buildings

MDPI

Review

Internet of Things (IoT), Building Information Modeling (BIM), and Digital Twin (DT) in Construction Industry: A Review, Bibliometric, and Network Analysis

Milad Baghalzadeh Shishehgarkhaneh [1], Afram Keivani [2,*], Robert C. Moehler [3], Nasim Jelodari [4] and Sevda Roshdi Laleh [5]

[1] Department of Construction Management, Tabriz Branch, Islamic Azad University, Tabriz 5157944533, Iran
[2] Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz 5157944533, Iran
[3] Department of Civil Engineering, Faculty of Engineering, Monash University, Clayton, VIC 3800, Australia
[4] Department of Computer Engineering, Tabriz Branch, Islamic Azad University, Tabriz 5157944533, Iran
[5] Department of Education Science, University of Tabriz, Tabriz 5166616471, Iran
* Correspondence: keivani@gmail.com or keivani@iaut.ac.ir

Abstract: The present study uses a bibliometric and systematic literature review (SLR) to examine the use of Building Information Modeling (BIM), the Internet of Things (IoT), and Digital Twins (DT) in the construction industry. The network visualization and other approaches based on the Web of Science (WOS) database and the patterns of research interactions were explored in 1879 academic publications using co-occurrence and co-citation investigations. Significant publications, conferences, influential authors, countries, organizations, and funding agencies have been recognized. Our study demonstrates that BIM, IoT, and DT in construction, Heritage BIM (HBIM), Smart Contracts, BIM, and Ontology, and VR and AR in BIM and DT are the main study themes. Finally, several prospective areas for future study are identified, including BIM and Metaverse technology, BIM and Artificial Intelligence (AI), Metaheuristic algorithms for optimization purposes in BIM, and the Circular Economy with BIM and IoT.

Keywords: Building Information Modeling (BIM); Internet of Things (IoT); Digital Twins (DT); bibliometric; systematic literature review (SLR); network analysis

Citation: Baghalzadeh Shishehgarkhaneh, M.; Keivani, A.; Moehler, R.C.; Jelodari, N.; Roshdi Laleh, S. Internet of Things (IoT), Building Information Modeling (BIM), and Digital Twin (DT) in Construction Industry: A Review, Bibliometric, and Network Analysis. *Buildings* **2022**, *12*, 1503. https://doi.org/10.3390/buildings12101503

Academic Editors: Saeed Reza Mohandes, Timothy Olawumi and Maxwell Fordjour Antwi-Afari

Received: 6 September 2022
Accepted: 19 September 2022
Published: 22 September 2022

1. Introduction

To address chronic low productivity and unsatisfactory construction project performance, researchers and professionals in the fields of architecture, engineering, and construction (AEC) are looking at alternatives to standard project delivery models and approaches. Failures of integration and collaboration, which are crucial for enhancing and regulating the value stream, have been recognized as a core reason for these performance concerns. The original design assistance tools to assist architects in building design were paper and pen; with the advent of Computer-Aided Design (CAD) tools, architects were able to use digital drawing methods to construct vertical and horizontal lines. In the previous several decades, CAD tool techniques have evolved iteratively, from their early limitation of copying pen and paper to the succeeding provision of numerous computing and linking capabilities [1,2]. A framework known as "construction 4.0" intends to bring together three major categories: (i) industrial production, (ii) cyber-physical systems, and (iii) digital and computational technologies. Prefabrication and off-site manufacturing are examples of industrial production, and sensors, the Internet of Things (IoT), robotics, and drones are the main emphasis of cyber-physical systems in these processes. Building Information Modeling (BIM), Digital Twin (DT), artificial intelligence (AI), augmented/virtual reality (AR/VR), and cloud computing are examples of digital-computational technology.

1.1. Building Information Modeling (BIM)

BIM can be an important component of information management in the AEC sectors by focusing on the need for information management and data interchange between stakeholders throughout the project lifecycle [3,4]. BIM is a set of procedures that helps enhance the building industry's outputs, relationships, and responsibilities. To facilitate better communication among BIM stakeholders, these deliverables are organized according to the notion of "level of development," a reference tool specifying minimum requirements for the features and details of components in 3D models [5–7]. Figure 1 shows the different dimensions of BIM.

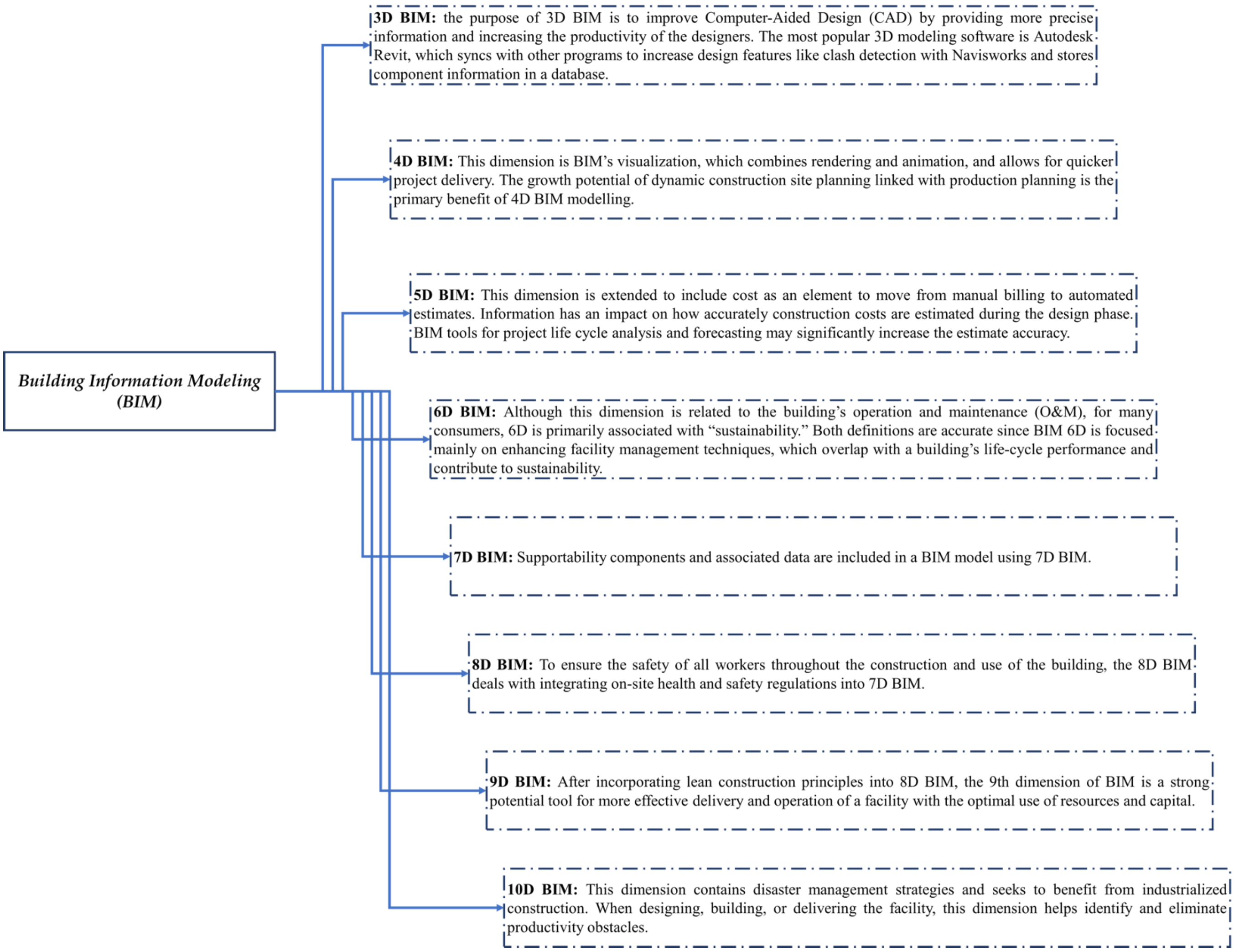


Figure 1. Different dimensions of BIM [8–21].

As can be seen in Figure 2, BIM is broken down into three distinct areas: policy, process, and technology. When these three disciplines work together, a framework emerges for digitally managing building data throughout the design and construction phases. Furthermore, BIM is a new approach to the whole building lifecycle data creation, use, and sharing process [22–24]. Furthermore, although some claim that BIM can only be used for construction projects, many contend that because the word "building" in BIM refers to the construction process rather than a physical structure, BIM can be applied to civil infrastructure projects to enhance project delivery [25]. Employing BIM in civil infrastructure facilities, such as bridges [26–29], tunnels [30–33], dams [34], airports [35,36], and railways [37–39], is called "civil information modeling" (CIM) in the AEC sector. BIM could be utilized for different purposes in civil infrastructure projects, including visualization, design and modeling, lifecycle information management, structural health analysis, traffic flow simulation, computational fluid dynamics, clash detection, time and cost management, and sustainability.

1.2. Digital Twins (DT)

However, the AEC sector has only lately started using the Digital Twin (DT) technique. The concept of using a twin model dates back to the 1970s when NASA's Apollo program created two identical spacecraft to mirror the circumstances of the spacecraft [40]. The terms "BIM" and "DT" are often used interchangeably. While a DT's key role is to simulate the object it reflects, BIM's primary goal is to produce a 3D extension of a real-world item. It is feasible to interchange data and information with other DT simulators and programs by including data and information throughout the lifecycle of an asset [41].

Technical capabilities (such as software, sensors, and actuators) and a solid comprehension of conceptual support techniques, such as industrial resource management, technology lifecycles, natural resource management, and communication tools, are necessary for the successful operation of a DT. According to research from Cambridge University, a method for using artificial intelligence to make Digital Twins of patients and track their health state has been discovered [42]. Additionally, a DT employs tools and technologies to map the physical thing's stored data, aiding in the production of current knowledge about the physical object. As in cyber-physical systems, it performs via synchronized real-time information coordination between the hardware (physical object) and software (virtual object) [43]. To describe the change from BIM to DT, Deng, et al. [44] developed a five-level ladder taxonomy. The stages of BIM include level 1, level 2, assisted simulations, level 3, integration with IoT, level 4, coupled with AI techniques for predictions, and level 5, optimum DT. Based on the building life cycle, each level of the ladder taxonomy was divided into a number of sub-categories with a focus on distinct study disciplines allocated to the design, construction, operation, and demolition stages.

Developing DT frameworks often involves integrating the Internet of Things (IoT), BIM, and finite element models. These DT frameworks provide updates that are practically real-time to improve construction management.

1.3. Internet of Things (IoT)

IoT is described by the International Organization for Standardization (ISO 2018) as "an infrastructure made up of linked systems, systems, people, and information resources, together with intelligent services that enable them to manage and respond to information from both the real world and the virtual world". Therefore, the IoT combines physical and virtual states that incorporate physical parts such as sensors, actuators, cloud services, communications, and protocols with varying designs to provide a framework and explanation for IoT systems [45]. Rapid advances in sensor and communication technology in recent years have fueled the expansion of the IoT, leading to the widespread use of connected devices and sensors in fields as diverse as transportation, safety, health, smart buildings, and automobile manufacturing [46]. Notably, IoT sensors allow Digital Twins to be synced with the state of physical assets by detecting one or more conditions in physical assets, transforming those circumstances into signals that humans or machines can read, and connecting to the internet to communicate with others. IoT sensors come in a wide variety of forms, and the AEC industry often uses devices such as GPS, image sensors, proximity sensors, radio frequency identification sensors, motion sensors, and biosensors [47].

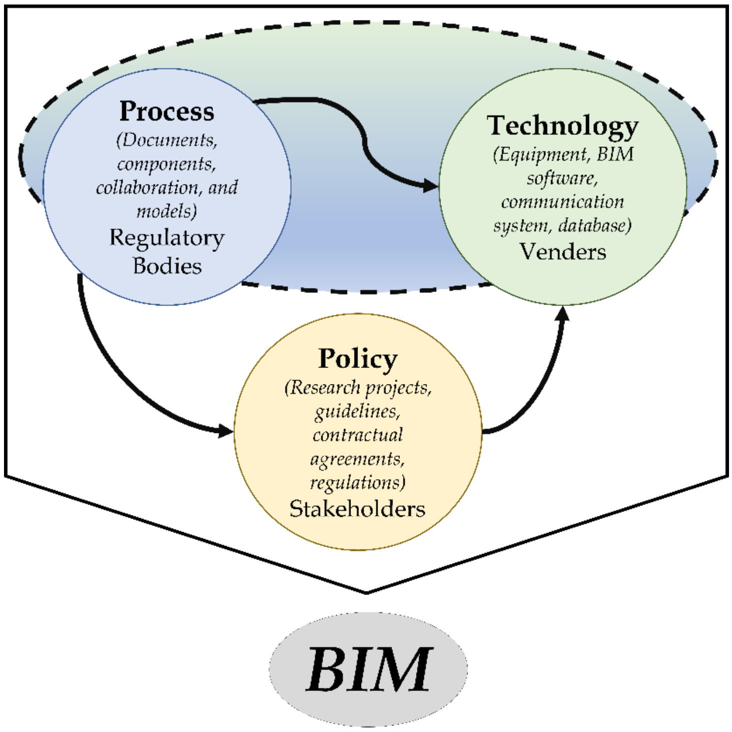


Figure 2. The three main fields in BIM [48].

A complete analysis of BIM, IoT, and DT in the construction industry should be conducted to extract multiple perspectives on user perceptions and experiences. In addition, it is required to identify emerging trends, provide research results, and suggest the potential for future research paths on the use of BIM, IoT, and DT to improve construction process management and service delivery. The following research questions will be addressed by this study using a bibliometric and systematic review analysis:

What keywords are most applicable to research on BIM, IoT, and DT in construction?

Which publications and authors have produced the most notable work on BIM, IoT, and DT in construction studies?

What are academics' most popular BIM, IoT, and DT topics?

What are the future trends of BIM, IoT, and DT in construction research works?

This literature study aims to ameliorate our perspectives on implementing BIM, IoT, and DT in the construction industry. This research will also assist academics in proposing novel research topics by analyzing Web of Science WOS database papers for their future research works. This study uses the systematic review approach to explore and map the literature on construction project management. The results of this study highlight the important topics in the BIM, IoT, and DT literature and provide a better understanding of current research directions.

2. Research Method

In this research, 5063 scholarly papers, including journal articles, proceeding articles, and book chapters concerning Building Information Modeling (BIM), Internet of Things (IoT), and Digital Twins (DT), have been gathered from the Web of Science (WOS) dataset as a data source. Subsequently, 3184 papers were omitted from further analysis since they were unrelated to the construction projects and were written in languages other than English. Consequently, 1879 papers were chosen for a bibliometric and systematic review analysis. In the field of construction management science, there are no established protocols for comprehensive literature reviews [49]. However, research might use keyword searches to discover relevant information and apply any necessary analysis. Figure 3 shows the methodological procedure framework of this study [50]. The four-step process used in this article has been implemented, including defining the borders, identifying the research questions, choosing the papers to include in the search, doing a bibliometric analysis, and presenting the findings. This review approach makes an effort to understand the relationships among authors, regions, keywords, and journal citations and offers a brief assessment of state-of-the-art existing or emerging research fields.

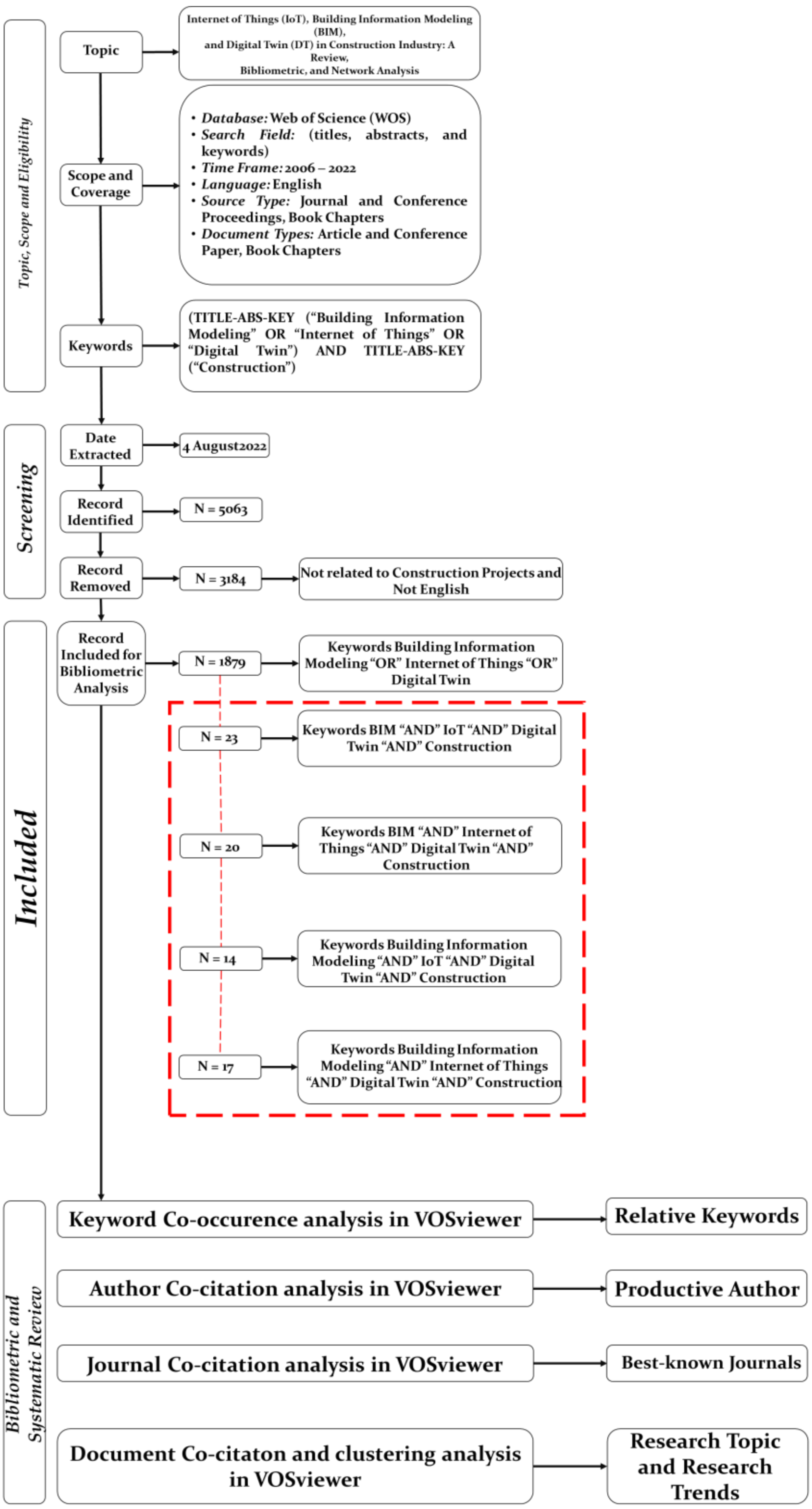


Figure 3. The methodological framework of the current research.

2.1. Bibliometric Analysis

In order to provide a quantitative examination of written publications, bibliometric methodologies have been utilized. The analytical workset quickly made use of statistical methods [51]. The growth and accessibility of bibliometric tools such as Gephi, Leximancer, and VOSviewer and scientific databases such as Scopus, Google Scholar, and the Web of Science (WOS), as well as the spread of bibliometrics from the field of information science into the business sector research, are two key reasons for the field's rising popularity [52].

Clarivate Analytics' Web of Science (WOS) was used to undertake a bibliometric analysis of BIM, IoT, and DT in construction projects from 2006 to 2022 as part of the present research.

2.2. Systematic Literature Review Analysis

The systematic literature review (SLR) emerged as a viable tool for examining prior literature to bring the subject closer [53,54]. A SLR can assist with several aspects of the research process, including establishing a context and defining a research problem, looking for theoretical support, rationalizing a problem and developing new lines of inquiry, separating what has been done from what needs to be done, identifying the main findings of, and avoiding fruitless research [55]. A bibliometric search employing the keywords, title, and abstract codes was conducted to thoroughly assess the BIM, IoT, and DT in construction literature. Keyword co-occurrence, author co-citation, burst identification, journal co-citation, document co-citation, and clustering analysis were all carried out to determine the research trend.

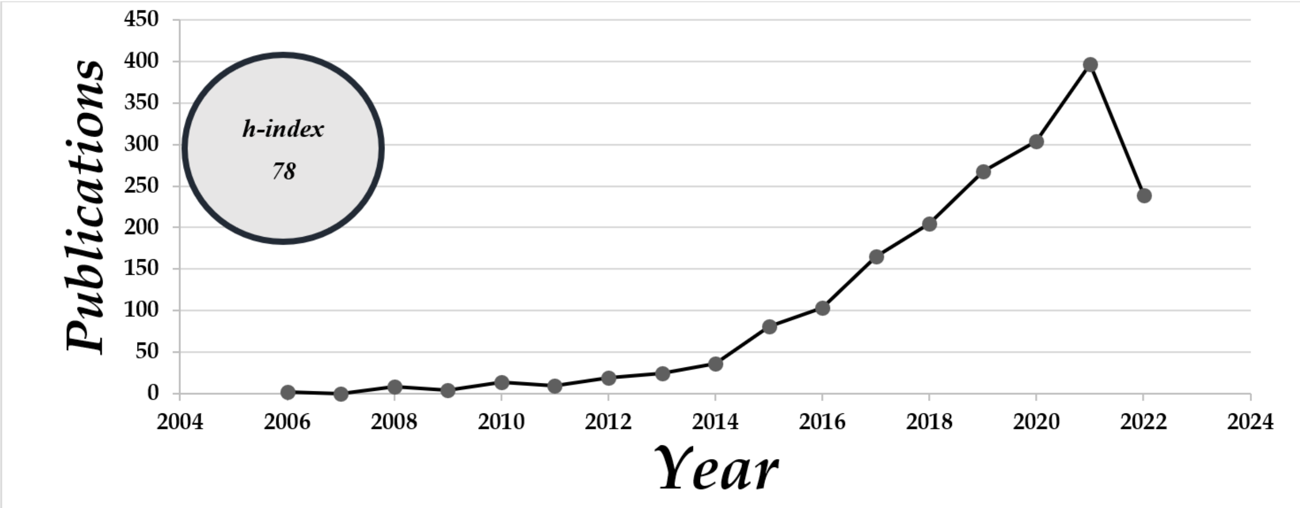
2.3. Tool for the Analyses

Bibliometrix, CitNetExplorer, VOSviewer, ScienceScape, Gephi, and Citspace are some tools developed to aid network analysis, visualization, and improved understanding of the vast amounts of data and information using database analytic methodologies. However, the present research utilized VOSviewer software. VOSviewer is freely accessible to the scholarly community engaged in bibliometrics research and can be used to create author or journal maps based on co-citation data and keyword maps based on co-occurrence data [56].

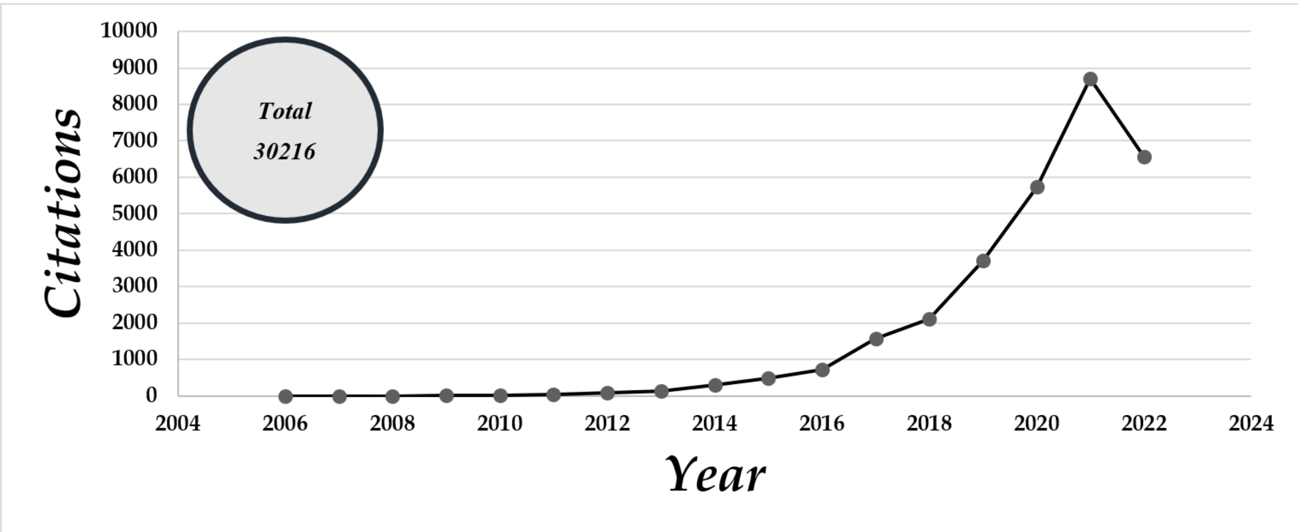
3. Data Collection and Analysis

In this study, academic documents, journals, and conference papers were extracted using the Web of Science (WOS) in the field of BIM, IoT, and DT in construction projects. Based on the WOS database, Figure 4a indicates the number of papers between 2006 and 2022. The number of documents increased from 2 in 2006 to 103 in 2016. Subsequently, the number of documents boomed to 397 in 2021. Finally, 239 documents were provided in the eight months of 2022 that this study evaluated.

Furthermore, the number of citations is provided in Figure 4b, in which the total number of citations is 30,216, and 22,746 are without self-citations. The average citation per item and H-index are 16.02 and 78, respectively. It is evident that the number of citations has increased exponentially from 2006 to 2021; even though there remains a reduction in the number of citations in 2022, only its first eight months have been considered in this study.



(**a**)



(**b**)

Figure 4. (**a**) Number of publications from 2006 to 2022; (**b**) Number of citations from 2006 to 2022.

3.1. Co-Authorship

This study conducted an authorship analysis utilizing the VOSviewer program to find prominent authors, active organizations, and nations and analyze their relationships.

3.1.1. Geographical Analysis of Publications

The sample used in this study contains 81 countries throughout the world. Figure 5 elucidates the bibliographic coupling for countries with 197 links, 7 clusters, and a total link strength of 615, with 10 minimum documents per country. However, Table 1 indicates the number of documents, citations, and link strength of the first 20 nations. The highest number of documents are from China, accounting for 506, followed by the USA, with 371 documents. In stark contrast, Israel has published the fewest papers regarding BIM, IoT, and DT in the construction industry, with 24 documents. However, although the USA ranks second in the number of documents, it has the highest number of citations in the 16 years, followed by China and South Korea. The least number of citations is given by India, with nearly 290 citations. Meanwhile, a country's impact can be measured by its average number of publications and citations per publication, of which Israel has the highest value among other nations.

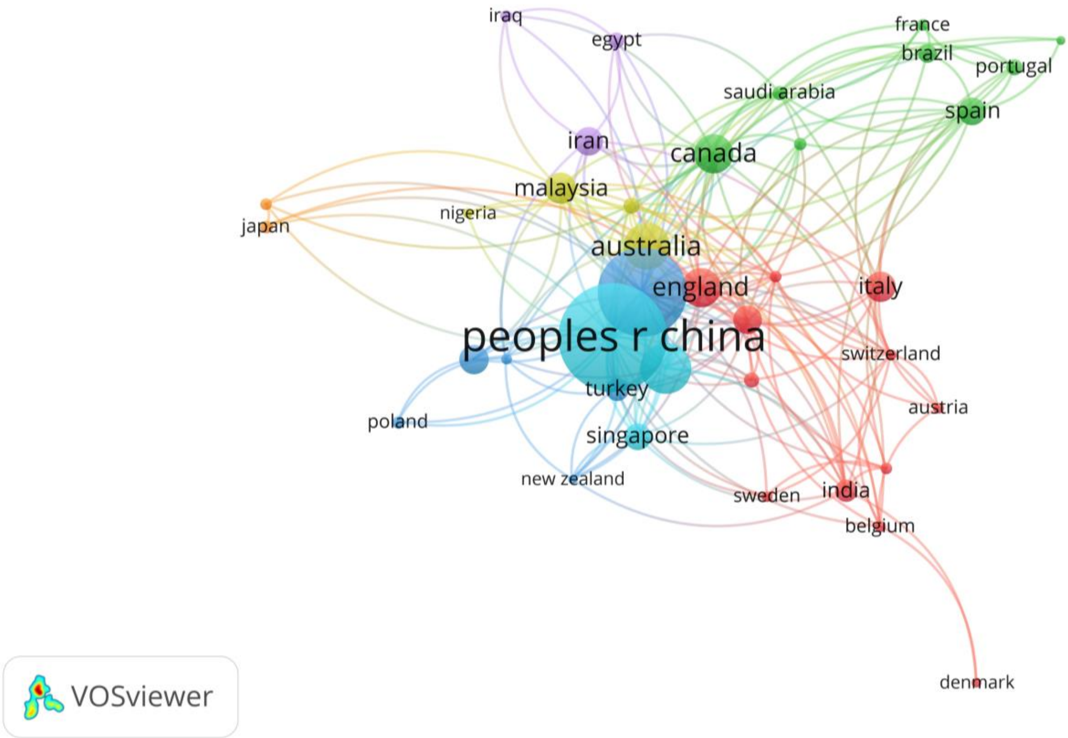


Figure 5. Bibliographic coupling for countries.

Table 1. The number of documents and citations of the top 20 countries.

No.	Country	Documents	Citations	Total Link Strength	Average Citation/Publication
1	China	506	7392	214	14.60869565
2	USA	371	8599	150	23.17789757
3	South Korea	151	3330	71	22.05298013
4	Australia	131	2825	134	21.5648855
5	England	102	1933	80	18.95098039
6	Canada	100	1870	49	18.7
7	Malaysia	71	398	63	5.605633803
8	Italy	67	678	15	10.11940299
9	Taiwan	65	1136	17	17.47692308
10	Iran	62	499	46	8.048387097
11	Germany	61	1610	29	26.39344262
12	Spain	58	726	29	12.51724138
13	Singapore	56	1105	54	19.73214286
14	Turkey	45	611	20	13.57777778
15	India	41	287	18	7
16	Brazil	31	474	12	15.29032258
17	Egypt	26	396	8	15.23076923
18	Pakistan	26	349	25	13.42307692
19	Portugal	26	534	14	20.53846154
20	Israel	24	967	14	40.29166667

3.1.2. Organizations

The 20 organizations with the most scholarly articles in the relevant fields are shown in Table 2. The categorization reveals that most of the productive institutions are from Asia. The University of Hong Kong is the most prolific organization and produced 51 publications over the mentioned period. The University of Florida has 50 publications, followed by

Hong Kong Polytechnic University (48 publications). Based on the data, it could be inferred that the most influential organizations are from Asia. Furthermore, the Georgia Institute of Technology has the highest average citation per publication value among 20 universities, and the National University of Singapore is the best university, with an excellent ranking worldwide in 2022. Figure 6 displays the renowned universities that published papers on the subjects and the institutional collaboration.

Table 2. Top 20 publishing organizations across the world.

No.	Organization	QS Ranking	Documents	Citations	Total Link Strength	Average Citation/Publication
1	The University of Hong Kong	21	51	1478	22	28.98039
2	University of Florida	188	50	876	14	17.52
3	Hong Kong Polytechnic University	65	48	1435	31	29.89583
4	Tongji University	212	43	845	13	19.65116
5	Georgia Institute of Technology	88	39	2136	6	54.76923
6	Hong Kong University of Science and Technology	40	39	1019	23	26.12821
7	Curtin University	193	37	1185	32	32.02703
8	Hanyang University	157	35	968	11	27.65714
9	Tsinghua University	14	32	639	9	19.96875
10	National University of Singapore	11	31	718	27	23.16129
11	Purdue University	129	28	241	4	8.607143
12	Penn State University	15	26	524	10	20.15385
13	University of Tehran	501–510	26	166	2	6.384615
14	National Taiwan University	77	24	391	5	16.29167
15	Shenzhen University	581–591	24	642	17	26.75
16	Southeast University	461	23	135	9	5.869565
17	Huazhong University of Science and Technology	306	20	415	7	20.75
18	Kyung Hee University	270	20	898	15	44.9
19	Politecnico di Milano	139	20	308	2	15.4
20	Yonsei University	73	19	297	3	15.63158

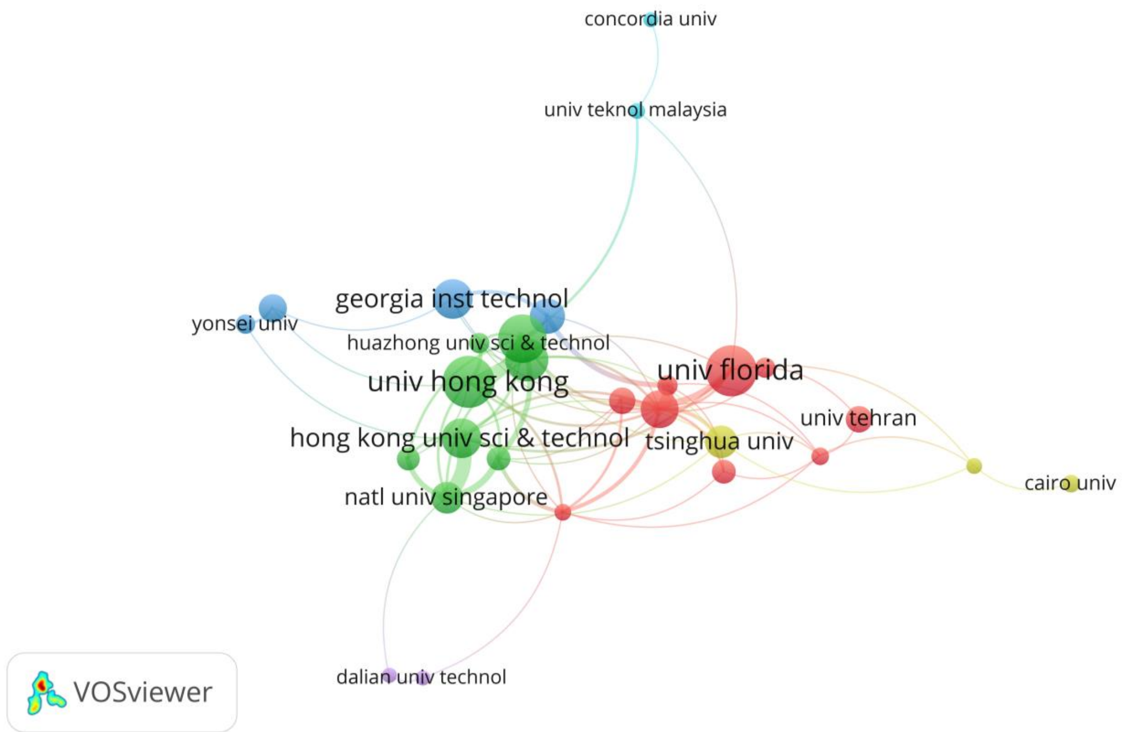


Figure 6. The network of organization cooperation.

3.1.3. Funding Agencies

Organizations known as funding agencies provide grants, scholarships, and other types of assistance to persons, programs, and projects in a particular field. Non-profit groups, private foundations, and governmental entities may all serve as funding sources. A financing agency's main objective is often to support excellence or foster enthusiasm for a specific field, such as renewable energy, the environment, charitable endeavors, or technological advancements in medicine. The entire cost of research is covered by funding agencies, which also contribute to overhead expenses. Table 3 shows the most prominent funding agencies extracted from the Web of Science (WOS) dataset. It can be seen that the National Natural Science Foundation of China (NSFC) has supported 154 documents in the mentioned fields, followed by the National Science Foundation (NSF) with 42 and the National Research Foundation of Korea providing 37with funding assistance.

Table 3. Top 10 funding agencies in the world.

No.	Name of Agency	Number of Documents
1	National Natural Science Foundation of China (NSFC)	154
2	National Science Foundation (NSF)	42
3	National Research Foundation of Korea	37
4	European Commission	32
5	Fundamental Research Funds for the Central Universities	30
6	Natural Sciences and Engineering Research Council of Canada (NSERC)	26
7	National Key R&D Programmes	21
8	Ministry of Science and Technology (Taiwan)	16
9	Ministry of Land, Infrastructure, and Transport of the Korean Government	13
10	The Hong Kong Polytechnic University	13

3.1.4. Author Productivity

The author productivity section uses the co-authorship indicator to identify more productive and collaborative authors. It helped us rate the authors according to the number of papers and citations they had received. There were 4632 authors responsible for publishing 1879 documents that were extracted; however, only 109 authors had published five or more publications. Of the 4632 authors identified by VOSviewer, we concentrated on the top 20 authors with documents and citations. Table 4 displays the twenty most prolific researchers in the topic under study. Jack C.P. Cheng of the Hong Kong University of Science and Technology is the most prolific author, having written 34 articles with a total of 936 citations over the analysis period. Regarding citations received in this study topic, CM Eastman placed first. With a total of 22 research publications, Wilson LU placed second, and Heap-Yih (John) Chong and Jiansong Zhang follow with 18 articles.

Table 4. Top 20 authors in the field of BIM, IoT, and DT in construction.

No	Author	Documents	Citations	Total Link Strength	Average Citation/Publication
1	Jack C.P. Cheng	34	936	28	27.52
2	Wilson LU	22	816	16	37.09
3	Heap-Yih (John) Chong	18	173	4	9.61
4	Jiansong Zhang	18	125	3	6.94
5	Xiangyu Wang	17	972	6	57.17
6	Issa Ramaji	15	379	0	25.26
7	CM Eastman	14	1103	7	78.78
8	Vincent J.L. GAN	13	283	13	21.76
9	Qian Wang	13	286	10	22
10	Ke Chen	12	396	11	33
11	Yong-Cheol Lee	12	196	9	16.33
12	Heng Li	12	239	1	19.91

Table 4. *Cont.*

No	Author	Documents	Citations	Total Link Strength	Average Citation/Publication
13	Mohamed Marzouk	12	245	0	20.41
14	Rafael Sacks	12	746	1	62.16
15	Shang-Hsien Hsieh	11	210	2	19.09
16	Fernanda Leite	11	172	0	15.63
17	Sheryl Staub-French	11	300	0	27.27
18	Keyu Chen	10	227	13	22.70
19	M. Reza Hosseini	10	183	0	18.30
20	Fan Xue	10	764	8	76.40

Furthermore, based on the co-authorship study, Figure 7 illustrates a cooperation map among the prominent authors. The colors reflect working groups, while the size of the circles represents the number of publications each author has published. The network's extensive dispersion might facilitate the rapid expansion of the study field.

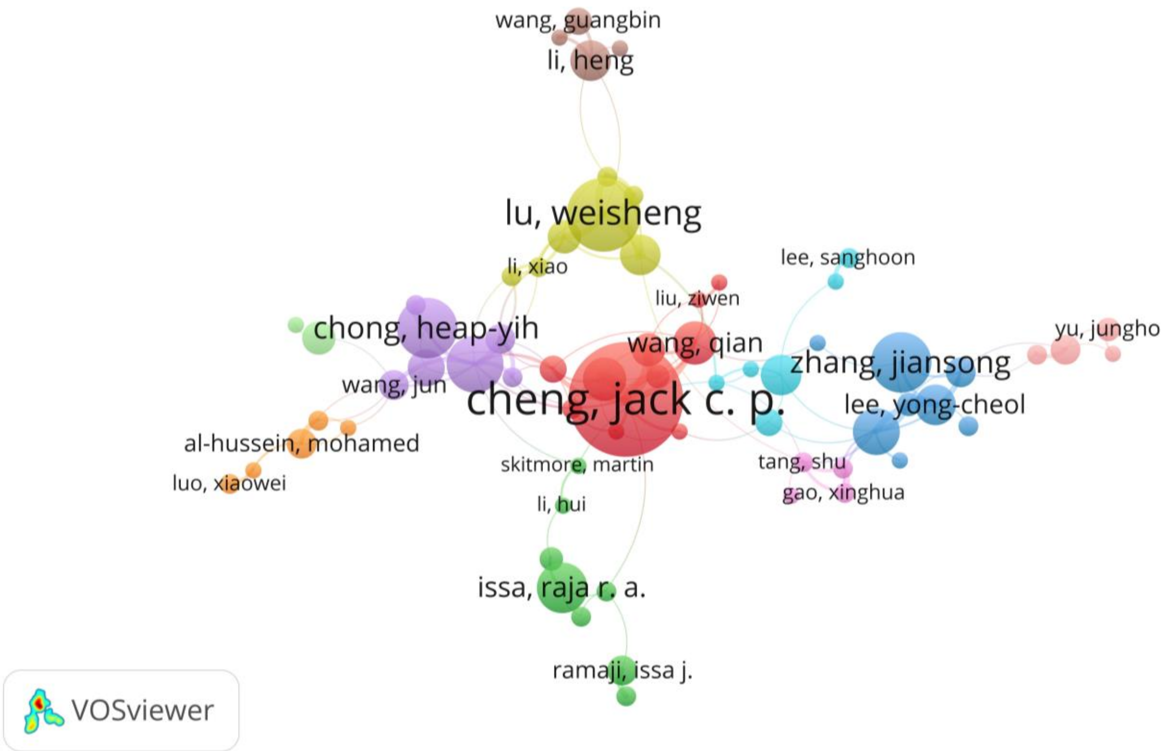


Figure 7. The network of cooperation considering co-authorship.

3.2. Keyword Co-Occurrence Analysis

In this study, networks are created utilizing data from the WOS database and the VOSviewer tool, which also does a keyword co-occurrence analysis. The network that was formed is based on distance, and the distance between nodes indicates how closely connected the keywords are to one another [57]. To display a reproducible visualization of the keywords of studies in the dataset, "Author keywords" were utilized instead of all keywords [58]. Hence, from the dataset, 4018 keywords in total were retrieved. With the minimum number of occurrences set to 15, 48 keywords connected through 412 links met the criteria to be included in the network. Figure 8 elucidates the keywords co-occurrence network. The most popular keywords are included in Table 5, along with their occurrence, links, and total link strength.

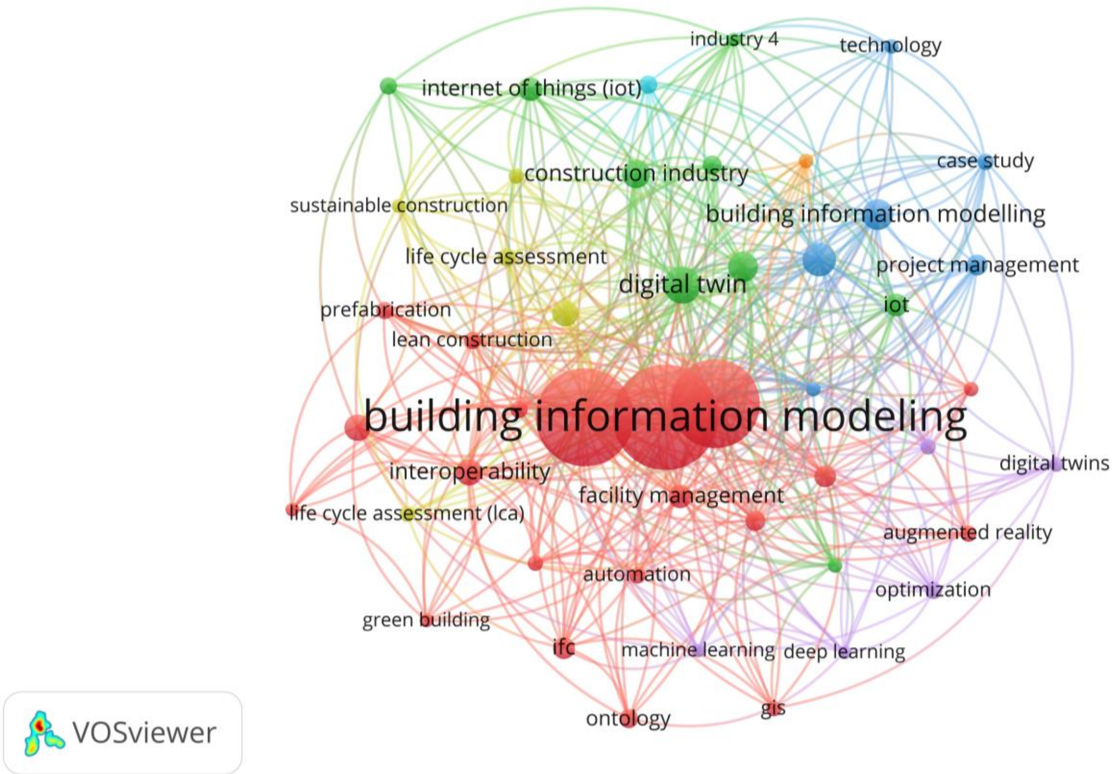


Figure 8. Network of keywords co-occurrence.

Table 5. The most prominent keywords in this study.

No.	Keyword	Occurrences	Total Link Strength
1	Building Information Modeling	434	315
2	Building Information Modeling (BIM)	383	225
3	BIM	327	291
4	digital twin	77	104
5	construction	64	105
6	building information modelling	57	80
7	Internet of Things	54	70
8	construction industry	48	62
9	industry foundation classes (ifc)	44	58
10	sustainability	44	75
11	interoperability	43	78
12	facility management	37	62
13	Internet of Things (IoT)	37	43
14	4D BIM	36	80
15	IoT	35	48
16	ifc	33	45
17	construction management	32	45
18	project management	30	49
19	visualization	28	47
20	blockchain	26	47
21	ontology	25	31
22	5D BIM	8	26
23	6D BIM	3	15

Meanwhile, after the coronavirus pandemic, the keywords “COVID-19” (three times) and “COVID-19 management” (one time) have been indicated as the keyword among studied documents in the field of BIM in construction projects. As shown in Table 1, the keyword “Building Information Modeling” is the most popular author keyword in the literature, followed by "Building Information Modeling (BIM)". Based on the data, Building Information Modeling has been used in different forms in the pieces of literature, such as *BIM, Building Information Modeling, Building Information Modeling (BIM), building information modelling (BIM), building information model (BIM), BIM implementation, building information modelling, building information model, BIM technology, building information model/modeling (BIM), and BIM (building information modelling).* Regarding the Internet of Things, the keywords "Internet of Things" and "Internet of Things (IoT)", and for Digital Twin, the keywords "digital twin" and "digital twins" are the most prominent. In terms of the number of links, "Building Information Modeling" and "Building Information Modeling (BIM)" have the highest among other nodes.

3.3. Co-Citation Analysis

3.3.1. Author Co-Citation

Co-citation analysis is a frequently used approach in bibliometric studies that helps map a subject's intellectual structure and explore the academic connections between the significant works in a field. The co-citation approach is based on the frequency with which two pieces of prior literature are cited in a subsequent paper [59–61]. Figure 9 shows the author's co-citation network, which consists of five clusters and 15,282 links. The author with the most citations is Azhar, et al. [62], with a total of 530. The second is Eastman, et al. [63], which has 524 citation counts. The third is Sacks and Pikas [64], which have 445 citations, and the fourth is Succar [48], with 291 citations.

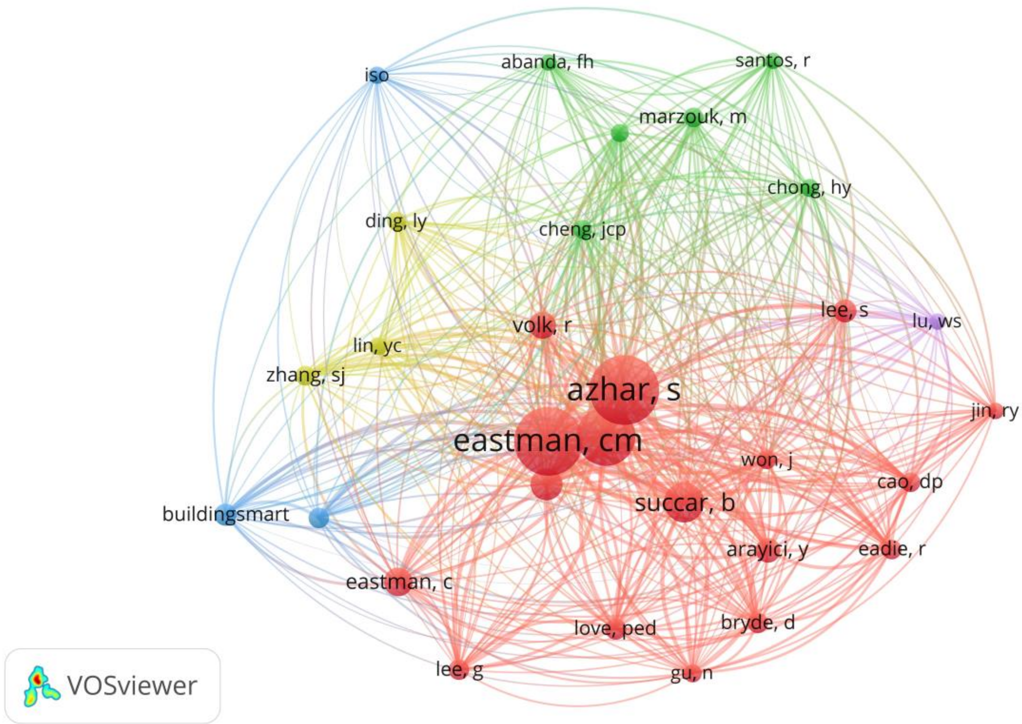


Figure 9. The network of author's co-citation.

3.3.2. Journal Citation

Table 6 displays the top 15 journals and ten conferences for BIM, IoT, and DT in construction projects from the statistics of the WOS database. The journals that publish the most articles include Automation in Construction, Sustainability, Journal of Construction Engineering and Management, and Applied Sciences. Furthermore, based on the data, 33% of the top journals are from Elsevier, followed by ASCE and MDPI. The Automation in Construction journal has the highest number of citations among academics, indicating its popularity and high-quality research works, followed by the Journal of Construction

Engineering and Management. Among the top 15 journals, the Journal of Cleaner Production journal has the most significant Impact Factor (IF) in 2022, accounting for 11.072. Meanwhile, Advances in Civil Engineering Journal have the highest Acceptance Rate (AR). Likewise, Construction Research Congress 2020: Computer Applications contributed the most to BIM, IoT, and DT research in construction projects.

Table 6. Top journals and conferences in the field of BIM, IoT, and DT in Construction.

No.	Journal	Publications	Citations	Total Link Strength	IF	AR (%)	Publisher	Total Publication (%)
1	Automation in Construction	239	11,115	2158	10.517	26	Elsevier	12.71
2	Sustainability	101	946	685	3.889	-	MDPI	5.37
3	Journal of Construction Engineering & Management	77	1939	720	3.951	-	ASCE	4.09
4	Applied Sciences	75	549	443	2.838	-	MDPI	3.99
5	Buildings	70	459	493	3.324	-	MDPI	3.72
6	Engineering, Construction and Architectural Management	60	589	491	3.850	-	Emerald	3.19
7	Journal of Management in Engineering	47	1247	502	6.415	-	ASCE	2.50
8	Advances in Civil Engineering	42	191	253	1.843	42	Hindawi	2.23
9	Journal of Computing in Civil Engineering	38	835	249	5.802	-	ASCE	2.02
10	Advanced Engineering Informatics	35	955	342	7.862	-	Elsevier	1.86
11	Journal of Information Technology in Construction (ITcon)	35	282	201	1.942	-	-	1.86
12	Journal of Building Engineering (JOBE)	31	459	273	7.144	26	Elsevier	1.64
13	Journal of Cleaner Production	29	1001	346	11.072	-	Elsevier	1.54
14	Building and Environment	26	989	254	7.093	21	Elsevier	1.38
15	International Journal of Construction Management	20	259	142	3.097	12	Taylor & Francis	1.06
No.	**Conference**	**Publications**	**Citations**	**Total Link Strength**	**-**	**-**	**-**	**Total Publication (%)**
1	Construction research congress 2020: computer applications	19	17	45	-	-	-	1.01
2	-E work and Ebusiness in architecture, engineering and construction	18	32	14	-	-	-	0.95
3	Construction research congress 2018: construction information technology	17	60	31	-	-	-	0.90
4	Computing in civil engineering 2019: visualization, information modeling, and simulation	13	48	23	-	-	-	0.69

Table 6. *Cont.*

No.	Conference	Publications	Citations	Total Link Strength	-	-	-	Total Publication (%)
5	Computing in civil engineering 2017: information modelling and data analytics	11	55	26	-	-	-	0.58
6	Construction research congress 2020: project management and controls, materials, and contracts	11	7	17	-	-	-	0.58
7	Construction research congress 2022: computer applications, automation, and data analytics	11	0	26	-	-	-	0.58
8	0z Construction research congress 2016: old and new construction technologies converge in historic San Juan	10	56	28	-	-	-	0.53
9	Creative construction conference 2017 (ccc 2017)	9	106	42	-	-	-	0.47
10	5th creative construction conference (ccc 2016)	7	178	37	-	-	-	0.37

IF: Impct Factor (2021); **AR**: Acceptance Rate (%).

Nonetheless, Figure 10 shows the journal citation analysis in VOSviewer software. 443 sources, including journal and conference papers, are identified using VOSviewer in this study, but with the minimum number of source documents set to 5, only 56 sources meet the set threshold. There remain 644 links, 4886 total link strengths, and 10 clusters. The clustered, red, green, and blue columns comprise the cluster colors file. The clustered column provides cluster identification numbers. A cluster number must be between 1 and 1000 integers. The red, green, and blue columns include the red, green, and blue cluster color components, respectively. Each color component must be a positive integer between 0 and 255 [65]. For example, cluster 1 is a red color (Automation in Construction, Ain Shams Engineering Journal, Canadian Journal of Civil Engineering, Construction Research Congress 2022: Project Management and Delivery, Controls, and Design and Materials, etc.), and cluster 4 is yellow (Building and Environment, Energy and Buildings, Journal of Architectural Engineering, etc.).

3.3.3. Document Co-Citation

The network of document co-citations is useful for mapping the research area and organizing documents based on citation links between publications [57]. As indicated in Figure 11, a network of document co-citations is created, consisting of 472 links and 3 clusters. In this regard, 50,813 cited references have been identified using VOSviewer, but the minimum number of citations of a cited reference is set to 50 in this study; consequently, 32 cited references meet the threshold. The number of co-citations is shown by each node's size, representing a document. Table 7 shows the ten most important papers and books in the studied field with the highest citations among academics. In [63], the authors presented an in-depth overview of BIM technology, the business and organizational difficulties connected with its adoption, and the significant benefits of proper BIM use. In [66], they covered the present trends, advantages, potential risks, and future difficulties of BIM in the AEC sector. Volk, et al. [67] evaluated 180 papers, emphasizing the phases of maintenance and deconstruction, that showed the state-of-the-art use and study of BIM in existing buildings. Succar [48] discovered a framework for research and delivery, a specialized ontology, and a visual language designed specifically to explore the BIM domain and provide useful outputs. Bryde, et al. [68] gathered secondary data from 35 construction projects that used BIM for examination of the degree to which the use of BIM has led to stated advantages on a cross-section of building projects.

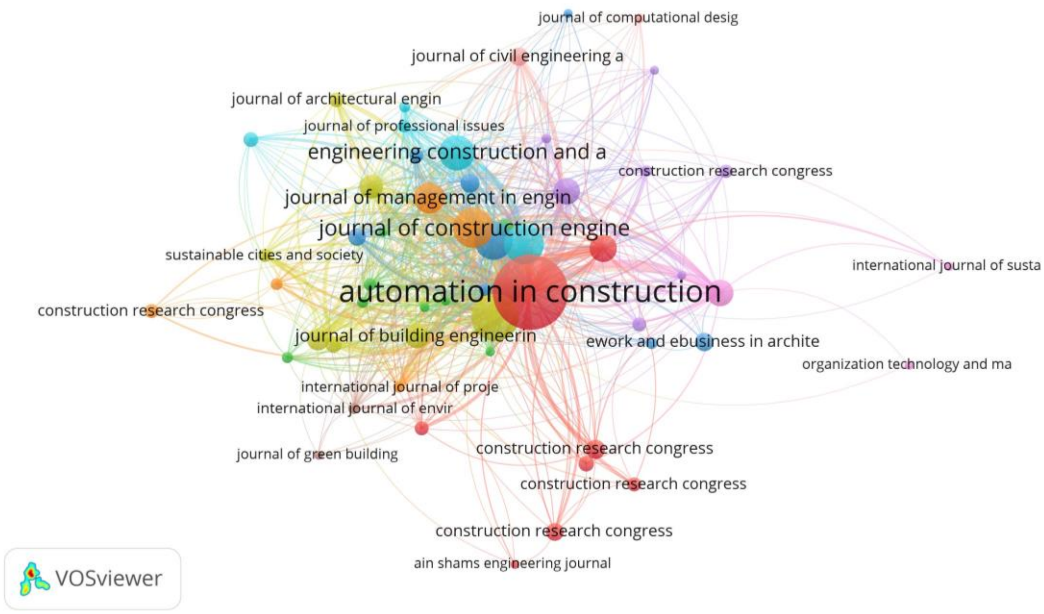


Figure 10. Network of journal co-citation.

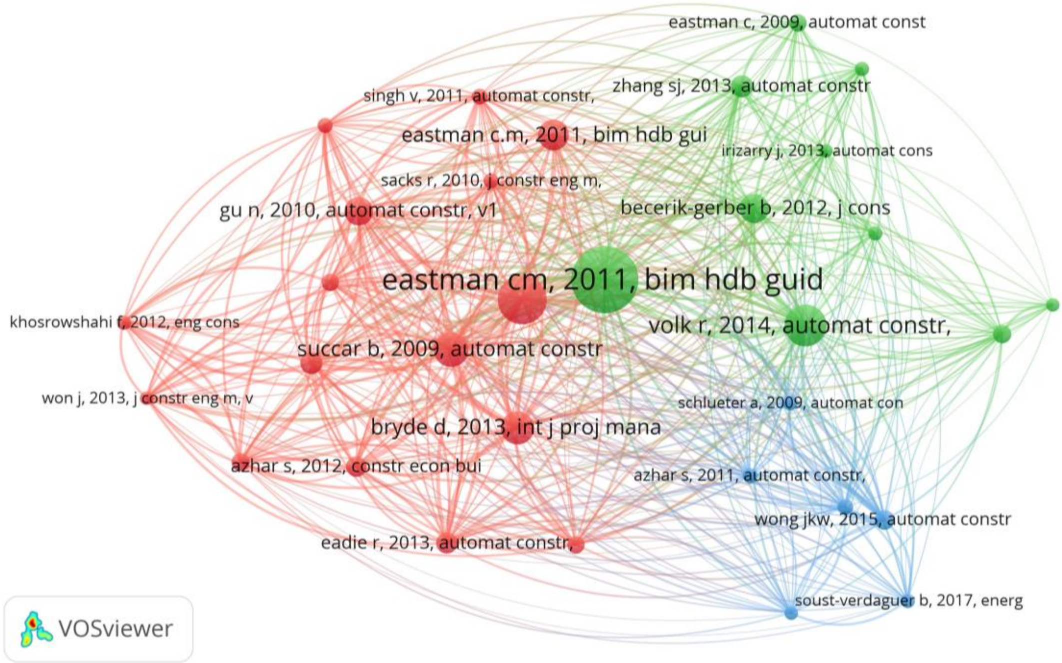


Figure 11. Network of document co-citations.

Table 7. The ten most influential papers in the studied field.

No.	Cited Reference	Year	Citations	Total Link Strength
1	[63]	2011	312	760
2	[66]	2011	218	762
3	[67]	2014	146	581
4	[68]	2013	141	570
5	[69]	2012	120	379
6	[70]	2010	116	521
7	[71]	2012	89	380
8	[72]	2013	89	239
9	[73]	2013	85	356
10	[74]	2012	81	310

3.4. Summary

VOSviewer is a piece of software used to build and display bibliometric networks. These networks can be created through citations, bibliographic coupling, co-citations, or authorship collaborations. With the use of text mining algorithms, VOSviewer can create and present networks of important phrase co-occurrences in scientific publications [75]. The current study conducts co-authorship analysis in the VOSviewer software regarding the country, organization, and author. China and the USA are the most influential nations in terms of publishing research articles in the field of BIM, IoT, and DT in construction projects, with the highest number of citations among other countries in the world. Furthermore, the University of Hong Kong has published the most significant number of documents compared to other mentioned organizations in this study. Asian universities play an important role in publishing papers in the mentioned field.

A bibliometric analysis of identified publications' keyword co-occurrence and citation networks has been done inside VOSviewer to reveal study patterns in this important area of research [76]. This research used a more specific search query to find 1879 publications from the WOS database that are linked to BIM, IoT, and DT in the construction sector. From 2006 to 2021, there was an increasing trend in publications in this field; the year with the most publications were 2021. The keyword co-occurrence network created by the VOSviewer program may be used to identify the most prominent keywords in the area of BIM, IoT, and DT, which was the initial research topic of this study. The top keywords from the WOS papers were determined and are shown in Table 5 in order of their high frequency of occurrence. The most significant authors and journals had to be identified, which was the second study question. Jack C.P. Cheng of the Hong Kong University of Science and Technology is the most prolific author; Wang, Xiangyu ranked second; Rafael Sacks placed third, followed by Wilson LU. Additionally, the most cited journals are Automation in Construction, Sustainability, and the Journal of Construction Engineering and Management. Furthermore, Construction Research Congress 2020: Computer Applications has the highest number of publications.

For the third research question, which focused on the most important themes of mentioned keywords, document co-citation and clustering analysis were used to identify the important study topics in the literature for BIM, IoT, and DT. The literature on BIM, IoT, and DT in construction were divided into five categories: BIM, IoT, and DT in construction, Heritage BIM (HBIM), Smart contract, BIM and ontology, and VR and AR in BIM and DT. This work also addressed the fourth research direction, which concerned the literature's present trends in BIM, IoT, and DT and potential future research topics. From this study, it can be inferred that research is moving more and more toward BIM and Metaverse technology, AI in BIM and DT, metaheuristic algorithms in BIM, and the Circular Economy in construction with BIM and IoT.

4. Key Areas in Construction

The provided clusters are discussed in this section, along with the most frequently referenced sources listed in each cluster. Subsequently, research domains are ranked according to the number of publications in each, and research subjects are examined based on the most relevant publication.

4.1. BIM, IoT, and DT

Figure 12 shows the number of publications and citations of papers that are directly related to BIM, IoT, and DT in construction projects. It could be understood that the initial paper regarding the combination of BIM, IoT, and DT in the construction industry was published in 2020. The keywords BIM "AND" IoT "AND" Digital Twin "AND" Construction are the most popular keywords in the literature (Figure 12a), followed by BIM "AND" Internet of Things "AND" Augmented Reality "AND" Construction (Figure 12b). Furthermore, the highest number of citations in all keywords is recorded in 2022 (see Figure 13). Table 8 summarizes papers regarding BIM, IoT, and DT in the construction industry. As can be seen, most of the studied papers are related to conducting a literature review of BIM, IoT, and DT in construction for different purposes. Furthermore, a novel technology called Blockchain has been integrated into this field to provide smart contracts, traceable data communication, and supply chain management.

4.2. Heritage BIM (HBIM)

The variability and accessibility of data throughout the different stages of the conservation process are two of the major concerns in the Heritage industry [99]. Due to recent advances in 3D data capture technologies such as terrestrial laser scanning (TLS), photogrammetry, and laser scanning, BIM application in the heritage sector (HBIM) has, to date, placed a strong emphasis on the digital documenting of cultural assets. Individual activities are executed as complicated processes, making the life cycle operations of a building project more efficient, quick, and affordable. HBIM assists in transforming individual executors into teams and decentralizing tools into complex solutions [100]. This method is being used to record several examples of cultural assets, and it is becoming clear that there are a number of advantages for visualization, structural and condition monitoring, teaching, and research for conservation practice [101]. Furthermore, The use of HBIM in the creation of Virtual Reality (VR) and Augmented Reality (AR) projects allows for the enhancement of new immersive experiences for both specialists and non-experts that are faithfully and correctly based on recorded real-world locations [102].

The laser scanner captures surface geometry directly, resulting in an accurate and dense 3D point cloud representation within a predetermined measurement uncertainty. Numerous disciplines of cultural preservation make use of the technique despite its cumbersome weight, exorbitant expense, and insufficient surface coloring. The amount of detail required by the project defines what scanning density or average distance between points must be chosen. The position of the device during data acquisition, the object-sensor distance, the angle of incidence of the laser beam with respect to the scanned surfaces, the properties of the object being scanned, and the signal reflection in certain materials, such as marble and gilded facades, are all potential sources of error in TLS point measurements and, consequently, noise in the resulting geometry [103].

4.3. Smart Contract

First coined by Szabo in 1994, the phrase "smart contract" refers to "a computerized transaction protocol that performs the conditions of a contract" [104]. This contract must include standard provisions such as dealing with payments, liens, confidentiality, and enforcement. This kind of contract is necessary for intelligent technology since it reduces the time and money spent on intermediaries, such as banks, the risk of fraud, the cost of arbitration and enforcement, and other transaction charges [105].

Numerous parties with varying interests and needs are involved in construction projects. Complex contractual arrangements are a consequence of the short duration of construction contracts, a lack of confidence, and various rules and laws. Long and transparent inspection procedures, ongoing conflicts, and protracted payment delays are commonplace when combined with a low degree of digitalization and process automation. Small and medium-sized businesses' high percentage of insolvencies is partially attributable to inefficient financial flow and needless bureaucracy [106]. A new programming paradigm was established by establishing the DApp (Decentralized Application) idea for Ethereum as the first usable distributed processing model to operate on top of a blockchain network in 2015. The main characteristics of blockchains and smart contracts are immutability, high availability, integrity, and transparency [107]. In other words, Immutability can be guaranteed with smart contracts, and all changes are safely documented and clearly visible.

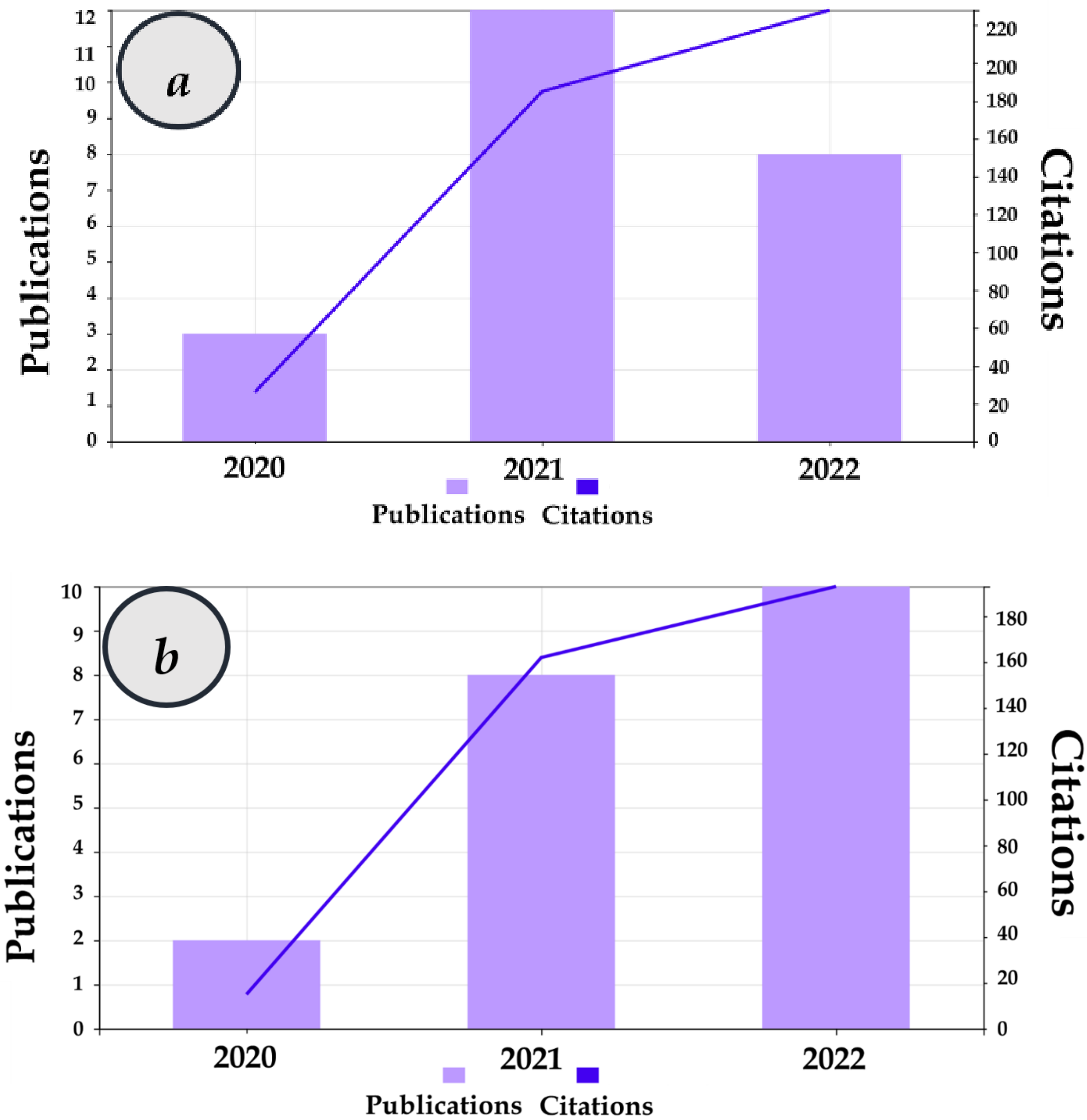
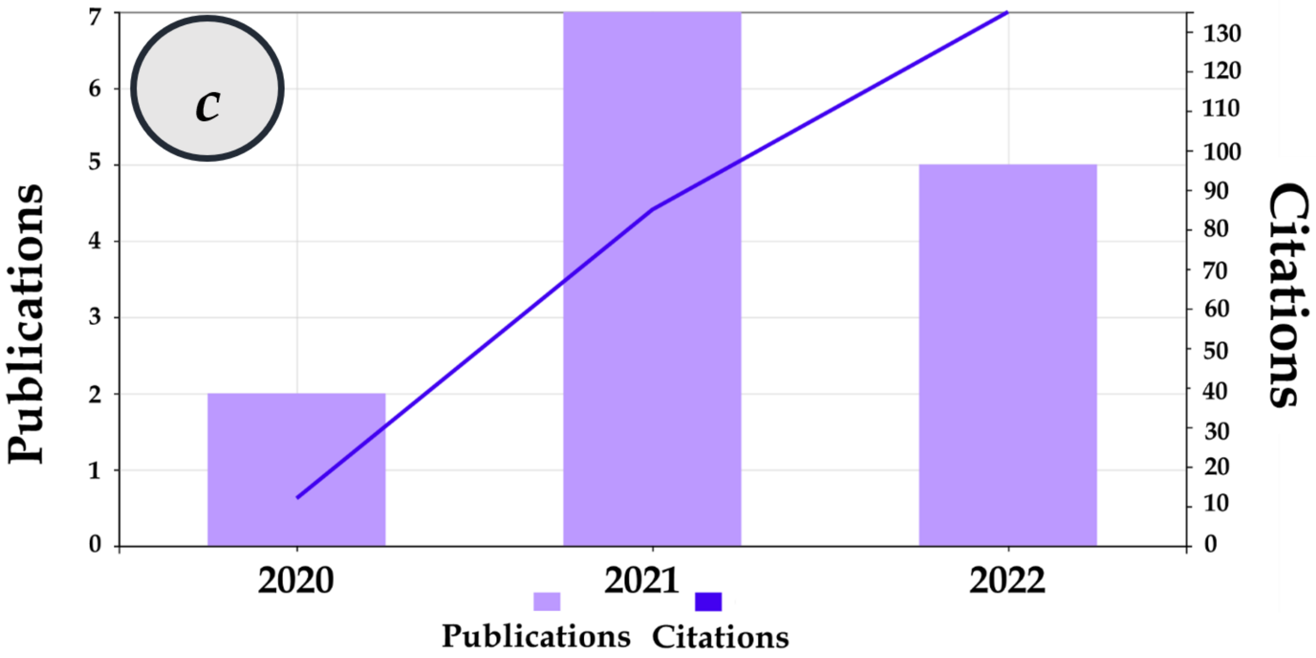


Figure 12. *Cont.*



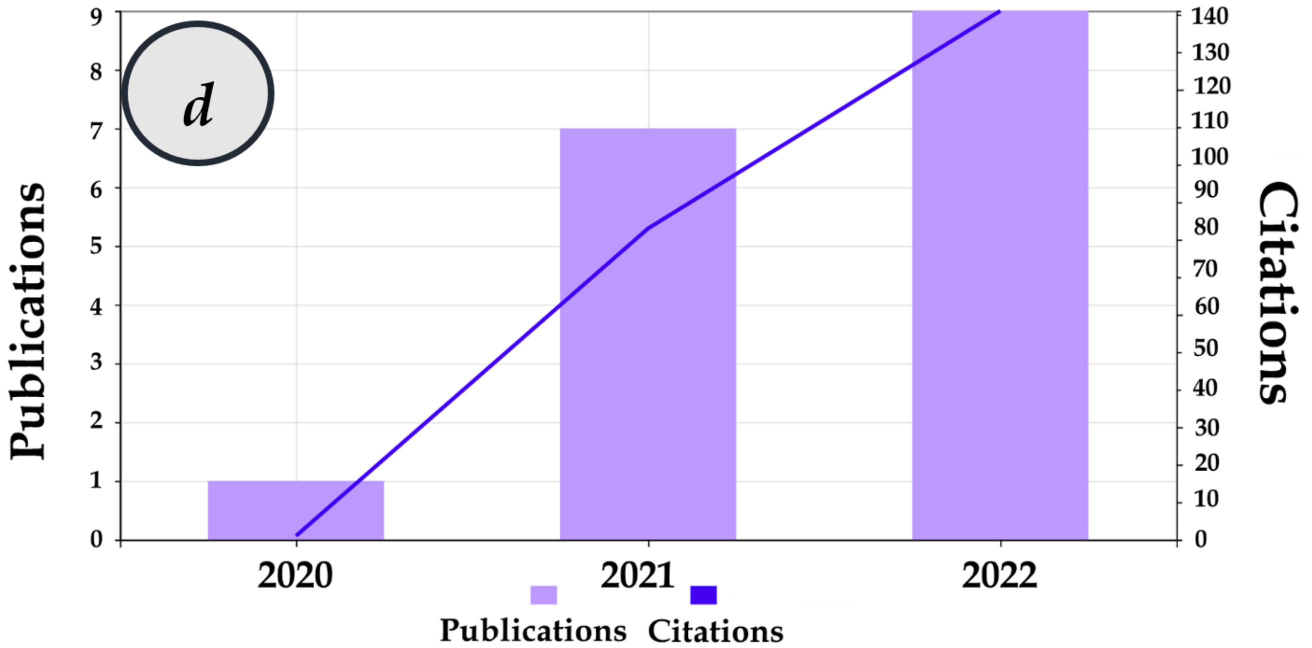


Figure 12. Trends of BIM, IoT, and DT in Construction: BIM "AND" IoT "AND" Digital Twin "AND" Construction (**a**); BIM "AND" Internet of Things "AND" Augmented Reality "AND" Construction (**b**); Building Information Modeling "AND" IoT "AND" Digital Twin "AND" Construction (**c**); and Building Information Modeling "AND" Internet of Things "AND" Digital Twin "AND" Construction (**d**).

Payment is another escalating issue. Construction projects must be completed successfully to have on-time payments and a consistent cash flow. Construction delays, higher expenses, lower performance, and disagreements are all caused by issues including non-, delayed, and inaccurate payment. Smart contract technology has recently advanced, making it possible to automate payments securely and reliably [105]. Figure 14 shows the network visualization of keywords "Blockchain" and "Smart Contract" in construction and their relationship with BIM, IoT, and DT.

Blockchain is a peer-to-peer (P2P) distributed data format that enables the chronological recording and safe storage of transactional data in a series or chain of blocks. It is a particular DLT type with certain qualities. A blockchain is a distributed, encrypted digital ledger that is accessible over either a public or private network [108,109]. A paper on Bitcoin, the first cryptocurrency ever, introduced Blockchain in 2008 by Satoshi Nakamoto.

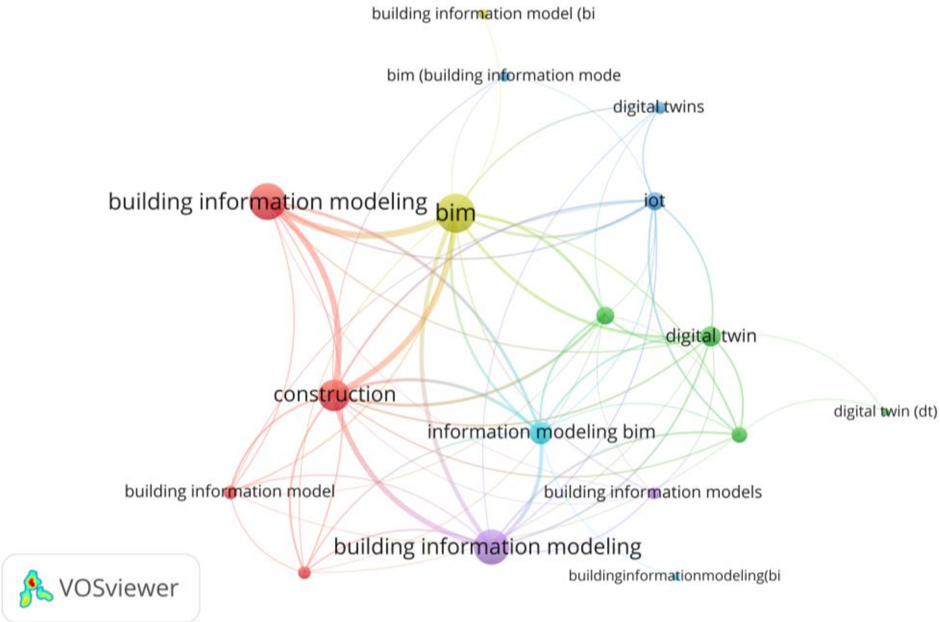


Figure 13. Network visualization of keyword co-occurrence of BIM, IoT, and DT in Construction.

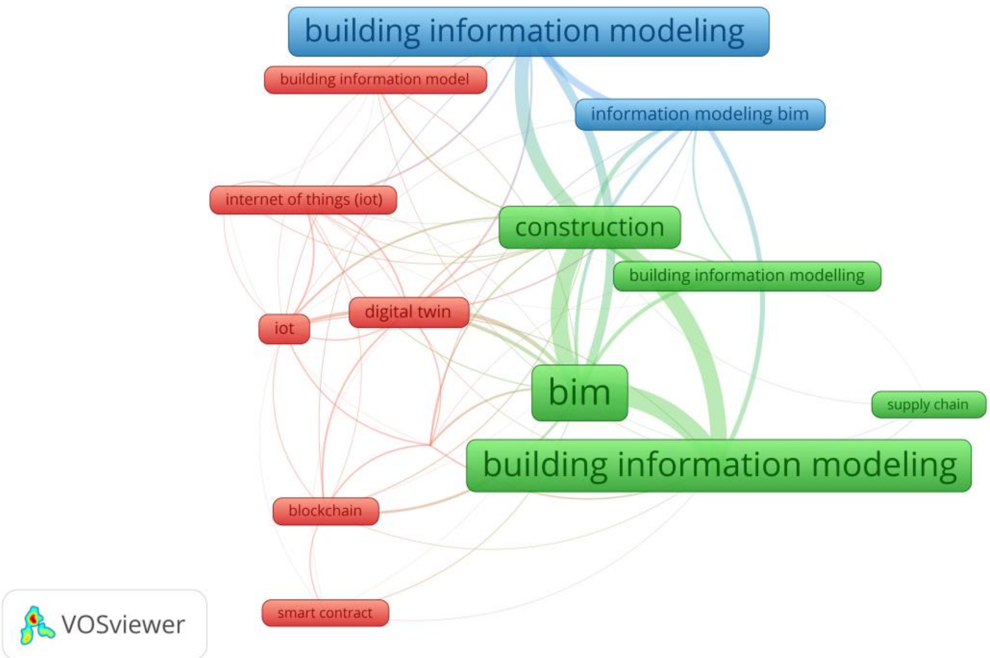


Figure 14. Network visualization of the keyword co-occurrence of Blockchain and Smart contract in BIM, IoT, and DT.

Table 8. A summary of the current papers in the field of BIM, IoT, and DT in construction.

No.	Author	Year	Journal/Conference	Citations	Field	Purpose	Conclusion
1	Ali, Alhajlah and Kassem [57]	2022	BUILDINGS	2	BIM	The current status and future trends in BIM literature from the WOS.	Due to the subject's significance, they discovered that only 88 publications specifically focused on collaboration and risks in BIM, while there is a clear trend toward increasing these research studies in recent years.
2	Zhang, et al. [77]	2022	JOURNAL OF MANAGEMENT IN ENGINEERING	4	BIM and DT	Putting out a framework for BIM employing Digital Twins and level of details (LoDs) for managing construction sites.	Improvements in quality, productivity, and worker safety result from using the suggested framework at construction sites.
3	Li, et al. [78]	2022	JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT	13	BIM and IoT	Implementing Blockchain for data-information-knowledge (DIK)-driven modular construction supply chain management with IoT-enabled BIM platform (IBP).	BIBP not only provides an efficient system design with acceptable throughput and latency, but it also helps realize a single point of truth in BIM and prevent a single point of failure for IoT networks by taking privacy and security precautions.
4	Sun and Liu [79]	2022	ADVANCES IN CIVIL ENGINEERING	2	BIM and DT	Proposing a new hybrid model of Digital Twin-BIM.	Thanks to these hybrid technologies, there is a better degree of efficacy in the dispatch systems for building projects.
5	Almatared, et al. [80]	2022	CONSTRUCTION RESEARCH CONGRESS 2022: COMPUTER APPLICATIONS, AUTOMATION, AND DATA ANALYTICS	25	DT	Bibliometric analysis is used to summarize the state-of-the-art DT in the AEC sector to identify research trends, problems, and gaps.	By statistically revealing research trends and demands for DT in the AEC sector, the findings added to the body of knowledge.
6	Teisserenc and Sepasgozar [81]	2021	BUILDINGS	7	DT	There is currently a novel conceptual model for deploying blockchain technology (BCT) for Digital Twins (DT) in the BECOM industry 4.0, aiming to improve trust, cyber security, efficiency, information management, information management, information sharing, and sustainability.	With the use of BCT, the decentralized Digital Twin cycle (DDTC) can enhance the data value chain regarding data sharing, cybersecurity, data integrity, immutability, traceability, and transparency or privacy of information.

Table 8. *Cont.*

No.	Author	Year	Journal/Conference	Citations	Field	Purpose	Conclusion
7	Lee and Lee [47]	2021	APPLIED SCIENCES	16	DT	Creating a Digital Twin architecture that can simulate real-time logistics and identify possible risks and module delivery times.	A Digital Twin can forecast potential logistical risks and accurately estimate arrival times based on a trustworthy simulation.
8	Villa, et al. [82]	2021	APPLIED SCIENCES	5	BIM and IoT	Integration of IoT alert systems with BIM models to track building facilities throughout their operating phase and digitally view their status.	Implementing a building structure's preventative maintenance approach into an IoT and BIM dashboard's architecture is practical and promising.
9	Sepasgozar [83]	2021	BUILDINGS	27	DT	Elucidation of the DT idea and its distinction from other cutting-edge information systems, digital shadows, and 3D modeling technologies.	Implementing the Sustainable Development Goals (SDGs) should be considered while developing the DT.
10	Pan and Zhang [84]	2021	AUTOMATION IN CONSTRUCTION	52	BIM, DT, and IoT	Proposing a closed-loop Digital Twin framework using methods from data mining (DM), BIM, and IoT.	Data exchange and exploration can be facilitated by a data-driven Digital Twin framework combining BIM, IoT, and DM for improved project management to better understand, forecast, and optimize the physical construction processes.
11	Menassa [44]	2021	JOURNAL OF INFORMATION TECHNOLOGY IN CONSTRUCTION	26	BIM and DT	Researching state of the art to determine whether new technologies are paving the way for the transition from BIM to Digital Twins in construction-related contexts.	The majority of early studies that have been done so far fall into the earlier ladder categories since they have not completely used or achieved the envisioned notion of the Digital Twin.
12	Sepasgozar, et al. [85]	2021	SUSTAINABILITY	18	BIM	Determining the most current initiatives to use BIM for lean goals over the past ten years.	There is an obvious gap in our knowledge of the synergistic connections between lean ideas and the use of BIM and the Internet of Things in construction, such as sustainable infrastructure projects.
13	Lin and Cheung [86]	2020	JOURNAL OF MANAGEMENT IN ENGINEERING	29	BIM and DT	Developing an advanced monitoring and control system for monitoring the environment in underground parking garages, adopting WSN and BIM technologies for the DT application of Industry 4.0, and providing a planning method for their integration.	The suggested method is an efficient visual monitoring solution for managing environmental monitoring.

Table 8. *Cont.*

No.	Author	Year	Journal/Conference	Citations	Field	Purpose	Conclusion
14	Al-Saeed, et al. [87]	2020	CONSTRUCTION INNOVATION-ENGLAND	31	BIM and DT	Innovative proof-of-concept framework proposed for integrating BIM Digital Objects (BDO) into construction product manufacturers' workflows to facilitate process automation and enhance lean manufacturing.	BDO can cut down on the number of manufacturing procedures, providing cost savings and lessening material waste, while successfully removing early model errors.
15	El Mokhtari, et al. [88]	2022	FRONTIERS IN BUILT ENVIRONMENT	58	DT	Presenting a case study of a Digital Twin (DT) in an academic facility that showcases many proof-of-concept applications of Cognitive Digital Twins (CDTs).	Cloud services provide the highest benefits for CDT scalability, availability, performance, and maintenance when coupled with EMs delivering reliable and secure data streaming.
16	Wei, et al. [89]	2022	BUILDINGS	1	DT	Proposing a model for an Off-site Construction Digital Twin.	The suggested approach could greatly decrease waste while increasing effectiveness.
17	Zhao, et al. [90]	2022	BUILDINGS	2	BIM, DT, and IoT	Putting out a system architecture integrating BIM and IoT to create a Digital Twin model (DTm) for hoisting control of prefabricated components.	The suggested framework can enhance the intelligent management of prefabricated building construction and introduces an innovative concept for intelligent building construction.
18	Marocco and Garofolo [91]	2021	AUTOMATION IN CONSTRUCTION	5	BIM, DT, and IoT	Presenting a thorough analysis of disruptive technology applications for FM, examining research trends, and highlighting research gaps and prospective future research areas.	The primary technology discussed in the publications under consideration was BIM. Creating Digital Twin platforms by fusing cloud computing, BIM, and IoT technologies is a good beginning point for enhancing FM.
19	Mannino, et al. [92]	2021	APPLIED SCIENCES	13	BIM and IoT	Presenting a literature review on the two primary pillars of digitalization in construction, BIM and IoT.	Studies on BIM and IoT are often built on closed ecosystems and proprietary files where information is not yet freely exchanged among stakeholders. Therefore, future research in the field of BIM-IoT integration should concentrate on open data and communication standards.
20	Hasan, et al. [93]	2022	JOURNAL OF ASIAN ARCHITECTURE AND BUILDING ENGINEERING	12	BIM and DT	Concentrating on using a Cyber-Physical System with AR and DT to track work and construction equipment operation.	Construction equipment that can be remotely controlled and tracked/monitored can speed up certain on-site tasks, such as 4D BIM and operations recording, while increasing accuracy and safety.

Table 8. *Cont.*

No.	Author	Year	Journal/Conference	Citations	Field	Purpose	Conclusion
21	Turner, et al. [94]	2021	IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS	29	BIM, DT, and IoT	Examining the applicability of the main Industry 4.0 technologies of data analytics and AI, robots and automation, BIM, sensors and wearables, DT, and industrial networking to the construction industry.	Future building sites will incorporate Industry 4.0 technologies that do not operate independently of one another but rather collaborate to resemble a sophisticated cyber-physical system. Smaller device sizes, better communication technologies, greater battery power densities, and more powerful processing in IoT edge devices will continually change the component technologies.
22	Alshammari, et al. [95]	2021	JOURNAL OF INFORMATION TECHNOLOGY IN CONSTRUCTION	9	IoT	Analyzing existing practices while reviewing pertinent literature on the application of IoT in the built environment.	In order to promote cybersecurity and ensure that Digital Twin and city standards can be linked entirely with future secure smart cities, BIM requirements can be upgraded to become IoT-compatible.
23	Boje, et al. [96]	2020	AUTOMATION IN CONSTRUCTION	136	BIM and DT	Reviewing the many BIM programs that are used during the construction stage and emphasizing the constraints and needs that led to the idea of a construction DT	The BIM, which is the digital representation of the building, serves as the foundation for the DT and is enhanced by the inclusion of big data, the Internet of Things, and sensing capabilities from the construction site through building operation.
24	Salem and Dragomir [42]	2022	APPLIED SCIENCES	40	BIM and DT	Proposing a three-stage framework for evaluating and monitoring the creation of Digital Twins that includes the widely used BIM, the current monitoring and actuation DTs, and a third step that utilizes AI.	The suggested framework can offer information security to preserve the proper flow of data for analytics in the digital world and worker and site safety in the physical world.
25	Shahzad, et al. [97]	2022	BUILDINGS	4	DT	Examine Digital Twins' benefits and applicability concerning already-existing digital technologies and highlight prospective applications and implementation issues.	DTs in built-environment projects can help design, construction, and operating processes.
26	Lee, et al. [98]	2021	AUTOMATION IN CONSTRUCTION	37	DT	Establishing and testing a blockchain and linked Digital Twin platform for traceable data exchange.	Data transmission that is traceable and unchangeable helps establish confidence for project-related data. The ensuing contract execution, payment, and even decision-making process could all be significantly accelerated by such accountable data, which ultimately promotes improved cooperation among the disparate project stakeholders.

4.4. BIM and Ontology

Ontology has lately gained popularity across various fields, particularly in the Semantic Web community. Ontology has recently been considered a useful tool for describing the communicable and shared understanding of domain knowledge. A hierarchical description of ideas, a description of the attributes of concepts, and possible additional components make up ontology in knowledge engineering [110]. The inherent difficulties of combining information about construction workflow from many sources and describing information from several contexts have not yet been addressed by the development of an ontology [111]. Since its inception, BIM has realized that its usefulness is maximized only when rich information is coupled with building object models. The static links of the information to the building objects models mean that once the project models or information change, the links have to be re-established again, even though BIM offers potential for many analysis and simulation processes that are impossible using traditional 2D design approaches. This adds to the challenge of deciding how much data to include in developing object models. The data should be dynamically and adaptably merged with (connected to) the constructing object model [112].

4.5. VR and AR in BIM and DT

More and more, cutting-edge technologies such as Augmented Reality (AR) and Virtual Reality (VR) are being implemented into construction projects to improve preventative safety, productivity, and quality. Virtual reality (VR) is built on a set of technologies that put the user in an artificial environment that can be either a representation of the real world or a completely made-up one. It is a computer-generated environment where the user can move around and have conversations in three dimensions [113]. In comparison to other conceptualization approaches, users are better able to retain more complex understandings of 3D phenomena after participating in extensive learning in a 3D virtual environment [114]. Since its inception by Jaron Lanier in the 1980s, virtual reality has evolved to provide high-performing but relatively cost consumer market hardware components, such as head-mounted displays. This has enabled a range of built environment disciplines to model projects while also establishing links with other technical sectors such as machine learning and robotics [115]. Generally speaking, VR could be divided into three distinct levels as follows: (i) Passive VR, (ii) Exploratory VR, and (iii) Immersive VR (See Figure 15).

Augmented Reality (AR), a subset of the broader field of mixed reality, is one of the real-to-virtual worlds defined by Milgram. The surrounding environment is virtual in augmented reality (AR), where actual items are added to virtual ones; whereas in VR, the surrounding environment is realistic [116]. VR technologies fully immerse the user in a synthetic world. While immersed, the user is unable to view the actual world. AR, on the other hand, enables the user to see the actual environment with virtual things overlaid or combined with it [117]. To successfully stimulate the sensation of actual surroundings and enable active engagement between subscribers and the contents, AR superimposes the computed data from an objective perspective. Three qualities could be found in augmented reality: real-time interaction between real and virtual things, cooperation between real and virtual objects, and integration of real and virtual objects into reality [118]. A BIM model can be linked to the real-world scenario using AR, which gives the stakeholder a better depiction.

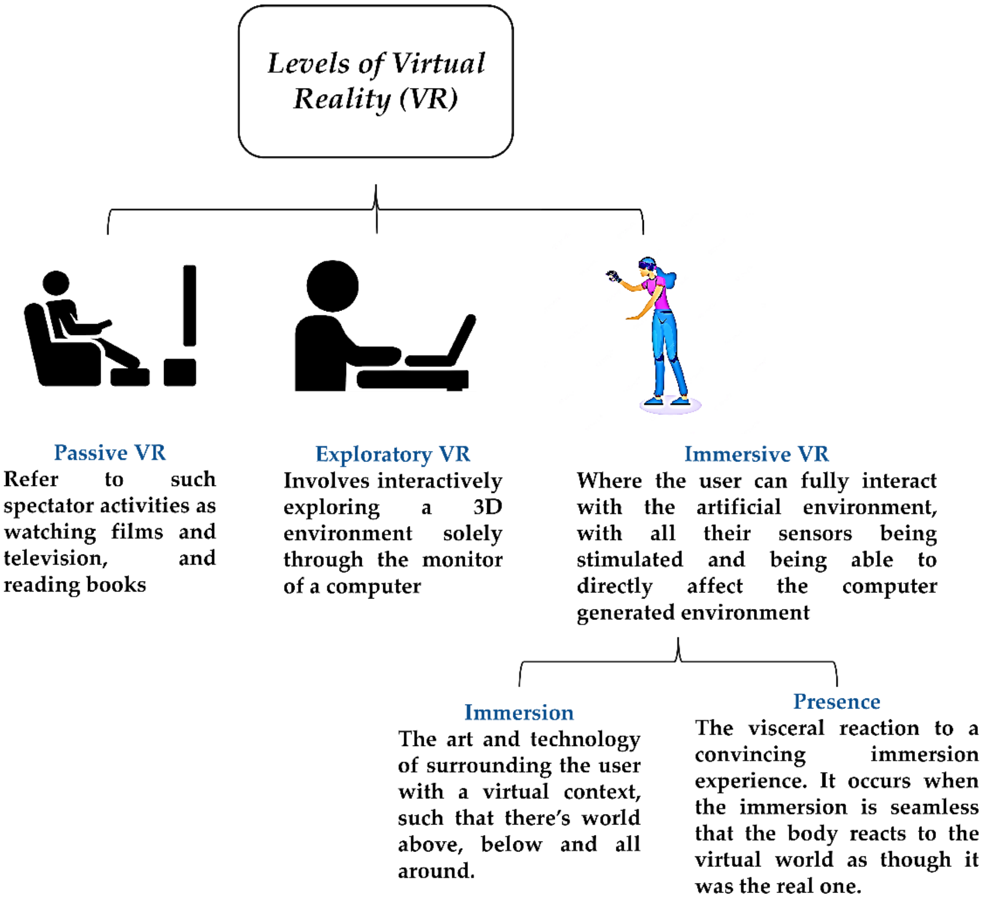


Figure 15. Different levels of Virtual Reality (VR).

5. Future Research Directions

The following highlights anticipated future research trends in the field of BIM, whereas the preceding section highlights important current BIM-related topics as follows:

- Metaverse technology in BIM and the construction industry;
- The combination of Artificial Intelligence (AI) with BIM and Digital Twin;
- Applications of different metaheuristic algorithms for optimization purposes in BIM;
- The application of the circular economy in the construction industry using BIM and IoT.

6. Conclusions

Building Information Modeling has been very popular recently, attracting more research and attention from practitioners and academia. This work provides a method for performing a topical literature review for BIM, IoT, and DT in construction and choosing suitable research themes. This is the first comprehensive study to map the BIM literature using a systematic review approach using 1879 academic papers. The BIM, IoT, and DT literature noted the most popular keywords, successful authors and countries, top journals and conferences, top funding organizations, and current research subjects. Future BIM trends were also suggested. Academics will have a deeper understanding of the subject matter and more structured knowledge by studying and arranging the BIM literature. Building practitioners should also study the review's findings and the impact of BIM, IoT, and DT to improve organizational performance. The research limits the scope of the reviewed Building Information Modeling, Internet of Things, and Digital Twin literature by concentrating exclusively on academic papers obtained from the Web of Science database. It would be fascinating to do an analogous analysis for future studies utilizing a more comprehensive range of BIM literature from other databases such as Google Scholar, Scopus, and PubMed. The main findings related to the research questions are as follows:

- The most applicable keywords in all mentioned fields are (i) Building Information Modeling; (ii) digital twin; and (iii) Internet of Things.
- The most prolific author is Jack C.P. Cheng.
- The most prominent journal is Automation in Construction.
- The most prolific nations are China and the USA.
- The most popular topics are BIM, IoT, and DT in construction, Heritage BIM (HBIM), Smart Contracts, BIM and Ontology, and VR and AR in BIM and DT.
- The future trends are BIM and Metaverse technology, BIM and Artificial Intelligence (AI), Metaheuristic algorithms for optimization purposes in BIM, and the circular economy with BIM and IoT.

However, using BIM, DT, and IoT in the construction sector might be seen as one of the most effective and impactful approaches to achieving "smart construction 4.0", involving a strong integration of data, processes, knowledge, and stakeholders.

Author Contributions: Conceptualization, M.B.S. and A.K.; methodology, M.B.S., A.K. and R.C.M.; software, M.B.S., A.K. and N.J.; validation, A.K. and R.C.M.; formal analysis, M.B.S. and A.K.; investigation, M.B.S. and N.J.; resources, M.B.S.; data curation, A.K. and R.C.M.; writing—original draft preparation, M.B.S.; writing—review and editing, A.K. and R.C.M.; visualization, M.B.S. and S.R.L.; supervision, A.K.; project administration, R.C.M.; funding acquisition, R.C.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wu, S.H.; Zhang, N.; Xiang, Y.J.; Wu, D.Z.; Qiao, D.P.; Luo, X.W.; Lu, W.Z. Automated Layout Design Approach of Floor Tiles: Based on Building Information Modeling (BIM) via Parametric Design (PD) Platform. *Buildings* **2022**, *12*, 250. [CrossRef]
2. Santos, L.; Schleicher, S.; Caldas, L. Automation of CAD models to BEM models for performance based goal-oriented design methods. *Build. Environ.* **2017**, *112*, 144–158. [CrossRef]
3. Safikhani, S.; Keller, S.; Schweiger, G.; Pirker, J. Immersive virtual reality for extending the potential of Building Information Modeling in architecture, engineering, and construction sector: Systematic review. *Int. J. Digit. Earth* **2022**, *15*, 503–526. [CrossRef]
4. Shishehgarkhaneh, M.B.; Azizi, M.; Basiri, M.; Moehler, R.C. BIM-Based Resource Tradeoff in Project Scheduling Using Fire Hawk Optimizer (FHO). *Buildings* **2022**, *12*, 1472. [CrossRef]
5. Avendano, J.I.; Zlatanova, S.; Domingo, A.; Perez, P.; Correa, C. Utilization of BIM in Steel Building Projects: A Systematic Literature Review. *Buildings* **2022**, *12*, 713. [CrossRef]
6. Miettinen, R.; Paavola, S. Beyond the BIM utopia: Approaches to the development and implementation of Building Information Modeling. *Autom. Constr.* **2014**, *43*, 84–91. [CrossRef]
7. Yang, L.; Cheng, J.C.; Wang, Q. Semi-automated generation of parametric BIM for steel structures based on terrestrial laser scanning data. *Autom. Constr.* **2020**, *112*, 103037. [CrossRef]
8. Ghaffarianhoseini, A.; Tookey, J.; Ghaffarianhoseini, A.; Naismith, N.; Azhar, S.; Efimova, O.; Raahemifar, K. Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renew. Sustain. Energy Rev.* **2017**, *75*, 1046–1053. [CrossRef]
9. Mehrbod, S.; Staub-French, S.; Mahyar, N.; Tory, M. Characterizing interactions with BIM tools and artifacts in building design coordination meetings. *Autom. Constr.* **2019**, *98*, 195–213. [CrossRef]
10. Lin, L.; Huang, M.; Li, J.; Song, X.; Sun, Y. The application and exploration of the TSTL in construction management based on BIM. *J. Appl. Sci. Eng.* **2017**, *20*, 309–317.
11. Caldart, C.W.; Scheer, S. Construction site design planning using 4D BIM modeling. *Gestão Produção* **2022**, *29*. [CrossRef]
12. Wu, K.Y.; Tang, S. BIM-Assisted Workflow Enhancement for Architecture Preliminary Design. *Buildings* **2022**, *12*, 601. [CrossRef]
13. Charef, R.; Alaka, H.; Emmitt, S. Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. *J. Build. Eng.* **2018**, *19*, 242–257. [CrossRef]
14. Ding, L.; Zhou, Y.; Akinci, B. Building Information Modeling (BIM) application framework: The process of expanding from 3D to computable nD. *Autom. Constr.* **2014**, *46*, 82–93. [CrossRef]

15. Lu, Q.; Won, J.; Cheng, J.C.P. A financial decision making framework for construction projects based on 5D Building Information Modeling (BIM). *Int. J. Proj. Manag.* **2016**, *34*, 3–21. [CrossRef]
16. Jin, Z.; Gambatese, J.; Liu, D.; Dharmapalan, V. Using 4D BIM to assess construction risks during the design phase. *Eng. Constr. Archit. Manag.* **2019**, *26*, 2637–2654. [CrossRef]
17. Martins, S.S.; Evangelista, A.C.J.; Hammad, A.W.A.; Tam, V.W.Y.; Haddad, A. Evaluation of 4D BIM tools applicability in construction planning efficiency. *Int. J. Constr. Manag.* **2020**, 1–14. [CrossRef]
18. Nical, A.K.; Wodynski, W. Enhancing Facility Management through BIM 6D. In Proceedings of the 5th Creative Construction Conference (CCC 2016), Budapest, Hungary, 25–28 June 2016; pp. 299–306.
19. Sivarajah, T. BIM Adaptation in Construction projects. *J. Res. Technol. Eng.* **2022**, *3*, 13–18.
20. Kamardeen, I. 8D BIM modelling tool for accident prevention through design. In Proceedings of the 26th Annual ARCOM Conference, Leeds, UK, 6–8 September 2010; pp. 281–289.
21. Ershadi, M.; Jefferies, M.; Davis, P.; Mojtahedi, M. Implementation of Building Information Modelling in infrastructure construction projects: A study of dimensions and strategies. *Int. J. Inf. Syst. Proj. Manag.* **2021**, *9*, 43–59. [CrossRef]
22. Hyarat, E.; Hyarat, T.; Al Kuisi, M. Barriers to the Implementation of Building Information Modeling among Jordanian AEC Companies. *Buildings* **2022**, *12*, 150. [CrossRef]
23. Zhang, L.H. *Building Information Modelling in the Canadian Architecture, Engineering, and Construction Industries*; University of Toronto: Toronto, ON, Canada, 2019.
24. Baghalzadeh Shishehgarkhaneh, M.; Fard Moradinia, S. The role of Building Information Modeling (BIM) in reducing the number of project dispute resolution sessions. In Proceedings of the 8th National Conference on Civil Engineering, Architecture and Sustainable Urban Development of Iran, Tehran, Iran, 5 November 2020.
25. Cheng, J.C.P.; Lu, Q.; Deng, Y. Analytical review and evaluation of civil information modeling. *Autom. Constr.* **2016**, *67*, 31–47. [CrossRef]
26. Kim, C.; Kim, H.; Park, T.; Kim, M.K. Applicability of 4D CAD in civil engineering construction: Case study of a cable-stayed bridge project. *J. Comput. Civ. Eng.* **2011**, *25*, 98. [CrossRef]
27. Yabuki, N.; Shitani, T. An IFC-based product model for RC or PC slab bridges. *CIB Rep.* **2003**, *284*, 463.
28. Scianna, A.; Gaglio, G.F.; La Guardia, M. Structure Monitoring with BIM and IoT: The Case Study of a Bridge Beam Model. *ISPRS Int. J. Geo Inform.* **2022**, *11*, 173. [CrossRef]
29. Deng, L.; Lai, S.; Ma, J.; Lei, L.; Zhong, M.; Liao, L.; Zhou, Z. Visualization and monitoring information management of bridge structure health and safety early warning based on BIM. *J. Asian Archit. Build. Eng.* **2022**, *21*, 427–438. [CrossRef]
30. Vollmann, G.; Stepien, M.; Riepe, W.; König, M.; Lehan, A.; Thewes, M.; Wahl, H. Use of BIM for the optimized operation of road tunnels: Modelling approach, information requirements, and exemplary implementation. *Geomech. Tunn.* **2022**, *15*, 167–174. [CrossRef]
31. Zhang, L.M.; Wu, X.G.; Ding, L.Y.; Skibniewski, M.J.; Lu, Y.J. Bim-Based Risk Identification System in Tunnel Construction. *J. Civ. Eng. Manag.* **2016**, *22*, 529–539. [CrossRef]
32. Menozzi, A.; Danzi, A. I-BIM: Digital Twin for Tunnels and Underground Structures. *Gallerie E Grandi Opere Sotterranee* **2019**, *130*, 17–28.
33. Li, S.; Zhang, Z.J.; Mei, G.; Lin, D.M.; Yu, J.; Qiu, R.K.; Su, X.J.; Lin, X.C.; Lou, C.H. Utilization of BIM in the Construction of a Submarine Tunnel: A Case Study in Xiamen City, China. *J. Civ. Eng. Manag.* **2021**, *27*, 14–26. [CrossRef]
34. Baghalzadeh Shishehgarkhaneh, M.; Fard Moradinia, S.; Keivani, A. Time and Cost Management of Dam Construction Projects based on Building Information Modeling (BIM) (A Case Study in Kurdistan Province). In Proceedings of the 7th International Congress on Civil Engineering, Architecture and Urban Development, Haikou, China, 23–25 December 2022.
35. Biancardo, S.A.; Viscione, N.; Oreto, C.; Veropalumbo, R.; Abbondati, F. BIM Approach for Modeling Airports Terminal Expansion. *Infrastructure* **2020**, *5*, 41. [CrossRef]
36. Keskin, B.; Salman, B.; Koseoglu, O. Architecting a BIM-Based Digital Twin Platform for Airport Asset Management: A Model-Based System Engineering with SysML Approach. *J. Constr. Eng. Manag.* **2022**, *148*, 04022020. [CrossRef]
37. Bensalah, M.; Elouadi, A.; Mharzi, H. Overview: The opportunity of BIM in railway. *Smart Sustain. Built Environ.* **2019**, *8*, 103–116. [CrossRef]
38. Kurwi, S.; Demian, P.; Hassan, T. Integrating BIM and GIS in railway projects: A critical review. In Proceedings of the 33rd Annual ARCOM Conference, Cambridge, UK, 4–6 September 2017.
39. Wu, S.; Zhang, X. Visualization of Railway Transportation Engineering Management Using BIM Technology under the Application of Internet of Things Edge Computing. *Wirel. Commun. Mob. Comput.* **2022**, *2022*, 4326437. [CrossRef]
40. Chen, B.-Q.; Videiro, P.M.; Guedes Soares, C. Opportunities and Challenges to Develop Digital Twins for Subsea Pipelines. *J. Mar. Sci. Eng.* **2022**, *10*, 739. [CrossRef]
41. Hosamo, H.H.; Imran, A.; Cardenas-Cartagena, J.; Svennevig, P.R.; Svidt, K.; Nielsen, H.K. A Review of the Digital Twin Technology in the AEC-FM Industry. *Adv. Civ. Eng.* **2022**, *2022*, 2185170. [CrossRef]
42. Salem, T.; Dragomir, M. Options for and Challenges of Employing Digital Twins in Construction Management. *Appl. Sci.* **2022**, *12*, 2928. [CrossRef]
43. Madubuike, O.C.; Anumba, C.J.; Khallaf, R. A review of digital twin applications in construction. *J. Inf. Technol. Constr. ITcon* **2022**, *27*, 145–172. [CrossRef]

44. Deng, M.; Menassa, C.C.; Kamat, V.R. From Bim to Digital Twins: A Systematic Review of the Evolution of Intelligent Building Representations in the AEC-FM Industry. *J. Inf. Technol. Constr.* **2021**, *26*, 58–83. [CrossRef]
45. Kor, M.; Yitmen, I.; Alizadehsalehi, S. An investigation for integration of deep learning and digital twins towards Construction 4.0. *Smart Sustain. Built Environ.* **2022**. [CrossRef]
46. Lin, Y.-C.; Cheung, W.-F. Internet of Things (IoT) and internet enabled physical devices for Construction 4.0. In *Construction 4.0*; Routledge: Oxfordshire, UK, 2020; pp. 350–369.
47. Lee, D.; Lee, S. Digital Twin for Supply Chain Coordination in Modular Construction. *Appl. Sci.* **2021**, *11*, 5909. [CrossRef]
48. Succar, B. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Autom. Constr.* **2009**, *18*, 357–375. [CrossRef]
49. Thomé, A.M.T.; Scavarda, L.F.; Scavarda, A.J. Conducting systematic literature review in operations management. *Prod. Plan. Control* **2016**, *27*, 408–420. [CrossRef]
50. Reed, J. Doing research in business and management: An essential guide to planning your project. *Action Learn. Res. Pract.* **2012**, *9*, 191–194. [CrossRef]
51. Ellegaard, O.; Wallin, J.A. The bibliometric analysis of scholarly production: How great is the impact? *Scientometrics* **2015**, *105*, 1809–1831. [CrossRef]
52. Donthu, N.; Kumar, S.; Mukherjee, D.; Pandey, N.; Lim, W.M. How to conduct a bibliometric analysis: An overview and guidelines. *J. Bus. Res.* **2021**, *133*, 285–296. [CrossRef]
53. Kraus, S.; Breier, M.; Dasí-Rodríguez, S. The art of crafting a systematic literature review in entrepreneurship research. *Int. Entrep. Manag. J.* **2020**, *16*, 1023–1042. [CrossRef]
54. Koke, B.; Moehler, R.C. Earned Green Value management for project management: A systematic review. *J. Clean. Prod.* **2019**, *230*, 180–197. [CrossRef]
55. Linnenluecke, M.K.; Marrone, M.; Singh, A.K. Conducting systematic literature reviews and bibliometric analyses. *Aust. J. Manag.* **2020**, *45*, 175–194. [CrossRef]
56. Van Eck, N.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef] [PubMed]
57. Ali, K.N.; Alhajlah, H.H.; Kassem, M.A. Collaboration and Risk in Building Information Modelling (BIM): A Systematic Literature Review. *Buildings* **2022**, *12*, 571. [CrossRef]
58. Oraee, M.; Hosseini, M.R.; Papadonikolaki, E.; Palliyaguru, R.; Arashpour, M. Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review. *Int. J. Proj. Manag.* **2017**, *35*, 1288–1301. [CrossRef]
59. Acedo, F.J.; Barroso, C.; Galan, J.L. The resource-based theory: Dissemination and main trends. *Strateg. Manag. J.* **2006**, *27*, 621–636. [CrossRef]
60. Calabretta, G.; Durisin, B.; Ogliengo, M. Uncovering the intellectual structure of research in business ethics: A journey through the history, the classics, and the pillars of Journal of Business Ethics. *J. Bus. Ethics* **2011**, *104*, 499–524. [CrossRef]
61. Small, H. Co-citation in the scientific literature: A new measure of the relationship between two documents. *J. Am. Soc. Inf. Sci.* **1973**, *24*, 265–269. [CrossRef]
62. Azhar, S.; Hein, M.; Sketo, B. Building Information Modeling (BIM): Benefits, risks and challenges. In Proceedings of the 44th ASC Annual Conference, Auburn, AL, USA, 2–5 April 2008; pp. 2–5.
63. Eastman, C.M.; Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*; John Wiley & Sons: Hoboken, NJ, USA, 2011.
64. Sacks, R.; Pikas, E. Building Information Modeling education for construction engineering and management. I: Industry requirements, state of the art, and gap analysis. *J. Constr. Eng. Manag.* **2013**, *139*, 04013016. [CrossRef]
65. Van Eck, N.J.; Waltman, L. *VOSviewer Manual*; Univeristeit Leiden: Leiden, The Netherlands, 2013; Volume 1, pp. 1–53.
66. Azhar, S. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadersh. Manag. Eng.* **2011**, *11*, 241–252. [CrossRef]
67. 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]
68. Bryde, D.; Broquetas, M.; Volm, J.M. The project benefits of building information modelling (BIM). *Int. J. Proj. Manag.* **2013**, *31*, 971–980. [CrossRef]
69. Becerik-Gerber, B.; Jazizadeh, F.; Li, N.; Calis, G. Application Areas and Data Requirements for BIM-Enabled Facilities Management. *J. Constr. Eng. Manag.* **2012**, *138*, 431–442. [CrossRef]
70. Gu, N.; London, K. Understanding and facilitating BIM adoption in the AEC industry. *Autom. Constr.* **2010**, *19*, 988–999. [CrossRef]
71. Barlish, K.; Sullivan, K. How to measure the benefits of BIM—A case study approach. *Autom. Constr.* **2012**, *24*, 149–159. [CrossRef]
72. Zhang, S.; Teizer, J.; Lee, J.-K.; Eastman, C.M.; Venugopal, M. Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules. *Autom. Constr.* **2013**, *29*, 183–195. [CrossRef]
73. Eadie, R.; Browne, M.; Odeyinka, H.; McKeown, C.; McNiff, S. BIM implementation throughout the UK construction project lifecycle: An analysis. *Autom. Constr.* **2013**, *36*, 145–151. [CrossRef]
74. Azhar, S.; Khalfan, M.; Maqsood, T. Building Information Modeling (BIM): Now and beyond. *Australas. J. Constr. Econ. Build.* **2012**, *12*, 15–28.

75. Alfadil, M.O.; Kassem, M.A.; Ali, K.N.; Alaghbari, W. Construction industry from perspective of force majeure and environmental risk compared to the CoViD-19 outbreak: A systematic literature review. *Sustainability* **2022**, *14*, 1135. [CrossRef]
76. Liu, H.; Abudayyeh, O.; Liou, W. *BIM-Based Smart Facility Management: A Review of Present Research Status, Challenges, and Future Needs*; ASCE: Reston, VA, USA, 2020; pp. 1087–1095.
77. Zhang, J.Y.; Cheng, J.C.P.; Chen, W.W.; Chen, K.Y. Digital Twins for Construction Sites: Concepts, LoD Definition, and Applications. *J. Manag. Eng.* **2022**, *38*, 04021094. [CrossRef]
78. Li, X.; Lu, W.S.; Xue, F.; Wu, L.P.F.; Zhao, R.; Lou, J.F.; Xu, J.Y. Blockchain-Enabled IoT-BIM Platform for Supply Chain Management in Modular Construction. *J. Manag. Eng.* **2022**, *148*, 04021195. [CrossRef]
79. Sun, H.; Liu, Z. Research on Intelligent Dispatching System Management Platform for Construction Projects Based on Digital Twin and BIM Technology. *Adv. Civ. Eng.* **2022**, *2022*, 8273451. [CrossRef]
80. Almatared, M.; Liu, H.X.; Tang, S.X.; Sulaiman, M.; Lei, Z.; Li, H.X. Digital Twin in the Architecture, Engineering, and Construction Industry: A Bibliometric Review. In Proceedings of the Construction Research Congress 2022: Computer Applications, Automation, and Data Analytics, Arlington, Virginia, 9–12 March 2022; pp. 670–678.
81. Teisserenc, B.; Sepasgozar, S. Adoption of Blockchain Technology through Digital Twins in the Construction Industry 4.0: A PESTELS Approach. *Buildings* **2021**, *11*, 670. [CrossRef]
82. Villa, V.; Naticchia, B.; Bruno, G.; Aliev, K.; Piantanida, P.; Antonelli, D. IoT Open-Source Architecture for the Maintenance of Building Facilities. *Appl. Sci.* **2021**, *11*, 5374. [CrossRef]
83. Sepasgozar, S.M.E. Differentiating Digital Twin from Digital Shadow: Elucidating a Paradigm Shift to Expedite a Smart, Sustainable Built Environment. *Buildings* **2021**, *11*, 151. [CrossRef]
84. Pan, Y.; Zhang, L.M. A BIM-data mining integrated digital twin framework for advanced project management. *Autom. Constr.* **2021**, *124*, 103564. [CrossRef]
85. Sepasgozar, S.M.E.; Hui, F.K.P.; Shirowzhan, S.; Foroozanfar, M.; Yang, L.M.; Aye, L. Lean Practices Using Building Information Modeling (BIM) and Digital Twinning for Sustainable Construction. *Sustainability* **2021**, *13*, 161. [CrossRef]
86. Lin, Y.C.; Cheung, W.F. Developing WSN/BIM-Based Environmental Monitoring Management System for Parking Garages in Smart Cities. *J. Manag. Eng.* **2020**, *36*, 04020012. [CrossRef]
87. Al-Saeed, Y.; Edwards, D.J.; Scaysbrook, S. Automating construction manufacturing procedures using BIM digital objects (BDOs) Case study of knowledge transfer partnership project in UK. *Constr. Engl.* **2020**, *20*, 345–377. [CrossRef]
88. El Mokhtari, K.; Panushev, I.; McArthur, J.J. Development of a Cognitive Digital Twin for Building Management and Operations. *Front. Built Environ.* **2022**, *8*. [CrossRef]
89. Wei, Y.X.; Lei, Z.; Altaf, S. An Off-Site Construction Digital Twin Assessment Framework Using Wood Panelized Construction as a Case Study. *Buildings* **2022**, *12*, 566. [CrossRef]
90. Zhao, Y.H.; Cao, C.F.; Liu, Z.S. A Framework for Prefabricated Component Hoisting Management Systems Based on Digital Twin Technology. *Buildings* **2022**, *12*, 276. [CrossRef]
91. Marocco, M.; Garofolo, I. Integrating disruptive technologies with facilities management: A literature review and future research directions. *Autom. Constr.* **2021**, *131*, 103917. [CrossRef]
92. Mannino, A.; Dejaco, M.C.; Cecconi, F.R. Building Information Modelling and Internet of Things Integration for Facility Management-Literature Review and Future Needs. *Appl. Sci.* **2021**, *11*, 3062. [CrossRef]
93. Hasan, S.M.; Lee, K.; Moon, D.; Kwon, S.; Jinwoo, S.; Lee, S. Augmented reality and digital twin system for interaction with construction machinery. *J. Asian Archit. Build. Eng.* **2022**, *21*, 564–575. [CrossRef]
94. Turner, C.J.; Oyekan, O.; Stergioulas, L.; Griffin, D. Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities. *IEEE Trans. Inform.* **2021**, *17*, 746–756. [CrossRef]
95. Alshammari, K.; Beach, T.; Rezgui, Y. Cybersecurity for Digital Twins in the Built Environment: Current Research and Future Directions. *J. Inf. Technol. Constr.* **2021**, *26*, 159–173. [CrossRef]
96. Boje, C.; Guerriero, A.; Kubicki, S.; Rezgui, Y. Towards a semantic Construction Digital Twin: Directions for future research. *Autom. Constr.* **2020**, *114*, 103179. [CrossRef]
97. Shahzad, M.; Shafiq, M.T.; Douglas, D.; Kassem, M. Digital Twins in Built Environments: An Investigation of the Characteristics, Applications, and Challenges. *Buildings* **2022**, *12*, 120. [CrossRef]
98. Lee, D.; Lee, S.H.; Masoud, N.; Krishnan, M.; Li, V.C. Integrated digital twin and blockchain framework to support accountable information sharing in construction projects. *Autom. Constr.* **2021**, *127*, 103688. [CrossRef]
99. Gigliarelli, E.; Calcerano, F.; Cessari, L. Heritage Bim, Numerical Simulation and Decision Support Systems: An Integrated Approach for Historical Buildings Retrofit. In Proceedings of the Climamed 2017—Mediterranean Conference of Hvac Historical Buildings Retrofit in the Mediterranean Area, Matera, Italy, 12–13 May 2017; pp. 135–144.
100. Khalil, A.; Stravoravdis, S. H-BIM and the Domains of Data Investigations of Heritage Buildings Current State of the Art. In Proceedings of the 2nd International Conference of Geomatics and Restoration (GEORES 2019), Milano, Italy, 8–10 May 2019; pp. 661–667.
101. Hull, J.; Ewart, I.J. Conservation data parameters for BIM-enabled heritage asset management. *Autom. Constr.* **2020**, *119*, 103333. [CrossRef]
102. Intignano, M.; Biancardo, S.A.; Oreto, C.; Viscione, N.; Veropalumbo, R.; Russo, F.; Ausiello, G.; Dell'Acqua, G. A Scan-to-BIM Methodology Applied to Stone Pavements in Archaeological Sites. *Heritage* **2021**, *4*, 169. [CrossRef]

103. Alshawabkeh, Y.; Baik, A.; Miky, Y. Integration of laser scanner and photogrammetry for heritage BIM enhancement. *ISPRS Int. J. Geo Inf.* **2021**, *10*, 316. [CrossRef]
104. Szabo, N. Smart Contracts. 1994. Available online: https://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart.contracts.html (accessed on 5 September 2022).
105. Ye, X.L.; Zeng, N.S.; Konig, M. Systematic literature review on smart contracts in the construction industry: Potentials, benefits, and challenges. *Front. Eng. Manag.* **2022**, *9*, 196–213. [CrossRef]
106. Sigalov, K.; Ye, X.L.; Konig, M.; Hagedorn, P.; Blum, F.; Severin, B.; Hettmer, M.; Huckinghaus, P.; Wolkerling, J.; Gross, D. Automated Payment and Contract Management in the Construction Industry by Integrating Building Information Modeling and Blockchain-Based Smart Contracts. *Appl. Sci.* **2021**, *11*, 7653. [CrossRef]
107. Nanayakkara, S.; Perera, S.; Senaratne, S.; Weerasuriya, G.T.; Bandara, H. Blockchain and Smart Contracts: A Solution for Payment Issues in Construction Supply Chains. *Informatics* **2021**, *8*, 36. [CrossRef]
108. Tezel, A.; Papadonikolaki, E.; Yitmen, I.; Hilletofth, P. Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions. *Front. Eng. Manag.* **2020**, *7*, 547–563. [CrossRef]
109. Li, J.; Greenwood, D.; Kassem, M. Blockchain in the construction sector: A socio-technical systems framework for the construction industry. In *Advances in Informatics and Computing in Civil and Construction Engineering*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 51–57.
110. Gu, H.; Lv, H.; Gao, J.; Shi, J. Towards a general fuzzy ontology and its construction. In Proceedings of the International Conference on Intelligent Systems and Knowledge Engineering 2007, Chengdu, China, 26–28 November 2007; pp. 984–989.
111. Zheng, Y.; Törmä, S.; Seppänen, O. A shared ontology suite for digital construction workflow. *Autom. Constr.* **2021**, *132*, 103930. [CrossRef]
112. Ding, L.; Zhong, B.; Wu, S.; Luo, H. Construction risk knowledge management in BIM using ontology and semantic web technology. *Saf. Sci.* **2016**, *87*, 202–213. [CrossRef]
113. Schiavi, B.; Havard, V.; Beddiar, K.; Baudry, D. BIM data flow architecture with AR/VR technologies: Use cases in architecture, engineering and construction. *Autom. Constr.* **2022**, *134*, 104054. [CrossRef]
114. Lucas, J. Rapid Development of Virtual Reality Based Construction Sequence Simulations: A Case Study. *J. Inf. Technol. Constr.* **2020**, *25*, 72–86. [CrossRef]
115. Nikolic, D.; Whyte, J. Visualizing a New Sustainable World: Toward the Next Generation of Virtual Reality in the Built Environment. *Buildings* **2021**, *11*, 546. [CrossRef]
116. Azuma, R.; Baillot, Y.; Behringer, R.; Feiner, S.; Julier, S.; MacIntyre, B. Recent advances in augmented reality. *IEEE Comput. Graph. Appl.* **2001**, *21*, 34–47. [CrossRef]
117. Azuma, R.T. A survey of augmented reality. *Presence Teleoper. Virtual Environ.* **1997**, *6*, 355–385. [CrossRef]
118. Chen, C.A.; Lai, H.I. Application of augmented reality in museums—Factors influencing the learning motivation and effectiveness. *Sci. Prog.* **2021**, *104*, 00368504211059045. [CrossRef] [PubMed]