and challenges, appearing mainly in the green, red, and blue clusters.

As shown in Figure 10, BIM is at the center of the green cluster, with construction, simulation, benefits, and sustainable building that are closely related to it. The modular construction method facilitates the use of advanced technologies that support the sustainability of construction projects [80]. In addition, BIM plays a huge role in building construction. On the one hand, BIM helps to guarantee the safety of building construction, in which the most feasible directions to guarantee construction safety are knowledge-based solutions, the safety improvements of BIM solutions, the horizontal application of BIM, dynamic visualization, and feedback [40]. On the other hand, the integration of BIM and sustainability practices in construction projects help to improve the ability to simulate building performance and energy utilization [81]. However, in practice, the non-standardization of BIM, including authoring, simulation, and balancing tools (e.g., LCA), inadequate connectivity, and a heavy time cost for data collection and the LCA process hinder the market for BIM adoption [82]. How to promote sustainable growth in construction projects has been explored, indicating that the most important strategies are via workshops, lectures, and conference events to raise public awareness, offering a better understanding of the costs and benefits of sustainable materials, and enhancing sustainable development [83].

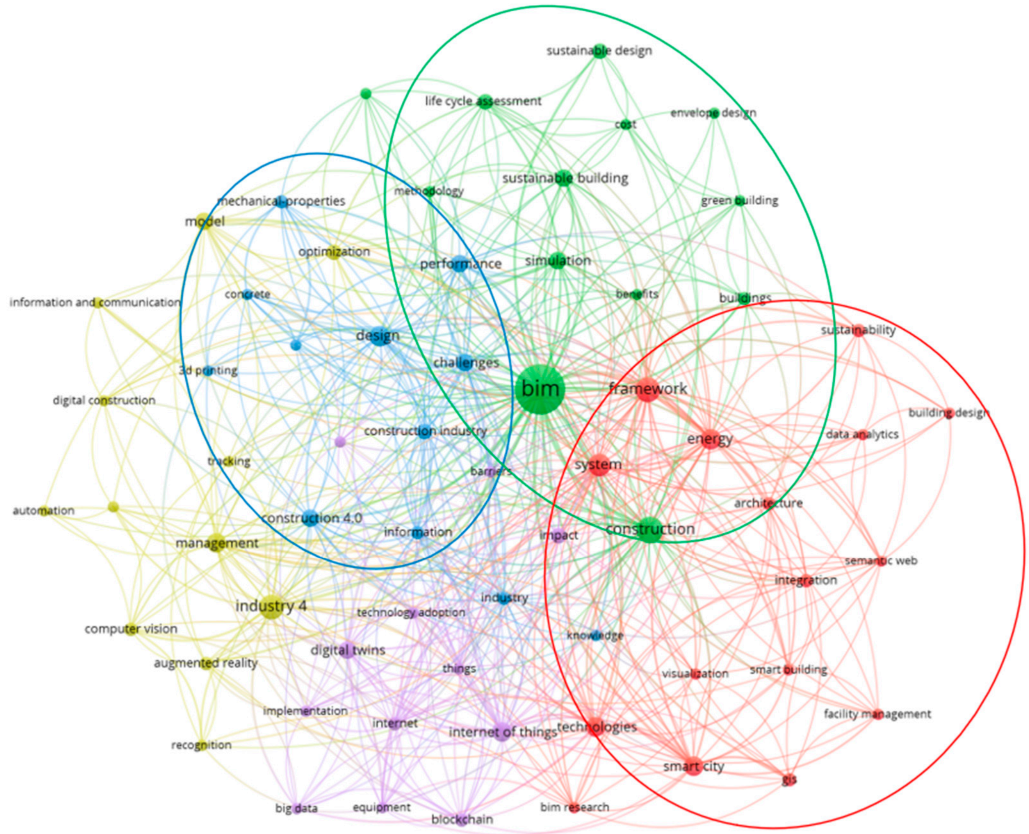


Figure 10. Keyword visualization of articles published between 2014 and 2021 in the field of construction building technology, depicting Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city via VOSviewer software (generated by the authors).

Keywords with strong links in the red cluster are framework, system, energy, and architecture, with the keyword "smart city" appearing frequently, as shown in Figure 10. Ensuring energy security through energy diversification is an important step toward meeting future demand and providing clean energy to the different industry sectors. Energy management for building design with BIM in terms of the power generation and building industry can mitigate environmental impacts and achieve the use of sustainable energy [84]. However, currently, there is a lack of consistency and coherence in the application of technology at different levels of management and at different stages in the building project life cycle [85]. To address the need for technical consistency, integrated systems based on the relevant technologies and methods are receiving more attention. For example, an urban energy planning system based on GIS-BIM carries out database creation and data analysis through GIS, via optimal energy system design, with the assistance of BIM, and the realignment of a smart city infrastructure beyond comprehensive analysis [86]. Starting from different stages in the life cycle, life cycle energy assessment can be conducted using uncertainty analysis methods to reduce the impact of uncertainty in building information on life-cycle energy assessment in the early design phase [87].

The blue cluster contains 12 keywords, including design, performance, and challenges, focusing on the challenges that exist in the area of construction building technology, as shown in Figure 10. Current challenges in the application of emerging technologies in industrialized construction include a lack of focus on specific structural systems or technologies, insufficient research on performance assessment measures, and the lack of an effective training program [88]. Knowledge in the field of construction and infrastructure is fragmented and diverse, and there is a lack of approaches that can address all sustainable issues in structural design, within which BIM has the potential to provide a platform for problem-solving [89]. Integrating BIM with digital programming for managing design workflows, with highly relevant information flows for sustainable building design and construction phases, assists in bridging the knowledge gap between maintenance theory and practical maintenance management [90]. In addition, the integration of BIM and multi-objective particle swarm optimization can be used to improve building performance [21]. The challenge in building renovations is to understand the complexity of the level of knowledge available today regarding renovation, in terms of the individual building project and the architecture, engineering, construction, and operations (AECO) community [91]. Future research into the AECO-FM industry should focus on the full integration of DTs and the corresponding real objects for better performance throughout the building's life cycle [53].

4. Science Technology and Other Topics

Figure 11 illustrates the co-occurrence network of keywords in the area of science technology and other topics regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city. BIM is the core of the co-occurrence network, which is surrounded by sustainability and management, Industry 4.0, and LCA, within yellow, red, and purple clusters forming a triad around BIM.

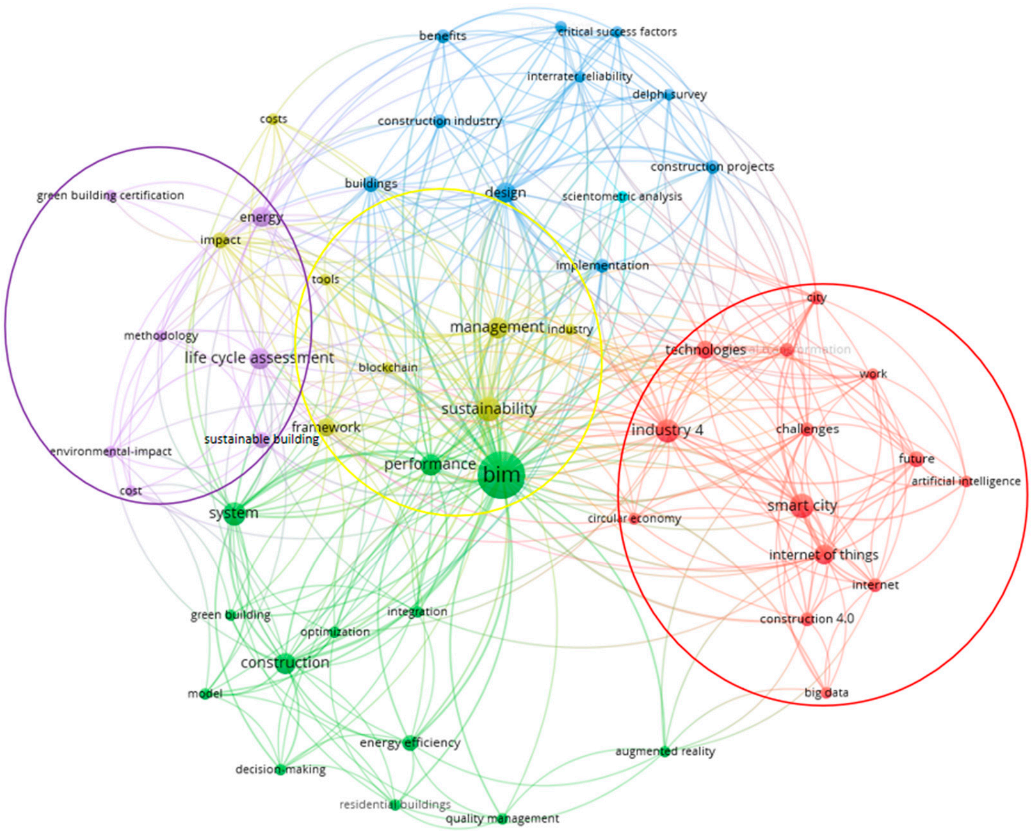


Figure 11. Keyword visualization of articles published between 2014 and 2021 in the field of science technology and other topics, in terms of Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

The yellow cluster has the strongest links to centrally located BIM and performance, which contains 8 keywords, such as sustainability, management, framework, and blockchain. BIM can be flexibly applied in sustainable building and management. In construction projects, critical success factors that can amplify the integration of BIM and sustainability practices are related to human-centered data and technology-centered interventions in the built environment [92]. Blockchain smart contracts are the latest trend in digital supply chains in the sustainable built environment [42]. In the development of DTs for facilities management and performance management, there are strong possibilities in the following fields in the future, such as enhanced interoperability in BIM, the testing and implementation of BIM concepts in an intelligent transport infrastructure, the integrated use of 3D analysis algorithms, and the cross-integration of BIM with GIS [93]. The inclusive framework integrating BIM and GIS can be used to plan and forecast the public infrastructure needs of emerging cities that are undergoing expansion [94].

Frequent keywords in the red cluster are Industry 4.0, smart city, and IoT. Since the continuous reconfiguration and expansion of production systems require highly flexible building structures, Industry 4.0 is capable of mass production and on-demand product personalization in terms of production systems. However, most studies and tools are currently focused exclusively on either production systems or building optimization; there is a need to integrate these two fields [95]. In addition, a smart city needs to rely on artificial intelligence and the IoT and must focus on all aspects of change, such as strategy, data, people and organizations, processes, and technology, to expand its reach [96]. However, the key driver of the IoT is sensing technology, in which the modeling of sensing information fundamentally affects the quality of smart city systems [97].

The purple cluster contains seven keywords that are centered on LCA, energy, and sustainable construction. The integration of BIM and the green rating system helps to evaluate the sustainability of buildings and promote green certification. Sustainable construction is important to reduce the environmental impact of buildings, and LCA and BIM can contribute to sustainability [98]. An integrated knowledge-based building management system has been used in one study to analyze the later life cycle of a building, to check energy efficiency, and promote the implementation of sustainable building performance [99]. Since identifying sustainable alternative materials and technologies in traditional masonry can reduce economic, environmental, and social impacts, such as energy use and costs during the building's life cycle [100], BIM assists in finding a suitable masonry solution for sustainable urban slum housing in India, using recycled paper-mill waste bricks [63]. Additionally, automation has been improved by integrating green material databases and new BIM technologies, such as visual programming, along with cloud-based databases [100].

5. Environmental Sciences Ecology

In the field of environmental sciences ecology, Figure 12 shows a keyword visualization regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city. BIM occupies the center of the keyword co-occurrence network, while other keywords closely related to the topic include LCA, Industry 4.0, and sustainability, which are distributed in the purple, green and red clusters.

As shown in Figure 12, the purple cluster includes seven keywords, mainly related to BIM and the LCA of buildings. BIM and LCA have been used to assist in the design of buildings with a lower environmental impact. Green construction-certified buildings exhibit better performance and have greater asset value [101]. However, construction professionals currently have a poor understanding of the process of the whole building life cycle assessment (WBLCA) that is associated with Leadership in Energy and Environmental Design (LEED), resulting in very low levels of adoption of WBLCA for new construction projects [102]. The sustainability of the building life cycle is mainly reflected in the environmental and economic aspects of using environmentally friendly materials. Construction materials affect a building's performance, for which reason the choice of sustainable building materials is critical [103]. The integration of BIM and environmental efficiency modeling enables the assessment of building life cycle costs and efficiencies, along with the retrofitting of existing building facades for energy-efficient design [104].

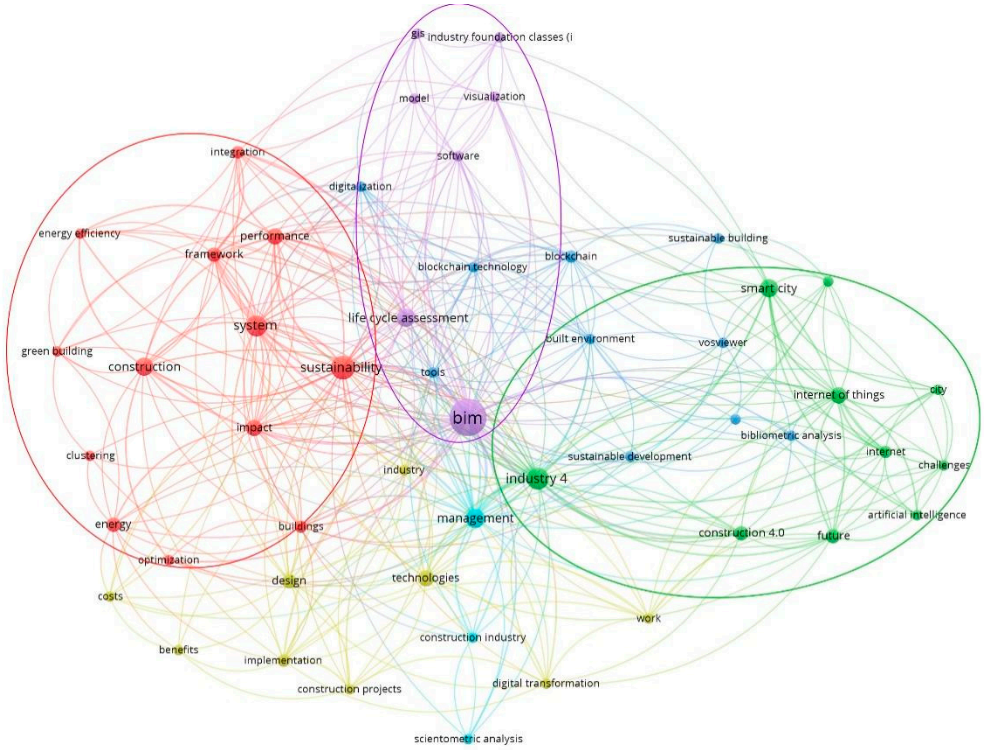


Figure 12. Keyword visualization of articles published between 2014 and 2021 in the field of environmental sciences ecology, regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

The green cluster contains 10 keywords, of which only Industry 4.0 and Construction 4.0 are strongly associated with the center, as shown in Figure 12. Industry 4.0 will drive sustainable development and will have the greatest impact on productivity growth in the construction industry. However, the construction industry is currently slow in adapting to digital technologies and the innovative processes of Industry 4.0 [10]. The Construction 4.0 concept could be associated with intelligent automation, predictive intelligence, and real-time data exchange. The integrated method enables driving the digitization of pavement assessment techniques in roads for the construction industry as a future circular method of promoting quality, efficiency, and safety [105]. Future in-depth studies need to focus on the synergies between possible ethical issues and Construction 4.0 technologies [32].

As shown in Figure 12, the red cluster has 13 keywords, including sustainability, which provides systematic frameworks for advancing sustainable building development and improving building performance, in which field BIM plays an important role. For example, BIM that is augmented with the stepwise weighted assessment ratio analysis method helps to identify and reduce time delays caused by reworking [106]. In addition, BIM-based approaches allow sustainable buildings to have a higher quality and comfort level. For example, "BIM-6D" simulations assist in making design and operational decisions for upgrading new and old buildings, to improve energy and lighting efficiency [107]. The framework of BIM parametric software integration improves the thermal comfort of aging buildings [108]. Furthermore, BIM facilitates the digital transformation of large infrastructure projects, such as electric road systems and expanded rail systems, toward sustainability and mitigating the effects of climate change [109]. The next emerging technology and opportunity for sustainable processes could be the digitization of the construction supply chain and procurement for the built environment [42].

6. Telecommunications

Figure 13 illustrates the keyword co-occurrence network of telecommunications with regard to Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city. IoT becomes the center of connections in the telecommunications field, which focuses on health, privacy, security, and efficiency with smart city and Industry 4.0 technologies as vehicles.

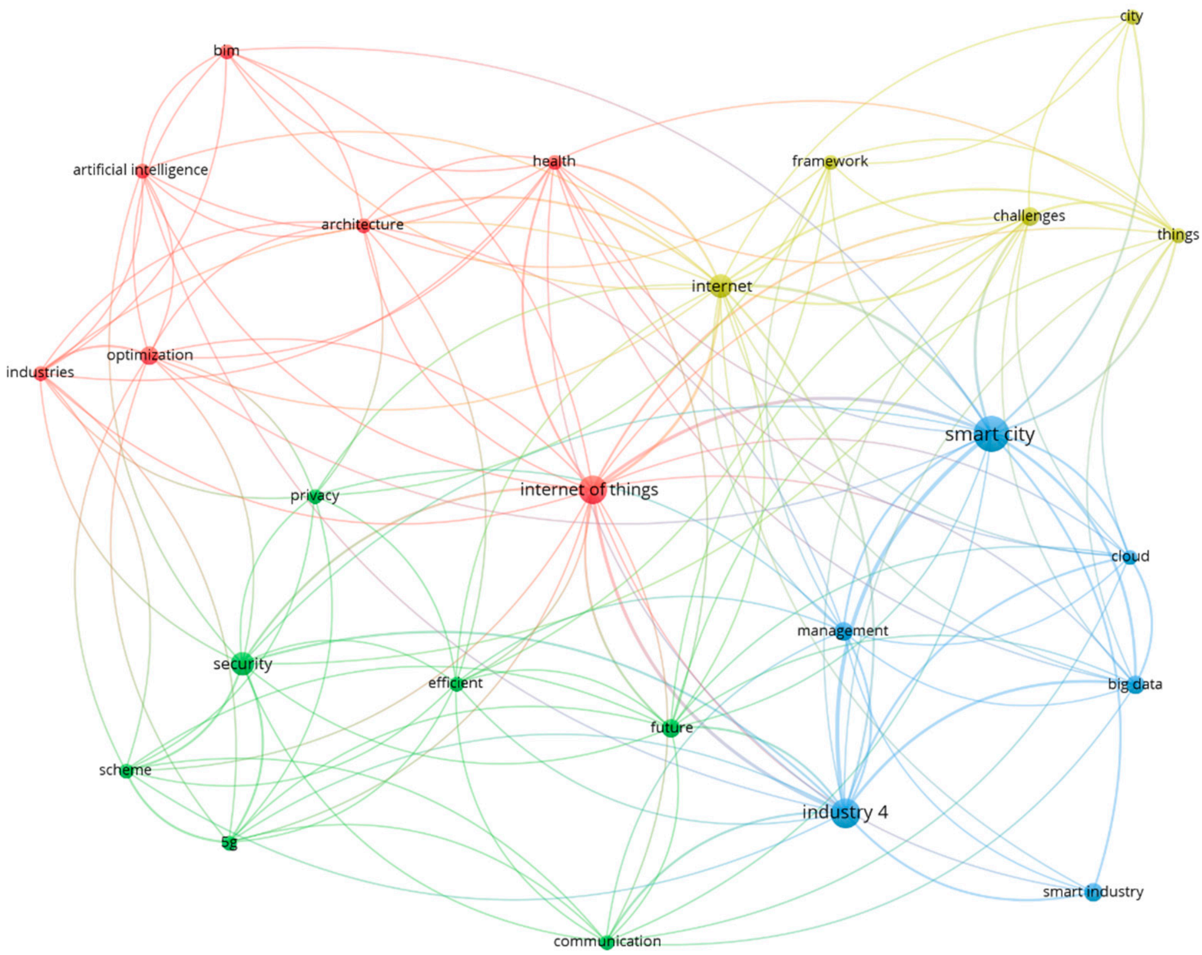


Figure 13. Keyword visualization of articles published between 2014 and 2021 in the field of telecommunications, regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

IoT, an important aspect of Industry 4.0, is widely represented in the literature on the policy-driven smart city, business-driven smart industry, and experience-driven smart living solutions [110]. The smart city promises to guarantee healthy living for indoor residents by sensing, processing, and controlling all possible indoor and outdoor measures. Formal verification and network analysis approaches enable developers to establish reliable and secure smart-city model frameworks in construction [111]. In addition, sustainability is also relevant to the built environment, and art therapy via BIM, in which the principles of therapeutic design should be considered in design elements and features from people's health, is needed to better promote human health and well-being [112]. Smart healthcare cyber-physical systems have the potential via BIM to monitor and control patients, medical devices, and the exterior of the equipment, enabling continuous communication and the information exchange of physiological data to facilitate the effective functioning of medical processes and treatments [113]. However, rapid technological developments bring privacy and security issues. The 5G technology uses IoT devices to connect everything at high speeds, which means that developers need to maintain three levels of privacy i.e., data, identity, and location [50]. The development of Industry 4.0 technologies, such as IoT, cloud computing, and social media for sensor data, services, and smart city applications may cause data security issues as well. Hence, distributed, intelligent, and secure data management systems need to address the data vulnerability issues, possibly with the help of blockchain and IoT [114]. Furthermore, smart objects in IoT environments are facing communication challenges, due to the mobility of IoT and limited resources in computation, storage, and energy capacity. This type of network needs a delay-tolerant IoT environment to improve efficiency and the delivery ratio, and to optimize resource consumption [115].

7. Energy Fuels

Figure 14 reveals the keyword clusters for energy fuels in the context of Construction 4.0, Industry 4.0, BIM, sustainable construction, and the smart city. The keywords are centered on BIM, with the frequent occurrence of design, sustainable building, energy, and LCA. The terms "sustainable building" and "energy" are linked to BIM through the node "system". Prioritizing the integration of BIM and sustainability practices in construction projects assists in improving overall project quality and efficiency, increases the ability to simulate building performance and energy use, and promotes better design products and multi-design alternatives [81]. In addition, energy consumption in buildings is an important issue regarding energy-efficient buildings in terms of achieving sustainability. The integration of BIM and LCA aids in optimizing the generation of energy-efficient buildings [62]. Additionally, achieving sustainable design in the field of energy-efficient design depends largely on the accuracy of the analysis of all its components and material details after the design is completed [116]. Using BIM in automatically/semi-automatically integrated energy and whole-life cost analysis for building envelope components helps in environmental and economic assessments throughout their life cycles [117].

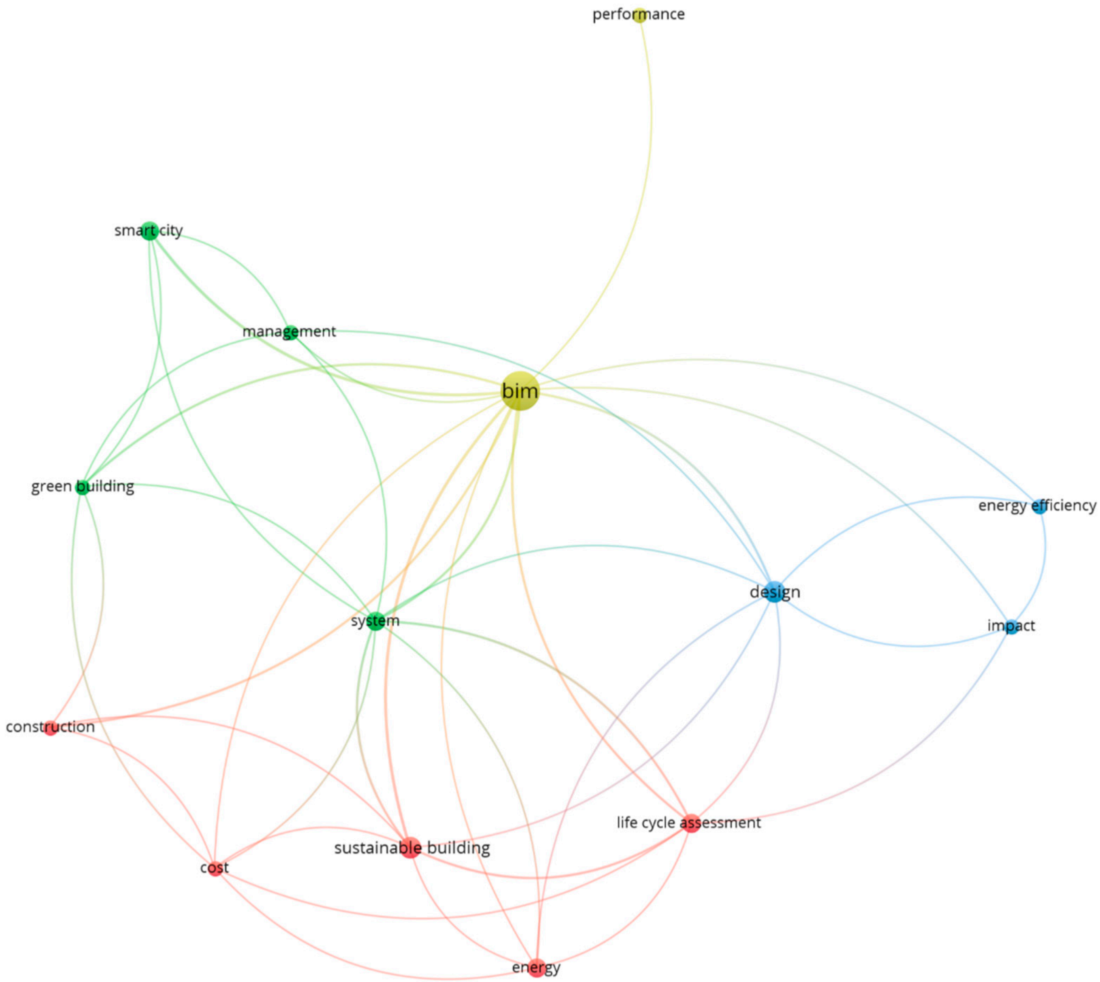


Figure 14. Keyword visualization of articles published between 2014 and 2021 in the field of energy fuels, in terms of Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

8. Business Economics

There are 13 keywords related to Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, forming a co-occurrence in the business economics sector, as shown in Figure 15.

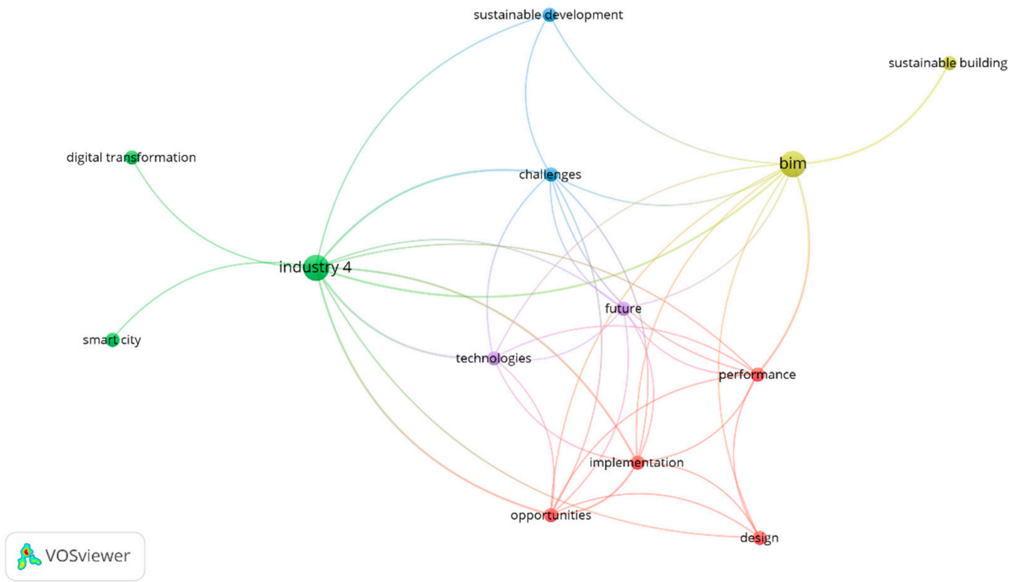


Figure 15. Keyword visualization of articles published between 2014 and 2021 in the field of business economics regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

The keywords, such as challenges, sustainable development, technologies, and future, are located in the middle of Figure 15, with Industry 4.0 and BIM close to the edges. The studies refer to the business economics aspect of sustainability in the construction industry, exploring the new opportunities and future challenges that technology presents, in which Industry 4.0 technologies assist in addressing issues regarding the use of resources and energy efficiency. The development of the smart city facilitates new industrialization, creates new conditions for living, working, and education, accumulates social and human capital, and attracts the financial resources needed for business development [66]. Industry 4.0 technologies also aid in simplifying employment for blind and visually impaired people, making working conditions friendly for them [118], and also driving industry digitization through BIM [119], encouraging integrated lifecycles and sustainable building management from design, construction, and prefabrication to operations and maintenance [120]. In addition, the development of BIM allows real estate owners to become owners of the physical assets themselves, as well as digital assets [121]. Furthermore, the positive impacts of Construction 4.0 technologies on environmental and economic sustainability far outweigh their negative effects [122]. However, the process of digital transformation in the construction industry is associated with high risks that have not yet been fully explored and identified [123]. Resistance to change, unclear benefits, and the cost of implementation are the challenges that prevent construction companies from adopting Industry 4.0. Interestingly, most construction organizations have successfully addressed the lack of standardization, legal and contractual issues, and implementation costs in driving the adoption of Industry 4.0 [124].

9. Chemistry

Figure 16 shows 12 keywords in the field of chemistry, with the core keyword Industry 4.0 being more strongly associated with its surroundings, i.e., BIM, management, the smart city, and DTs. Optimizing data collection and management effectively drives the digitization of sustainable construction, as Industry 4.0 has extended the use of sensors in buildings and infrastructure [125]. On the other hand, the sustainable management of water resources is gaining more attention in terms of energy consumption, enabling smart water management platforms for intelligent water consumption measurement and crisis detection [126]. The integration of heterogeneously distributed information enables the identification of object architectures in smart environments, in which information is used for particular processes, such as reconstructing environmental maps of the smart city or for the intelligent navigation of vehicles [127].

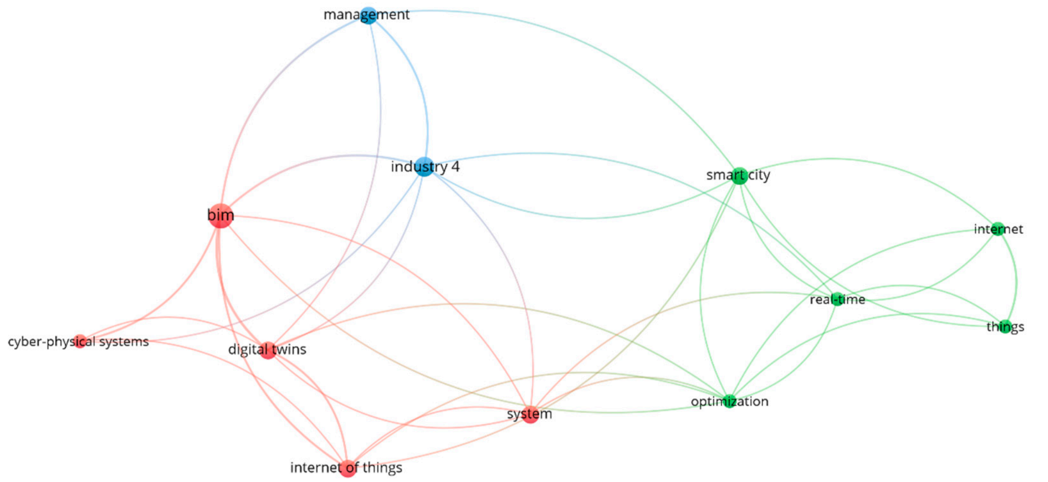


Figure 16. Keyword visualization of articles published between 2014 and 2021 in the field of chemistry, regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

10. Automation Control Systems

Figure 17 illustrates 11 co-occurring keywords for automation control systems, with the central keywords being IoT and Industry 4.0. Industrial connectivity is a key aspect of Industry 4.0 technologies and the construction industry, which ensures that all Industry 4.0 technologies are interconnected so that the full benefits of connectivity can be realized [128]. In addition, complex mobile control systems with sensors, machine vision, positioning systems, and remote management clouds need to be connected to the IoT world to meet the criteria for predictive cloud systems in the smart city in extreme environments [129]. Furthermore, in the context of Industry 4.0, in one paper, a BIM and IoT-based smart steel bridge construction pattern enable the real-time collaborative management and closed-loop control of activities across the whole life cycle of the bridge [130].

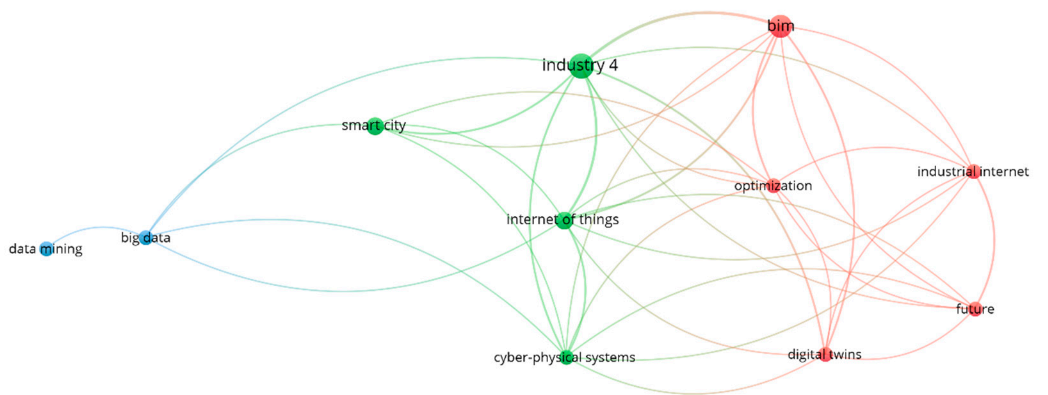


Figure 17. Keyword visualization of articles published between 2014 and 2021 in the field of automation control systems regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

11. Materials Science

Figure 18 exhibits seven co-occurring keywords in the area of materials science, in which BIM is the central keyword and the closely related keywords include Industry 4.0, DTs, and cyber-physical systems. High-performance production processes based on DTs and cyber-physical systems in Industry 4.0 are emerging in the construction industry for digital automation processes, in terms of materials [131]. Information-planning in physical systems for materials can be adapted to BIM functionality to improve the construction lifecycle, in which collaborative and autonomously synchronized systems automate the design and build processes and increase the network's ability to handle large amounts of heterogeneous data [132].

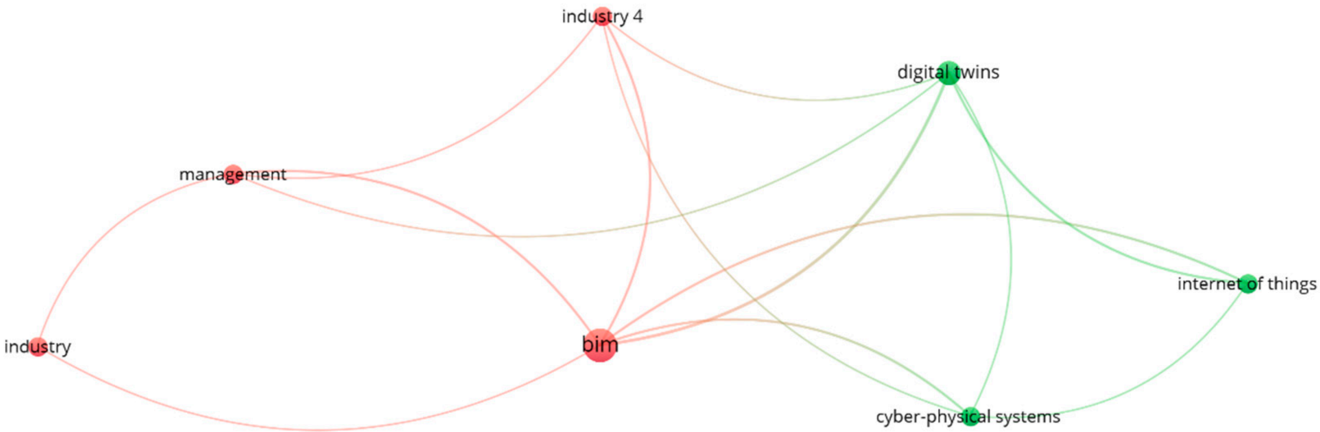


Figure 18. Keyword visualization of articles published between 2014 and 2021 in the field of materials science, regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, created via VOSviewer software (generated by the authors).

3.2.3. Micro-Qualitative Analysis of Life-Cycle Stages

The building's life-cycle stages are divided into four stages: design, construction, operation and maintenance, and renovation and demolition.

During the design stage, as shown in Table 5, the modeling [60,65,82,103,133–135] and literature review [21,132,136–139] are the most commonly used methods; of the remaining articles, five used the combination of modeling and a case study [39,59,87,140,141], and two used only the case study [107,142]. These articles are intended to investigate solutions for solving sustainable building design problems, on the one hand, making the most of BIM by applying it to sustainable low-income housing projects [103,136], simulating and evaluating the effects of deep shade-type balcony designs [133], and to integrate the economic and environmental impact analyses [59]. In addition, an information model has been developed for smart city buildings, based on a "BP neural network model" [134]. On the other hand, this phase also focuses on costs [21,137], LCA [82] and energy [65,87,138], such as the integration of whole life cycle costs into the BIM process to assist decision-making [137]; the method has been used for uncertainty analysis in early life cycle energy assessment [87], the integration of BIM with the Canadian green building certification system [141], open BIM-based interface mapping for energy performance assessment [138], and for facilitating designers in optimizing the design [139].

Table 5. The design stage and application areas of the literature regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, from the year 2014 to 2021 (generated by the authors).

Source	Year	Research Method	Topic
Ekasanti et al.	2021	Literature review	BIM as a tool for assessing the quality of sustainable design for low-income housing
Harter et al.	2020	Modeling and case study	Uncertainty analysis of the design in early LCA
Li et al.	2020	Modeling	BIM for a smart city, based on a "BP neural network model"
Montiel-Santiago et al.	2020	Case study	Lighting system improvements in hospitals
Tao et al.	2020	Modeling and case study	Sustainable and healthy building design and operation
Zanni et al.	2019	Literature review	Integrating whole life cycle costs into the BIM process
Ebertshauser et al.	2019	Modeling	Connecting LCA tools with BIM
Liu et al.	2019	Modeling	BIM and blockchain-based sustainable building design information management
Liu et al.	2019	Modeling	BIM-based water saving framework
Maskuriy et al.	2019	Literature review	Industry 4.0 for the construction industry
Mgbere et al.	2018	Case study	Methods and tools to illustrate the use of BIM
Ahmad et al.	2017	Modeling	Design-iterative BIM
Liu et al.	2017	Modeling	Building energy simulation
Marzouk et al.	2016	Modeling	Framework for sustainable low-income housing projects
Inyim et al.	2015	Modeling and case study	The BIM extension component, SimulEICon, helps with building design decisions
Choi et al.	2015	Literature review	Interface mapping approach for energy performance assessment
Liu	2015	Literature review	Optimizing building design solutions and saving costs
Jalaei et al.	2015	Modeling and case study	Green building certification system and BIM
Liu et al.	2015	Literature review	Building design optimization methodology
Wong et al.	2014	Modeling and case study	Sustainable building assessment

As shown in Table 6, in the construction stage, the studies mainly use a literature review [128,132,143] to investigate the current status of Construction 4.0 in the context of the BIM 4.0 premise [143], Industry 4.0 in the construction industry [132], and the challenges and opportunities faced during the construction phase [128], followed by modeling [60,65], which is employed to explore the integration of BIM with other technologies and systems for sustainable building development, such as blockchain-enhanced BIM for an information management framework [60], BIM-based sustainable building design and a construction management framework for water conservation [65]. One article introduces methods and tools for BIM use by employing a case-study approach [142]. In the end, Wong et al. used the integration of modeling and a case study [140] to put forward the BIM-Beam Plus sustainable building assessment framework and then verified the framework using a case study.

Table 6. The construction stage and application areas of the literature regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city from the year 2014 to 2021 (generated by the authors).

Source	Year	Research Method	Topic
Begic et al.	2021	Literature review	BIM 4.0 for Construction 4.0
Turner et al.	2021	Literature review	Industry 4.0 on construction sites
Maskuriy et al.	2019	Literature review	Industry 4.0 for the construction industry
Liu et al.	2019	Modeling	Sustainable building design information management, based on BIM and blockchain
Liu et al.	2019	Modeling	BIM-based framework for water-saving
Mgbere et al.	2018	Case study	Methods and tools for BIM use
Wong et al.	2014	Modeling and case study	Sustainable building assessment

As shown in Table 7, these articles on the operation and maintenance stages mainly use the case study approach [39,107]; these applications include the data infrastructure for modeling human-centered sustainable and healthy building design and operation [39], and for the improvement of lighting systems in hospitals [107]. In addition to the main case study approach, this phase also uses modeling [90] to design an integrated management workflow for a structural maintenance schedule and cost planning, and also combines a literature review with modeling [99] to create an integrated knowledge-based building management system for energy efficiency testing.

Table 7. The operation and maintenance stages and application areas of the literature regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, from the year 2014 to 2021 (generated by the authors).

Source	Year	Research Method	Topic
Tao et al.	2020	Case study	Data infrastructure for sustainable health in building design and operational modeling
Montiel-Santiago et al.	2020	Case study	Lighting system improvements for hospitals
Chen et al.	2019	Modeling	Integration of building structure maintenance schedules and cost planning
GhaffarianHoseini et al.	2017	Literature review and modeling	Post-construction energy efficiency testing

In terms of the integration of Construction 4.0, Industry 4.0, and BIM for sustainable building in the context of the smart city, there has been much interest in sustainable renovation and reuse. The five articles shown in Table 8 focus on the construction renovation and recycling aspects. Articles included in the renovation and demolition stage mainly use a combined approach with modeling and a case study [104,144]. The remainder of the articles were researched using a literature review [105], modeling [145], and a method of combining a literature review with modeling [99]. The main application areas of this stage are the reuse of building components [144], road regeneration [105], the modernization of public buildings [145], post-construction energy efficiency testing [99], and the energy-efficiency retrofitting of existing building facades [104].

Table 8. The renovation and demolition stages and application areas of the literature regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city, from the year 2014 to 2021 (generated by the authors).

Source	Year	Research Method	Topic
Xing et al.	2020	Modeling and case study	Reuse of building components
Widyatmoko et al.	2020	Literature review	Construction of roads with recycled materials
Starynina et al.	2020	Modeling	Modernization of public building
GhaffarianHoseini et al.	2017	Literature review and modeling	Post-construction energy efficiency testing
Liu et al.	2014	Modeling and case study	Energy-efficiency design retrofit of existing building facades

In terms of the integration of Construction 4.0, Industry 4.0, and BIM for sustainable building in the context of the smart city, the whole-building life cycle-related articles account for the largest number of published works (46%). As shown in Table 9, the research methodologies for this field are mainly literature reviews [20,23,38,53,75,98,100,101,117,120,146–152], followed by the use of modeling method [62,85,130,153–156]. The remaining two articles use a combination of research methods from a literature review and a case study [61,102].

Table 9. The whole-building life cycle and application areas of the literature regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city from the year 2014 to 2021 (generated by the authors).

Source	Year	Research Method	Topic
Ozturk et al.	2021	Literature review	An overview of the AECO-FM industry's DTs
Pai et al.	2021	Literature review and case study	LEED's approach to WBLCA compliance
Yitmen et al.	2021	Modeling	A cognitive DTs model for building lifecycle management
Liu et al.	2021	Literature review	Integration of blockchain and BIM in smart city
Xue et al.	2021	Literature review	BIM integrated LCA and the circular economy
Liu et al.	2021	Literature review	Sustainable building management
Lorenzo et al.	2020	Modeling	Bamboo straw digitization for structural applications
Horn et al.	2020	Literature review	Integrating LCA into master planning
Veselka et al.	2020	Literature review	LCA integrated BIM in green building certification
Panteli et al.	2020	Literature review	Building integration models in the smart building sector
Pucko et al.	2020	Literature review	Integrated energy and whole life cycle cost analysis of building envelope components
Teply	2020	Literature review	EDSM method for additive technology to help with complete lifecycle management
Chelyshkov	2019	Modeling	Development and application of data exchange and management processes
Kuzina	2019	Modeling	Development of operational information models for smart city control systems
Brockmann	2019	Literature review	Open international data networks
Figl et al.	2019	Modeling	Life cycle analysis in building planning and construction, with a focus on carbon dioxide neutrality
Shrivastava et al.	2019	Literature review	Development of BIM tools for green and sustainable building design
Najjar et al.	2019	Modeling	Integration and optimization of energy-efficient building power generation
Ding et al.	2018	Modeling	Smart steel bridge construction
Seghier et al.	2018	Literature review	BIM and green building rating system integration
Najjar et al.	2017	Literature review and case study	BIM integrated with LCA
Shahrour et al.	2017	Literature review	Synthesis of minimal tools for city, infrastructure, and building modeling
Postranecky et al.	2017	Literature review	Industry 4.0 for theoretical models of smart city
Kylili et al.	2017	Literature review	Policies and trends in sustainability assessment of existing building materials in Europe
Chen et al.	2017	Literature review	BIM technology to enhance sustainable building goals and performance
Ginzburg	2016	Literature review	The use of unified information models (BIM models) throughout the building life cycle in the Russian Federation

The main research directions of the literature reviews are to explore the application and impact of Industry 4.0 technologies, BIM and their integrated models in the smart city and the construction industry, and their contribution to green and sustainable buildings. These include theoretical models of a smart city under Industry 4.0 [75]; BIM helps to enhance sustainable building goals [120,151], integrating DTs, blockchain, and BIM regarding more sustainable buildings [53,146]. The concept of green and sustainable construction has also been widely researched by academics and currently falls into three main sectors. Firstly, there is an overview and trend analysis of the government policies on an existing sustainability assessment of building materials [23]. Secondly, the papers study the integration of BIM in LCA, being dedicated to controlling building costs and energy consumption throughout the building's life cycle [61,98,101]. Lastly, they study the integration of BIM with green building systems and rating systems to generate green sustainable modeling tools [100,102,150].

Articles using the modeling approach focus more on detailed aspects of the sustainable building sector. Articles using this research approach all propose new models and frameworks for clarifying the existing problems. For example, one study focuses on the optimization of power generation in energy-efficient buildings [62]; one focuses on carbon dioxide neutrality in the life cycle analysis [153]; one focuses on sustainable building materials, digitizing bamboo straw materials for structural applications [154]; one focuses on cyber-physical system data exchange and management processes [85]; one combines the DTs model for easy building lifecycle management [155]; one proposes a framework for smart steel bridge construction [130].

4. Discussion

4.1. Current and Future Trends

The traditional approaches of the construction industry must change to meet the new demands from society for achieving a sustainable built environment [157]. The results in Section 3.1.2. indicates that BIM, Industry 4.0, and the smart city are currently closely related and have attracted extensive attention, while the investigation of Construction 4.0, sustainable construction, and their integration is rare. The integration of BIM with LCA and green rating systems can better address sustainable building issues.

In addition, the results in Section 3.1.2. suggest that, currently, Construction 4.0 studies focus on digitalization, design, and management, but these studies are rarely related to the smart city, while studies in sustainable construction are interested in energy, building performance optimization and environmental impact, which are heavily associated with BIM, suggesting that the integration of Construction 4.0 and a smart city is currently in its preliminary stages; the research on sustainable construction is currently limited to a more independent field. In the future, interdisciplinary and multidisciplinary research in Construction 4.0, associated with Industry 4.0 for sustainable construction in the context of the smart city, could become a new trend, in which an upgraded version of BIM can be the bridge to integrating the two, in which study CIM is deemed to be the latest development in BIM [158] that can meet the requirements for the design, planning, management, and recovery of smart city systems for sustainable urban development [159], the integration of BIM, GIS, and a complete urban database [160], employing the major decision-making systems, such as 3D city models, DTs, and urban analysis, informatics and planning support systems [161].

Furthermore, in terms of the above findings, as shown in Table 3, BIM is the most frequent keyword regarding the integration of Construction 4.0, Industry 4.0, and BIM for sustainable construction in the context of the smart city, from the year 2014 to 2021, followed by the smart city and Industry 4.0. The IoT has been mentioned frequently as an emerging technology, while the keywords such as construction, sustainability, performance, energy, and optimization reveal that the construction industry is transforming itself toward sustainability, while management, framework, design, and challenges assist in active exploration in future challenges. In addition, the results in Section 3.1.2. suggest that virtual reality and augmented reality became research hotspots in 2018, while artificial intelligence and DT technologies became research hotspots after 2020, in which field the integration of the virtual world and the real world can bring greater scope for the sustainable development of construction. In the future, based on the application of Industry 4.0 and Construction 4.0, even the radically innovative concepts of Industry 5.0 [162], Construction 5.0, and the Metaverse have the potential to become a future research direction in the construction industry. The eight-year window from the year 2014 to 2021 can be treated as an early research phase in the Industry Metaverse and Construction Metaverse. The benefit of Industry 5.0 is that it offers greener solutions compared to the existing Industry 4.0 transformation, in which edge computing, DTs, collaborative robotics, IoT, blockchain, and 6G technologies are the supporting technologies for Industry 5.0 [162]. The DT process can be applied fully in all phases of building construction. A DT framework, based on BIM for 3D modeling, can achieve the goals of intelligent building manufacture and improved construction efficiency, comprising physical site-entity modeling, DT virtual body modeling, and virtual reality interaction modeling [163]. The 6G technology for

Industry 5.0 will extend the service subjects away from people, machines, and things in the physical world to the "environment" in the virtual world, providing a network foundation for the Metaverse [54]. The development and maturity of augmented reality, virtual reality, and the network have also given rise to the use of the Metaverse in its various aspects, such as the digital architecture, engineering, and construction, which may well become one of the major players of the future. However, Metaverse research in the AEC industry is still at an early stage, being mostly at the conceptual level [164], and artificial intelligence and blockchain technologies are expected to play an important role in the Construction Metaverse [165].

4.2. The Development and Challenges of Multidisciplinary and Building Life Cycle Research

In terms of the integration of Construction 4.0, Industry 4.0, and BIM for sustainable construction in the context of the smart city is a multidisciplinary and cross-over research domain. The organizational environment is changing to a more multidisciplinary, open, collaborative, and multicultural environment [166]. Sustainable development requires contributions from major disciplines, such as civil engineering, architecture, and urban planning, and close collaboration between these disciplines [167]. Industry upgrading is used in a smart city and with sustainable building, and the emergence of new technologies and their integrations into the construction industry are converging to drive digitalization and intelligent automation within the industry. In the multidisciplinary results of Sections 3.2.1 and 3.2.2, the greatest research achievements regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city are in engineering, computer science, and technology and building construction technology. Most research papers on sustainable construction have been related to optimizing design, saving energy and water, and making buildings more environmentally friendly by reducing their carbon emissions [168]. In addition, emerging technologies are enhancing security, management, and privacy to face new challenges. Smart buildings protect highly sensitive information about their inhabitants and against new privacy threats and vulnerabilities [169]. As such, there is always a need for smart building systems to protect sensitive information [170]. Studies have confirmed that smart buildings with well-provisioned and managed IoT frameworks can maintain the security and privacy of IoT data sources and contexts [171].

In addition, the results of Section 3.2.3 indicate that, in terms of the building life cycle, the current research regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city tends to solve problems during the design stage and the whole-building life cycle, but few studies have focused on the stages, i.e., construction, operation and maintenance, and renovation and demolition. However, sustainable building retrofitting is an important approach by which to address energy and environmental issues, and retrofitting building performance, in which the model and energy efficiency represent a hot topic [172]. Decision-support tools for building renovation are essential in the design process, to set and achieve sustainability goals. Future research could highlight the selection and weighting of sustainability criteria, to provide clear guidelines for screening existing buildings and prioritizing renovation actions in the building portfolio [173]. The application of BIM for retrofitting existing buildings is challenging, due to the multidisciplinary nature and timeliness of information exchange, wherein a wide range of technical components are required to ensure optimal information exchange [174]. As a result, most existing buildings have not been properly maintained, renovated, or deconstructed using BIM [175]. Additionally, waste management is key to achieving sustainable resource management, in which quantifying the amount of construction and demolition waste generated is a prerequisite for implementing successful waste management [176]. Furthermore, the complexity of products in the construction process and the lack of information on these products hinder dismantling and sorting, thereby creating barriers to recycling [177].

5. Conclusions

This paper adopts a bibliometric approach to explore the integration and development of Construction 4.0, Industry 4.0, BIM, and sustainable building in the context of the smart city. The main contributions of this study are as follows: (1) in terms of the research methodology, this is the first attempt to use macro-quantitative analysis and micro-qualitative analysis methods to investigate this multidisciplinary research topic. (2) In terms of the research technique, by using the VOSviewer software's visual bibliometric tool, and based on the macro keyword co-occurrence, this paper is the first to reveal the five keyword-constructed schemes, research hotspots, and development trends of the smart city, Construction 4.0, Industry 4.0, BIM, and sustainable construction from the year 2014 to 2021. (3) In terms of results, by addressing the multidisciplinary research topic, the top 11 productive subject areas have been identified using the VOSviewer software keyword clustering analysis status and application, in topics including engineering, computer science, construction building technology, science technology and other topics, environmental sciences ecology, telecommunications, energy fuels, business economics, chemistry, automation control systems, and materials science. (4) This paper uses selected articles related to the life cycle of buildings, by discussing a building's life cycle stages and the related application fields to establish the gap and trend of the study, providing suggestions for future research.

From the year 2014 to 2021, the number of articles published regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city has been increasing every year. BIM, Industry 4.0, smart city, IoT, system, management, and sustainability are keywords that are closely related to the topic. Artificial intelligence, DTs, and other technologies have become research hotspots in 2021. Human-machine collaboration opens up the era of Industry 5.0, and the formation of Construction 5.0 in the construction industry is just around the corner. This paper reveals the potential future directions in the integration of Industry 5.0 and Construction 5.0, or even the integration of the Industry Metaverse and the Construction Metaverse, with an association with the upgraded BIM, namely, CIM. Furthermore, the top research keywords have been visualized through the overlay of areas regarding Construction 4.0, Industry 4.0, BIM, sustainable building, and the smart city during the past eight years. Five schemes have been identified, i.e., cutting-edge concepts, a building's sustainable development, the development of influential factors, activity for building the life cycle, and the emerging technologies and integrated model. In terms of its multidisciplinary nature, the most frequent disciplines appearing in past studies are engineering, computer science and technology, and building construction technology. Meanwhile, the study of a building's life cycle is crucial for the sustainable development of buildings. Additionally, the renovation and demolition stage has not been paid sufficient attention, due to most of the current studies focusing on the design stage and the whole-building life cycle. However, this paper employs only one database, i.e., the WoS, and some relevant studies may be indexed in other databases, such as the Engineering Index Compendex [178]. In addition, only one visual bibliometric tool, i.e., VOSviewer software, has been used. As such, future follow-up studies may consider using data from multi-databases such as Scopus, while using multiple visual bibliometric tools, such as Citespace software. In addition, future research could have a multidisciplinary mindset, especially in terms of the impact of Industry 5.0 on the construction industry and even the formation of Construction 5.0, which could be studied in depth and could develop the Construction Metaverse, from concept to practice.

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References

1. Silva, B.N.; Khan, M.; Han, K. Towards Sustainable Smart Cities: A Review of Trends, Architectures, Components, and Open Challenges in Smart Cities. *Sustain. Cities Soc.* **2018**, *38*, 697–713. [CrossRef]
2. Graham, S.; Marvin, S. *Telecommunications and the City: Electronic Spaces, Urban Places*, 1st ed.; Routledge: London, UK, 1995.
3. Neirotti, P.; De Marco, A.; Cagliano, A.C.; Mangano, G.; Scorrano, F. Current Trends in Smart City Initiatives: Some Stylised Facts. *Cities* **2014**, *38*, 25–36. [CrossRef]
4. Ramaprasad, A.; Sánchez-Ortiz, A.; Syn, T. A Unified Definition of a Smart City. In Proceedings of the International Conference on Electronic Government, Petersburg, Russia, 4–7 September 2017.
5. Dameri, R. Searching for Smart City Definition: A Comprehensive Proposal. *Int. J. Comput. Technol.* **2013**, *11*, 2544–2551. [CrossRef]
6. Ejaz, W.; Naeem, M.; Shahid, A.; Anpalagan, A.; Jo, M. Efficient Energy Management for the Internet of Things in Smart Cities. *IEEE Commun. Mag.* **2017**, *55*, 84–91. [CrossRef]
7. Mohanty, S.P.; Choppali, U.; Kougianos, E. Everything You Wanted to Know about Smart Cities: The Internet of Things Is the Backbone. *IEEE Consum. Electron. Mag.* **2016**, *5*, 60–70. [CrossRef]
8. Yigitcanlar, T.; Kamruzzaman, M.; Foth, M.; Sabatini-Marques, J.; da Costa, E.; Ioppolo, G. Can Cities Become Smart without Being Sustainable? A Systematic Review of the Literature. *Sustain. Cities Soc.* **2019**, *45*, 348–365. [CrossRef]
9. Bock, T. The Future of Construction Automation: Technological Disruption and the Upcoming Ubiquity of Robotics. *Autom. Constr.* **2015**, *59*, 113–121. [CrossRef]
10. Karmakar, A.; Delhi, V.S.K. Construction 4.0: What We Know and Where We Are Headed? *J. Inf. Technol. Constr. ITcon* **2021**, *26*, 526–545. [CrossRef]
11. Boyes, H.; Hallaq, B.; Cunningham, J.; Watson, T. The Industrial Internet of Things (IIoT): An Analysis Framework. *Comput. Ind.* **2018**, *101*, 1–12. [CrossRef]
12. Roblek, V.; Meško, M.; Krapež, A. A Complex View of Industry 4.0. *SAGE Open* **2016**, *6*, 1–11. [CrossRef]
13. Lasi, H.; Fettke, P.; Kemper, H.-G.; Feld, T.; Hoffmann, M. Industry 4.0. *Bus. Inf. Syst. Eng.* **2014**, *6*, 239–242. [CrossRef]
14. Forcael, E.; Ferrari, I.; Opazo-Vega, A.; Pulido-Arcas, J.A. Construction 4.0: A Literature Review. *Sustainability* **2020**, *12*, 9755. [CrossRef]
15. Schober, K.S.; Hoff, P. Digitization in the Construction Industry: Building Europe's Road to 'Construction 4.0'. In *Think Act*; Roland Berger GMBH: Munich, Germany, 2016; pp. 1–16.
16. Sacks, R.; Brilakis, I.; Pikas, E.; Xie, H.S.; Girolami, M. Construction with Digital Twin Information Systems. *Data-Centric Eng.* **2020**, *1*, e14. [CrossRef]
17. Osunsanmi, O.; Aigbavboa, C.; Oke, A.; Ohiomah, I. Construction 4.0: Towards Delivering of Sustainable Houses in South Africa. In Proceedings of the Creative Construction Conference 2018, Ljubljana, Slovenia, 30 June–3 July 2018.
18. Sawhney, A.; Riley, M.; Irizarry, J.; Pérez, C.T. A Proposed Framework for Construction 4.0 Based on a Review of Literature. *EPiC Ser. Built Environ.* **2020**, *1*, 301–309.
19. Hossan, M.; Nadeem, A. Towards Digitizing the Construction Industry: State of the Art of Construction 4.0. In Proceedings of the 10th International Structural Engineering and Construction, Chicago, IL, USA, 1 May 2019.
20. Panteli, C.; Kylili, A.; Fokaides, P.A. Building Information Modelling Applications in Smart Buildings: From Design to Commissioning and beyond A Critical Review. *J. Clean. Prod.* **2020**, *265*, 121766. [CrossRef]
21. Liu, S. Sustainable Building Design Optimization Using Building Information Modeling. In Proceedings of the International Conference on Construction and Real Estate Management, Luleå, Sweden, 11–12 August 2015; pp. 326–335.
22. Crippa, J.; Araujo, A.M.F.; Bem, D.; Ugaya, C.M.L.; Scheer, S. A Systematic Review of BIM Usage for Life Cycle Impact Assessment. *Built Environ. Proj. Asset Manag.* **2020**, *10*, 603–618. [CrossRef]
23. Kylili, A.; Fokaides, P.A. Policy Trends for the Sustainability Assessment of Construction Materials: A Review. *Sustain. Cities Soc.* **2017**, *35*, 280–288. [CrossRef]
24. Panteli, C.; Polycarpou, K.; Morsink-Georgalli, F.Z.; Stasiuliene, L.; Pupeikis, D.; Jurelionis, A.; Fokaides, P.A. Overview of BIM Integration into the Construction Sector in European Member States and European Union Acquis. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *410*, 012073. [CrossRef]

25. Ayman, R.; Alwan, Z.; McIntyre, L. BIM for Sustainable Project Delivery: Review Paper and Future Development Areas. *Archit. Sci. Rev.* **2020**, *63*, 15–33. [CrossRef]
26. Ding, Z.; Zheng, K.; Tan, Y. BIM Research vs. BIM Practice: A Bibliometric-Qualitative Analysis from China. *Eng. Constr. Archit. Manag.* 2021. [CrossRef]
27. Khudhair, A.; Li, H.; Ren, G.; Liu, S. Towards Future BIM Technology Innovations: A Bibliometric Analysis of the Literature. *Appl. Sci.* **2021**, *11*, 1232. [CrossRef]
28. Liu, H.; Skibniewski, M.J.; Ju, Q.; Li, J.; Jiang, H. BIM-Enabled Construction Innovation through Collaboration: A Mixed-Methods Systematic Review. *Eng. Constr. Archit. Manag.* **2021**, *28*, 1541–1560. [CrossRef]
29. Olawumi, T.O.; Chan, D.W.M.; Wong, J.K.W. Evolution in the Intellectual Structure of BIM Research: A Bibliometric Analysis. *J. Civ. Eng. Manag.* **2017**, *23*, 1060–1081. [CrossRef]
30. Zhong, L.; Zhang, L.; Li, Y.; Liang, X.; Kong, L.; Shen, X.; Wu, T. Assessment of the Toxicity of Quantum Dots through Biliometric Analysis. *Int. J. Environ. Res. Public. Health* **2021**, *18*, 5768. [CrossRef] [PubMed]
31. Dias, G.P. Smart Cities Research in Portugal and Spain: An Exploratory Biliometric Analysis. In Proceedings of the 2018 13th Iberian Conference on Information Systems and Technologies (CISTI), Caceres, Spain, 13–16 June 2018.
32. Kozlovska, M.; Klosova, D.; Strukova, Z. Impact of Industry 4.0 Platform on the Formation of Construction 4.0 Concept: A Literature Review. *Sustainability* **2021**, *13*, 2683. [CrossRef]
33. Shkundalov, D.; Vilutienė, T. Bibliometric Analysis of Building Information Modeling, Geographic Information Systems and Web Environment Integration. *Autom. Constr.* **2021**, *128*, 103757. [CrossRef]
34. Wang, X.; Fang, Z.; Sun, X. Usage Patterns of Scholarly Articles on Web of Science: A Study on Web of Science Usage Count. *Scientometrics* **2016**, *109*, 917–926. [CrossRef]
35. Powell, K.R.; Peterson, S.R. Coverage and Quality: A Comparison of Web of Science and Scopus Databases for Reporting Faculty Nursing Publication Metrics. *Nurs. Outlook* **2017**, *65*, 572–578. [CrossRef] [PubMed]
36. Hosseini, M.R.; Martek, I.; Zavadskas, E.K.; Aibinu, A.A.; Arashpour, M.; Chileshe, N. Critical Evaluation of Off-Site Construction Research: A Scientometric Analysis. *Autom. Constr.* **2018**, *87*, 235–247. [CrossRef]
37. Van Eck, N.J.; Waltman, L. VOS: A New Method for Visualizing Similarities Between Objects. In Proceedings of the 30th Annual Conference of the German-Classification-Society, Berlin, Germany, 08–10 March 2006.
38. Shahrour, I.; Alileche, L.; Alfurjani, A. Smart Cities: System and Tools Used for the Digital Modelling of Physical Urban Systems. In Proceedings of the 2017 Sensors Networks Smart and Emerging Technologies (SENSET), Beiriut, Lebanon, 12–14 September 2017.
39. Tao, Y.X.; Zhu, Y.; Passe, U. Modeling and Data Infrastructure for Human-Centric Design and Operation of Sustainable, Healthy Buildings through a Case Study. *Build. Environ.* **2020**, *170*, 106518. [CrossRef]
40. Fargnoli, M.; Lombardi, M. Building Information Modelling (BIM) to Enhance Occupational Safety in Construction Activities: Research Trends Emerging from One Decade of Studies. *Buildings* **2020**, *10*, 98. [CrossRef]
41. Baldanzi, L.; Crocetti, L.; Di Matteo, S.; Fanucci, L.; Saponara, S.; Hameau, P. Crypto Accelerators for Power-Efficient and Real-Time on-Chip Implementation of Secure Algorithms. In Proceedings of the 2019 26th IEEE International Conference on Electronics, Circuits and Systems (ICECS), Genoa, Italy, 27–29 November 2019.
42. Yevu, S.K.; Yu, A.T.W.; Darko, A. Digitalization of Construction Supply Chain and Procurement in the Built Environment: Emerging Technologies and Opportunities for Sustainable Processes. *J. Clean. Prod.* **2021**, *322*, 129093. [CrossRef]
43. Sun, X. Semantic 3D Building Model Construction for Smart Urban Management. In Proceedings of the 2015 International Conference on Industrial Technology and Management Science (ITMS 2015), Tianjin, China, 27–28 March 2015.
44. Xue, F.; Wu, L.; Lu, W. Semantic Enrichment of Building and City Information Models: A Ten-Year Review. *Adv. Eng. Inform.* **2021**, *47*, 101245. [CrossRef]
45. Xue, F.; Lu, W.; Chen, K.; Webster, C.J. BIM Reconstruction from 3D Point Clouds: A Semantic Registration Approach Based on Multimodal Optimization and Architectural Design Knowledge. *Adv. Eng. Inform.* **2019**, *42*, 100965. [CrossRef]
46. Xue, F.; Lu, W.; Chen, K.; Zetkulic, A. From Semantic Segmentation to Semantic Registration: Derivative-Free Optimization–Based Approach for Automatic Generation of Semantically Rich As-Built Building Information Models from 3D Point Clouds. *J. Comput. Civ. Eng.* **2019**, *33*, 04019024. [CrossRef]
47. Milanov, Y.; Badenko, V.; Yadykin, V.; Perlovsky, L. Method for Clustering and Identification of Objects in Laser Scanning Point Clouds Using Dynamic Logic. *Int. J. Adv. Manuf. Technol.* **2021**, *117*, 2309–2318. [CrossRef]
48. Petrova, E.; Pauwels, P.; Svidt, K.; Jensen, R.L. Towards Data-Driven Sustainable Design: Decision Support Based on Knowledge Discovery in Disparate Building Data. *Archit. Eng. Des. Manag.* **2019**, *15*, 334–356. [CrossRef]
49. Wagire, A.A.; Rathore, A.P.S.; Jain, R. Exploration of Pillars of Industry 4.0 Using Latent Semantic Analysis Technique. *Intell. Manuf. Energy Sustain.* **2020**, *169*, 711–719.
50. Humayun, M.; Jhanjhi, N.; Alruwaili, M.; Amalathas, S.S.; Balasubramanian, V.; Selvaraj, B. Privacy Protection and Energy Optimization for 5G-Aided Industrial Internet of Things. *IEEE Access* **2020**, *8*, 183665–183677. [CrossRef]
51. Leccisi, M.; Leccese, F.; Moretti, F.; Blaso, L.; Brutti, A.; Gozo, N. An IoT Application for Industry 4.0: A New and Efficient Public Lighting Management Model. In Proceedings of the 2020 IEEE International Workshop on Metrology for Industry 4.0 & IoT, Roma, Italy, 3–5 June 2020.
52. Mylonas, G.; Kalogeras, A.; Kalogeras, G.; Anagnostopoulos, C.; Alexakos, C.; Muñoz, L. Digital Twins from Smart Manufacturing to Smart Cities: A Survey. *IEEE Access* **2021**, *9*, 143222–143249. [CrossRef]

53. Ozturk, G.B. Digital Twin Research in the AECO-FM Industry. *J. Build. Eng.* **2021**, *40*, 102730. [CrossRef]
54. Ning, H.; Wang, H.; Lin, Y.; Wang, W.; Dhelim, S.; Farha, F.; Ding, J.; Daneshmand, M. A Survey on Metaverse: The State-of-the-Art, Technologies, Applications, and Challenges. *arXiv* **2021**, arXiv:2111.09673.
55. Darko, A.; Chan, A.P.C.; Adabre, M.A.; Edwards, D.J.; Hosseini, M.R.; Ameyaw, E.E. Artificial Intelligence in the AEC Industry: Scientometric Analysis and Visualization of Research Activities. *Autom. Constr.* **2020**, *112*, 103081. [CrossRef]
56. Maureira, C.; Pinto, H.; Yepes, V.; García, J. Towards an AEC-AI Industry Optimization Algorithmic Knowledge Mapping: An Adaptive Methodology for Macroscopic Conceptual Analysis. *IEEE Access* **2021**, *9*, 110842–110879. [CrossRef]
57. Martynov, V.V.; Shavaleeva, D.N.; Zaytseva, A.A. Information Technology as the Basis for Transformation into a Digital Society and Industry 5.0. In Proceedings of the 2019 International Conference "Quality Management, Transport and Information Security, Information Technologies" (IT&QM&IS), Sochi, Russia, 23–27 September 2019.
58. Haruna, A.; Shafiq, N.; Montasir, O.A. Building Information Modelling Application for Developing Sustainable Building (Multi Criteria Decision Making Approach). *Ain Shams Eng. J.* **2021**, *12*, 293–302. [CrossRef]
59. Inyim, P.; Rivera, J.; Zhu, Y. Integration of Building Information Modeling and Economic and Environmental Impact Analysis to Support Sustainable Building Design. *J. Manag. Eng.* **2015**, *31*, A4014002. [CrossRef]
60. Liu, Z.; Jiang, L.; Osmani, M.; Demian, P. Building Information Management (BIM) and Blockchain (BC) for Sustainable Building Design Information Management Framework. *Electronics* **2019**, *8*, 724. [CrossRef]
61. Najjar, M.; Figueiredo, K.; Palumbo, M.; Haddad, A. Integration of BIM and LCA: Evaluating the Environmental Impacts of Building Materials at an Early Stage of Designing a Typical Office Building. *J. Build. Eng.* **2017**, *14*, 115–126. [CrossRef]
62. Najjar, M.; Figueiredo, K.; Hammad, A.W.A.; Haddad, A. Integrated Optimization with Building Information Modeling and Life Cycle Assessment for Generating Energy Efficient Buildings. *Appl. Energy* **2019**, *250*, 1366–1382. [CrossRef]
63. Gavali, H.R.; Ralegaonkar, R.V. Application of Information Modelling for Sustainable Urban-Poor Housing in India. *Proc. Inst. Civ. Eng.—Eng. Sustain.* **2019**, *172*, 68–75. [CrossRef]
64. Kurian, C.P.; Milhoutra, S.; George, V.I. Sustainable Building Design Based on Building Information Modeling (BIM). In Proceedings of the 2016 IEEE International Conference on Power System Technology (POWERCON), Wollongong, NSW, Australia, 28 September–1 October 2016.
65. Liu, Z.; Zhang, C.; Guo, Y.; Osmani, M.; Demian, P. A Building Information Modelling (BIM) Based Water Efficiency (BWe) Framework for Sustainable Building Design and Construction Management. *Electronics* **2019**, *8*, 599. [CrossRef]
66. Safiullin, A.; Krasnyuk, L.; Kapelyuk, Z. Integration of Industry 4.0 Technologies for "Smart Cities" Development. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *497*, 012089. [CrossRef]
67. Boton, C.; Rivest, L.; Ghnaya, O.; Chouchen, M. What Is at the Root of Construction 4.0: A Systematic Review of the Recent Research Effort. *Arch. Comput. Methods Eng.* **2021**, *28*, 2331–2350. [CrossRef]
68. Scheffer, M.; Konig, M.; Engelmann, T.; Tagliabue, L.C.; Ciribini, A.L.C.; Rinaldi, S.; Pasetti, M. Evaluation of Open Data Models for the Exchange of Sensor Data in Cognitive Building. In Proceedings of the 2018 Workshop on Metrology for Industry 4.0 and IoT, Brescia, Italy, 16–18 April 2018.
69. Nesi, P.; Pantaleo, G.; Paolucci, M.; Zaza, I. Auditing and Assessment of Data Traffic Flows in an IoT Architecture. In Proceedings of the 2018 IEEE 4th International Conference on Collaboration and Internet Computing (CIC), Philadelphia, PA, USA, 18–20 October 2018.
70. Noje, D.; Dzitac, I.; Pop, N.; Tarca, R. IoT Devices Signals Processing Based on Shepard Local Approximation Operators Defined in Riesz MV-Algebras. *Informatica* **2020**, *31*, 131–142. [CrossRef]
71. Oztemel, E.; Gursev, S. Literature Review of Industry 4.0 and Related Technologies. *J. Intell. Manuf.* **2020**, *31*, 127–182. [CrossRef]
72. López Martínez, P.; Dintén, R.; Drake, J.M.; Zorrilla, M. A Big Data-Centric Architecture Metamodel for Industry 4.0. *Future Gener. Comput. Syst.* **2021**, *125*, 263–284. [CrossRef]
73. Ren, S.; Kim, J.-S.; Cho, W.-S.; Soeng, S.; Kong, S.; Lee, K.-H. Big Data Platform for Intelligence Industrial IoT Sensor Monitoring System Based on Edge Computing and AI. In Proceedings of the 2021 International Conference on Artificial Intelligence in Information and Communication (ICAIIC), Jeju Island, Korea, 13–16 April 2021.
74. Augustine, P. The Industry Use Cases for the Digital Twin Idea. In *Advances in Computers*; Elsevier: Amsterdam, The Netherlands, 2020; Volume 117, pp. 79–105.
75. Postránecký, M.; Svítek, M. Smart City near to 4.0—An Adoption of Industry 4.0 Conceptual Model. In Proceedings of the 2017 Smart City Symposium Prague (SCSP), Prague, Czech Republic, 25–26 May 2017.
76. Akın, Ş.; Ergün, O.; Surer, E.; Dino, İ.G. An Immersive Design Environment for Performance-Based Architectural Design: A BIM-Based Approach. In Proceedings of the 4th EAI International Conference on Smart Objects and Technologies for Social Good, Bologna, Italy, 28–30 November 2018.
77. Predescu, A.; Mocanu, M.; Lupu, C. ARMAX: A Mobile Geospatial Augmented Reality Platform for Serious Gaming. In Proceedings of the 2019 IEEE 15th International Conference on Intelligent Computer Communication and Processing (ICCP), Cluj-Napoca, Romania, 5–7 September 2019.
78. Mystakidis, S. Metaverse. *Encyclopedia* **2022**, *2*, 486–497. [CrossRef]
79. Chen, Q.; Chen, J.; Huang, W. Visualizing Large-Scale Building Information Modeling Models within Indoor and Outdoor Environments Using a Semantics-Based Method. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 756. [CrossRef]

80. Lee, J.; Kim, J. BIM-Based 4D Simulation to Improve Module Manufacturing Productivity for Sustainable Building Projects. *Sustainability* **2017**, *9*, 426. [CrossRef]
81. Olawumi, T.O.; Chan, D.W.M. Identifying and Prioritizing the Benefits of Integrating BIM and Sustainability Practices in Construction Projects: A Delphi Survey of International Experts. *Sustain. Cities Soc.* **2018**, *40*, 16–27. [CrossRef]
82. Ebertshäuser, S.; Graf, K.; Both, P.V.; Rexroth, K.; Bari, R.D.; Horn, R. Sustainable Building Information Modeling in the Context of Model-Based Integral Planning. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *323*, 012113. [CrossRef]
83. Manzoor, B.; Othman, I.; Gardezi, S.S.S.; Harirchian, E. Strategies for Adopting Building Information Modeling (BIM) in Sustainable Building Projects—A Case of Malaysia. *Buildings* **2021**, *11*, 249. [CrossRef]
84. Azzi, M.; Duc, H.; Ha, Q.P. Toward Sustainable Energy Usage in the Power Generation and Construction Sectors—A Case Study of Australia. *Autom. Constr.* **2015**, *59*, 122–127. [CrossRef]
85. Chelyshkov, P. Computer-Aided Design of Cyber-Physical Building Systems. *E3S Web Conf.* **2019**, *97*, 01012. [CrossRef]
86. Yamamura, S.; Fan, L.; Suzuki, Y. Assessment of Urban Energy Performance through Integration of BIM and GIS for Smart City Planning. *Procedia Eng.* **2017**, *180*, 1462–1472. [CrossRef]
87. Harter, H.; Singh, M.M.; Schneider-Marin, P.; Lang, W.; Geyer, P. Uncertainty Analysis of Life Cycle Energy Assessment in Early Stages of Design. *Energy Build.* **2020**, *208*, 109635. [CrossRef]
88. Qi, B.; Razkenari, M.; Costin, A.; Kibert, C.; Fu, M. A Systematic Review of Emerging Technologies in Industrialized Construction. *J. Build. Eng.* **2021**, *39*, 102265. [CrossRef]
89. Zhang, J.; Zhao, L.; Ren, G.; Li, H.; Li, X. Special Issue "Digital Twin Technology in the AEC Industry". *Adv. Civ. Eng.* **2020**, *2020*, e8842113. [CrossRef]
90. Chen, C.; Tang, L. BIM-Based Integrated Management Workflow Design for Schedule and Cost Planning of Building Fabric Maintenance. *Autom. Constr.* **2019**, *107*, 102944. [CrossRef]
91. Kamari, A.; Schultz, C.P.L.; Kirkegaard, P.H. Constraint-Based Renovation Design Support through the Renovation Domain Model. *Autom. Constr.* **2019**, *104*, 265–280. [CrossRef]
92. Olawumi, T.O.; Chan, D.W.M. Critical Success Factors for Implementing Building Information Modeling and Sustainability Practices in Construction Projects: A Delphi Survey. *Sustain. Dev.* **2019**, *27*, 587–602. [CrossRef]
93. Lee, J.Y.; Irisboev, I.O.; Ryu, Y.-S. Literature Review on Digitalization in Facilities Management and Facilities Management Performance Measurement: Contribution of Industry 4.0 in the Global Era. *Sustainability* **2021**, *13*, 13432. [CrossRef]
94. Marzouk, M.; Othman, A. Planning Utility Infrastructure Requirements for Smart Cities Using the Integration between BIM and GIS. *Sustain. Cities Soc.* **2020**, *57*, 102120. [CrossRef]
95. Reisinger, J.; Hollinsky, P.; Kovacic, I. Design Guideline for Flexible Industrial Buildings Integrating Industry 4.0 Parameters. *Sustainability* **2021**, *13*, 10627. [CrossRef]
96. Kuguoglu, B.K.; van der Voort, H.; Janssen, M. The Giant Leap for Smart Cities: Scaling Up Smart City Artificial Intelligence of Things (AIoT) Initiatives. *Sustainability* **2021**, *13*, 12295. [CrossRef]
97. Wang, H. Sensing Information Modelling for Smart City. In Proceedings of the 2015 IEEE International Conference on Smart City/SocialCom/SustainCom (SmartCity), Chengdu, China, 19–21 December 2015.
98. Xue, K.; Hossain, M.U.; Liu, M.; Ma, M.; Zhang, Y.; Hu, M.; Chen, X.; Cao, G. BIM Integrated LCA for Promoting Circular Economy towards Sustainable Construction: An Analytical Review. *Sustainability* **2021**, *13*, 1310. [CrossRef]
99. GhaffarianHoseini, A.; Zhang, T.; Nwadigo, O.; GhaffarianHoseini, A.; Naismith, N.; Tookey, J.; Raahemifar, K. Application of ND BIM Integrated Knowledge-Based Building Management System (BIM-IKBMS) for Inspecting Post-Construction Energy Efficiency. *Renew. Sustain. Energy Rev.* **2017**, *72*, 935–949. [CrossRef]
100. Seghier, T.E.; Ahmad, M.H.; Wah, L.Y.; Samuel, W.O. Integration Models of Building Information Modelling and Green Building Rating Systems: A Review. *Adv. Sci. Lett.* **2018**, *24*, 4121–4125. [CrossRef]
101. Veselka, J.; Nehasilová, M.; Dvořáková, K.; Ryklová, P.; Volf, M.; Růžička, J.; Lupíšek, A. Recommendations for Developing a BIM for the Purpose of LCA in Green Building Certifications. *Sustainability* **2020**, *12*, 6151. [CrossRef]
102. Pai, V.; Elzarka, H. Whole Building Life Cycle Assessment for Buildings: A Case Study ON HOW to Achieve the LEED Credit. *J. Clean. Prod.* **2021**, *297*, 126501. [CrossRef]
103. Marzouk, M.; Azab, S.; Metawie, M. Framework for Sustainable Low-Income Housing Projects Using Building Information Modeling. *J. Environ. Inform.* **2016**, *28*, 25–38. [CrossRef]
104. Liu, K.S.; Shih, Y.L.; Tzeng, C.T.; Chen, C.C. Research on Energy-saving Design Transformation on the External Shell of Existing Buildings—The Example of Kaohsiung City Townhouses. *J. Environ. Prot. Ecol. JEPE* **2014**, *15*, 1303–1314.
105. Widyatmoko, I. Digital Transformation to Improve Quality, Efficiency and Safety in Construction of Roads Incorporating Recycled Materials. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *599*, 012093. [CrossRef]
106. Khalesi, H.; Balali, A.; Valipour, A.; Antucheviciene, J.; Migilinskas, D.; Zigmund, V. Application of Hybrid SWARA–BIM in Reducing Reworks of Building Construction Projects from the Perspective of Time. *Sustainability* **2020**, *12*, 8927. [CrossRef]
107. Montiel-Santiago, F.J.; Hermoso-Orzáez, M.J.; Terrados-Cepeda, J. Sustainability and Energy Efficiency: BIM 6D. Study of the BIM Methodology Applied to Hospital Buildings. Value of Interior Lighting and Daylight in Energy Simulation. *Sustainability* **2020**, *12*, 5731. [CrossRef]
108. Amoruso, F.M.; Dietrich, U.; Schuetze, T. Indoor Thermal Comfort Improvement through the Integrated BIM-Parametric Workflow-Based Sustainable Renovation of an Exemplary Apartment in Seoul, Korea. *Sustainability* **2019**, *11*, 3950. [CrossRef]

109. Hetemi, E.; Ordieres-Meré, J.; Nuur, C. An Institutional Approach to Digitalization in Sustainability-Oriented Infrastructure Projects: The Limits of the Building Information Model. *Sustainability* **2020**, *12*, 3893. [CrossRef]
110. Saragih, L.R.; Dachyar, M.; Zagloel, T.Y.M.; Satar, M. The Industrial IoT for Nusantara. In Proceedings of the 2018 IEEE International Conference on Internet of Things and Intelligence System (IOTAIS), Bali, Indonesia, 1–3 November 2018.
111. Dahmane, W.M.; Ouchani, S.; Bouarfa, H. Towards a Reliable Smart City through Formal Verification and Network Analysis. *Comput. Commun.* **2021**, *180*, 171–187. [CrossRef]
112. Liu, Z.; Yang, Z.; Osmani, M. The Relationship between Sustainable Built Environment, Art Therapy and Therapeutic Design in Promoting Health and Well-Being. *Int. J. Environ. Res. Public. Health* **2021**, *18*, 10906. [CrossRef]
113. Verma, R. Smart City Healthcare Cyber Physical System: Characteristics, Technologies and Challenges. *Wirel. Pers. Commun.* **2022**, *122*, 1413–1433. [CrossRef]
114. Abbas, K.; Tawalbeh, L.A.; Rafiq, A.; Muthanna, A.; Elgendy, I.A.; Abd El-Latif, A.A. Convergence of Blockchain and IoT for Secure Transportation Systems in Smart Cities. *Secur. Commun. Netw.* **2021**, *2021*, e5597679. [CrossRef]
115. Benhamida, F.Z.; Casado-Mansilla, D.; Bennani, C.; López-de-Ipiña, D. Toward a Delay Tolerant Internet of Things. In Proceedings of the 9th International Conference on the Internet of Things, Bilbao, Spain, 22–25 October 2019.
116. Abdelhameed, W. Sustainable Design Approach: A Case Study of BIM Use. *E3S Web Conf.* **2017**, *23*, 2001. [CrossRef]
117. Pučko, Z.; Maučec, D.; Šuman, N. Energy and Cost Analysis of Building Envelope Components Using BIM: A Systematic Approach. *Energies* **2020**, *13*, 2643. [CrossRef]
118. Zubov, D.; Siniak, N.; Grencikova, A. Impact of Industry 4.0 Technologies on the Employment of the People with Eye Problems: A Case Study on the Spatial Cognition Within Industrial Facilities. In Proceedings of the International Scientific Conference on The Impact of Industry 4.0 on Job Creation, Trencianske Teplice, Slovakia, 22 November 2018.
119. Maskuriy, R.; Selamat, A.; Ali, K.N.; Mahdzir, A.; Marešová, P.; Krejcar, O. University Spin-Off: Effective Solution on Technology Transfer in AEC Industry for Intelligent City Transformation. In Proceedings of the 19th International Scientific Conference on Hradec Economic Days, Hradec Kralove, Czech Republic, 25–26 March 2021.
120. Chen, Z.; Liu, P.; Yang, Y. Optimizing Sustainable Building's Performance through Integrated Building Information Modeling Technology. In Proceedings of the 7th International Conference on Education, Management, Information and Mechanical Engineering (EMIM 2017), Shenyang, China, 28–30 April 2017.
121. Bolshakov, N.; Badenko, V.; Yadykin, V.; Celani, A. As-Built BIM in Real Estate Management: The Change of Paradigm in Digital Transformation of Economy. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *940*, 012017. [CrossRef]
122. Balasubramanian, S.; Shukla, V.; Islam, N.; Manghat, S. Construction Industry 4.0 and Sustainability: An Enabling Framework. *IEEE Trans. Eng. Manag.* **2021**, 1–19. [CrossRef]
123. Ziolkowski, A. Modelling of Digital Transformation Processes in Organizations. In Proceedings of the 35th International-Business-Information-Management-Association Conference (IBIMA), Seville, Spain, 1–2 April 2020.
124. Demirkesen, S.; Tezel, A. Investigating Major Challenges for Industry 4.0 Adoption among Construction Companies. *Eng. Constr. Archit. Manag.* **2021**, *29*, 1470–1503. [CrossRef]
125. Mannino, A.; Dejaco, M.C.; Re Cecconi, F. Building Information Modelling and Internet of Things Integration for Facility Management—Literature Review and Future Needs. *Appl. Sci.* **2021**, *11*, 3062. [CrossRef]
126. Slaný, V.; Lučanský, A.; Koudelka, P.; Mareček, J.; Krčálová, E.; Martínek, R. An Integrated IoT Architecture for Smart Metering Using Next Generation Sensor for Water Management Based on LoRaWAN Technology: A Pilot Study. *Sensors* **2020**, *20*, 4712. [CrossRef]
127. Poza-Lujan, J.-L.; Posadas-Yagüe, J.-L.; Simó-Ten, J.-E.; Blanes, F. Distributed Architecture to Integrate Sensor Information: Object Recognition for Smart Cities. *Sensors* **2020**, *20*, 112. [CrossRef] [PubMed]
128. Turner, C.J.; Oyekan, J.; Stergioulas, L.; Griffin, D. Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities. *IEEE Trans. Ind. Inform.* **2021**, *17*, 746–756. [CrossRef]
129. Sorokač, A.; Rigali, L. Industry 4.0 and Smart City in Mobile Machine's Control Systems. *IFAC-PapersOnLine* **2019**, *52*, 473–476. [CrossRef]
130. Ding, K.; Shi, H.; Hui, J.; Liu, Y.; Zhu, B.; Zhang, F.; Cao, W. Smart Steel Bridge Construction Enabled by BIM and Internet of Things in Industry 4.0: A Framework. In Proceedings of the 2018 IEEE 15th International Conference on Networking, Sensing and Control (ICNSC), Zhuhai, China, 27–29 March 2018.
131. Schimanski, C.P.; Pasetti Monizza, G.; Marcher, C.; Matt, D.T. Pushing Digital Automation of Configure-to-Order Services in Small and Medium Enterprises of the Construction Equipment Industry: A Design Science Research Approach. *Appl. Sci.* **2019**, *9*, 3780. [CrossRef]
132. Maskuriy, R.; Selamat, A.; Ali, K.N.; Maresova, P.; Krejcar, O. Industry 4.0 for the Construction Industry—How Ready Is the Industry? *Appl. Sci.* **2019**, *9*, 2819. [CrossRef]
133. Liu, K.S.; Chen, C.C. The Effects of Deep Balcony of Different Building Heights on Indoor Lighting and Thermo-Environment. *Appl. Ecol. Environ. Res.* **2017**, *15*, 103–109. [CrossRef]
134. Li, Y.-W.; Cao, K. Establishment and Application of Intelligent City Building Information Model Based on BP Neural Network Model. *Comput. Commun.* **2020**, *153*, 382–389. [CrossRef]
135. Ahmad, T.; Aibinu, A.; Thaheem, M.J. BIM-Based Iterative Tool for Sustainable Building Design: A Conceptual Framework. *Procedia Eng.* **2017**, *180*, 782–792. [CrossRef]

136. Ekasanti, A.; Dewi, O.C.; Putra, N.S.D. Green BIM Potential in Assessing the Sustainable Design Quality of Low-Income Housing: A Review. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1098*, 022078. [CrossRef]
137. Zanni, M.; Sharpe, T.; Lammers, P.; Arnold, L.; Pickard, J. Developing a Methodology for Integration of Whole Life Costs into BIM Processes to Assist Design Decision Making. *Buildings* **2019**, *9*, 114. [CrossRef]
138. Choi, J.; Kim, M.; Kim, I. A Methodology of Mapping Interface for Energy Performance Assessment Based on Open BIM. In Proceedings of the 20th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA 2015), Daegu, Korea, 20–22 May 2015.
139. Liu, S.; Meng, X.; Tam, C. Building Information Modeling Based Building Design Optimization for Sustainability. *Energy Build.* **2015**, *105*, 139–153. [CrossRef]
140. Wong, J.K.-W.; Kuan, K.-L. Implementing 'BEAM Plus' for BIM-Based Sustainability Analysis. *Autom. Constr.* **2014**, *44*, 163–175. [CrossRef]
141. Jalaei, F.; Jrade, A. Green BIM Potential in Assessing the Sustainable Design Quality of Low-Income Housing: A Review. *Sustain. Cities Soc.* **2015**, *18*, 95–107. [CrossRef]
142. Mgbere, C.; Knyshenko, V.A.; Bakirova, A.B. Building Information Modeling. A Management Tool for Smart City. In Proceedings of the 2018 IEEE 13th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT), Lviv, Ukraine, 11–14 September 2018.
143. Begić, H.; Galić, M. A Systematic Review of Construction 4.0 in the Context of the BIM 4.0 Premise. *Buildings* **2021**, *11*, 337. [CrossRef]
144. Xing, K.; Kim, K.P.; Ness, D. Cloud-BIM Enabled Cyber-Physical Data and Service Platforms for Building Component Reuse. *Sustainability* **2020**, *12*, 10329. [CrossRef]
145. Starynina, J.; Ustinovichius, L. A Multi-Criteria Decision-Making Synthesis Method to Determine the Most Effective Option for Modernising a Public Building. *Technol. Econ. Dev. Econ.* **2020**, *26*, 1237–1262. [CrossRef]
146. Liu, Z.; Chi, Z.; Osmani, M.; Demian, P. Blockchain and Building Information Management (BIM) for Sustainable Building Development within the Context of Smart Cities. *Sustainability* **2021**, *13*, 2090. [CrossRef]
147. Horn, R.; Ebertshäuser, S.; Di Bari, R.; Jorgji, O.; Traunspurger, R.; Both, P.V. The BIM2LCA Approach: An Industry Foundation Classes (IFC)-Based Interface to Integrate Life Cycle Assessment in Integral Planning. *Sustainability* **2020**, *12*, 6558. [CrossRef]
148. Liu, Z.; Lu, Y.; Shen, M.; Peh, L.C. Transition from Building Information Modeling (BIM) to Integrated Digital Delivery (IDD) in Sustainable Building Management: A Knowledge Discovery Approach Based Review. *J. Clean. Prod.* **2021**, *291*, 125223. [CrossRef]
149. Brockmann, T. Digitalization of Building LCA and International Activities—In the Context of German Assessment System for Sustainable Building. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *323*, 012108. [CrossRef]
150. Shrivastava, H.; Akhtar, S. Development of a Building Information Modeling Tool for Green Sustainable Building Design: A Review. *AIP Conf. Proc.* **2019**, *2158*, 020026.
151. Ginzburg, A. Sustainable Building Life Cycle Design. *MATEC Web Conf.* **2016**, *73*, 02018. [CrossRef]
152. Teply, R. Study of EDSM for Additive Technology in a Smart City. In Proceedings of the 59th International Conference of Machine Design Departments (ICMD), Demanovska Dolina, Slovakia, 11–14 September 2018.
153. Figl, H.; Ilg, M.; Battisti, K. 6D BIM-Terminal: Missing Link for the Design of CO2-Neutral Buildings. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *323*, 012104. [CrossRef]
154. Lorenzo, R.; Mimendi, L. Digitisation of Bamboo Culms for Structural Applications. *J. Build. Eng.* **2020**, *29*, 101193. [CrossRef]
155. Yitmen, I.; Alizadehsalehi, S.; Akıner, İ.; Akıner, M.E. An Adapted Model of Cognitive Digital Twins for Building Lifecycle Management. *Appl. Sci.* **2021**, *11*, 4276. [CrossRef]
156. Kuzina, O. Conception of the Operational Information Model of Smart City Control System. *E3S Web Conf.* **2019**, *97*, 01024. [CrossRef]
157. Zeiler, W. Integral Design: To Combine Architecture and Engineering for a Sustainable Built Environment. In Proceedings of the 18th International Conference on Engineering Design (ICED 11), Copenhagen, Denmark, 15–19 August 2011.
158. Dall'O', G.; Zichi, A.; Torri, M. Green BIM and CIM: Sustainable Planning Using Building Information Modelling. In *Green Planning for Cities and Communities. Research for Development*; Dall'O', G., Ed.; Springer: Cham, Switzerland; Berlin/Heidelberg, Germany, 2020; pp. 383–409.
159. Dantas, H.S.; Sousa, J.M.M.S.; Melo, H.C. The Importance of City Information Modeling (CIM) for Cities' Sustainability. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *225*, 012074. [CrossRef]
160. Souza, L.; Bueno, C. City Information Modelling as a Support Decision Tool for Planning and Management of Cities: A Systematic Literature Review and Bibliometric Analysis. *Build. Environ.* **2022**, *207*, 108403. [CrossRef]
161. Gil, J. City Information Modelling: A Conceptual Framework for Research and Practice in Digital Urban Planning. *Built Environ.* **2020**, *46*, 501–527. [CrossRef]
162. Reddy, P.; Pham, Q.-V.; Prabadevi, B.; Deepa, N.; Dev, K.; Gadekallu, T.; Ruby, R.; Liyanage, M. Industry 5.0: A Survey on Enabling Technologies and Potential Applications. *J. Ind. Inf. Integr.* **2021**, *26*, 100257.
163. Wang, W.; Guo, H.; Li, X.; Tang, S.; Li, Y.; Xie, L.; Lv, Z. BIM Information Integration Based VR Modeling in Digital Twins in Industry 5.0. *J. Ind. Inf. Integr.* **2022**, *28*, 100351. [CrossRef]
164. Kwok, T.K. Sustainable Engineering Paradigm Shift in Digital Architecture, Engineering and Construction Ecology within Metaverse. *Int. J. Comput. Inf. Eng.* **2022**, *16*, 112–115.

165. Yang, Q.; Zhao, Y.; Huang, H.; Xiong, Z.; Kang, J.; Zheng, Z. Fusing Blockchain and AI with Metaverse: A Survey. *IEEE Open J. Comput. Soc.* **2022**, *3*, 122–136. [CrossRef]
166. Zonta, T.; da Costa, C.A.; da Rosa Righi, R.; de Lima, M.J.; da Trindade, E.S.; Li, G.P. Predictive Maintenance in the Industry 4.0: A Systematic Literature Review. *Comput. Ind. Eng.* **2020**, *150*, 106889. [CrossRef]
167. Durmisevic, S.; Sariyildiz, I.; Durmisevic, E.; Brouwer, J. Sustainability by Strengthening the Relation between Disciplines Involved (Zie Ook Informatica). *Durab. Build. Mater. Compon. 8 Serv. Life Durab. Mater. Compon.* **1999**, *3*, 2012–2020.
168. Wang, N.; Adeli, H. Sustainable Building Design. *J. Civ. Eng. Manag.* **2014**, *20*, 1–10. [CrossRef]
169. Pathmabandu, C.; Grundy, J.; Chhetri, M.B.; Baig, Z. ICME: An Informed Consent Management Engine for Conformance in Smart Building Environments. In Proceedings of the 29th ACM Joint Meeting on European Software Engineering Conference and Symposium on the Foundations of Software Engineering, Athens, Greece, 23–28 August 2021.
170. Bo, W.; Zhang, Y.; Hong, X.; Sun, H.; Huang, X. Usable Security Mechanisms in Smart Building. In Proceedings of the 2014 IEEE 17th International Conference on Computational Science and Engineering, Chengdu, China, 19–21 December 2014.
171. Inibhunu, C.; McGregor, C. Privacy Preserving Framework for Big Data Management in Smart Buildings. In Proceedings of the 2021 IEEE International Conference on Pervasive Computing and Communications Workshops and other Affiliated Events (PerCom Workshops), Kassel, Germany, 22–26 March 2021.
172. He, C.; Hou, Y.; Ding, L.; Li, P. Visualized Literature Review on Sustainable Building Renovation. *J. Build. Eng.* **2021**, *44*, 102622. [CrossRef]
173. Nielsen, A.N.; Jensen, R.L.; Larsen, T.S.; Nissen, S.B. Early Stage Decision Support for Sustainable Building Renovation—A Review. *Build. Environ.* **2016**, *103*, 165–181. [CrossRef]
174. Khaddaj, M.; Srour, I. Using BIM to Retrofit Existing Buildings. *Procedia Eng.* **2016**, *145*, 1526–1533. [CrossRef]
175. Volk, R.; Stengel, J.; Schultmann, F. Building Information Modeling (BIM) for Existing Buildings—Literature Review and Future Needs. *Autom. Constr.* **2014**, *38*, 109–127. [CrossRef]
176. Wu, Z.; Yu, A.T.W.; Shen, L.; Liu, G. Quantifying Construction and Demolition Waste: An Analytical Review. *Waste Manag.* **2014**, *34*, 1683–1692. [CrossRef]
177. Casabianca, A. Economic and Environmental Effectiveness of Incentives Tools for the Building Waste Recycling. In Proceedings of the 2006 First International Symposium on Environment Identities and Mediterranean Area, Corte-Ajaccio, France, 9–12 July 2006.
178. Ei Compendex. Available online: https://www.elsevier.com/solutions/engineering-village/content/compendex (accessed on 10 August 2022).