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Collaboration and Risk in Building Information Modelling (BIM): A Systematic Literature Review

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Abstract: Building information modelling (BIM) has become increasingly popular in construction projects in recent years. Simultaneously, project management has received more attention from academics and practitioners worldwide. Many studies have suggested that perceiving collaboration and risk are critical for successful construction project management. This study investigates the current status and future trends in building information modeling (BIM) literature from the Web of Science database. This review systematically uses bibliometric and systematic literature review (SLR) methods through co-occurrence and co-citation analysis. First, 650 academic documents were retrieved from the Web of Science database. Then, co-occurrence and co-citation analyses were performed along with network visualization to examine research interconnections' patterns. As a result, relevant keywords, productive authors, and important journals have been highlighted. The prominent research topics within the literature on building information modelling focus on the following topics: collaborative in BIM, integration of BIM, GIS and Internet of Things (IoT), barriers to the integration of BIM, sustainability and BIM, and risk assessment and uncertainty. Finally, the potential research directions are developing towards digital twin technology, integration of BIM and AI, and Augmented Reality (AR) and BIM. The presented findings of only 88 articles discuss the collaboration and risk issue in BIM for the construction industry and thus confirms the need for more studies on this topic to enhance the chances of successfully building information modelling projects. The review focuses only on the academic documents retrieved from the Web of Science database, thus restricting the coverage of the reviewed literature relating to building information modelling collaboration and risk.

Keywords: building information modelling (BIM); collaboration; risk; systematic literature review (SLR); bibliometrics; systematic review analysis

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Citation: 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. https://doi.org/10.3390/buildings12050571

Academic Editor: Lucio Soibelman

Received: 30 March 2022
Accepted: 26 April 2022
Published: 29 April 2022

1. Introduction

Building information modelling (BIM) is becoming more prevalent and is being utilized throughout the building phase of projects. General contractors (GCs) often use BIM technology throughout the phase for a number of construction management applications. If the architect uses traditional paper-based, two-dimensional designs, general contractors will need to create a construction management model [1]. However, one practical challenge that general contractors have is finishing BIM model generation on time for large and complex projects. As a consequence, the majority of GCs use collaborative work to produce BIM models, which requires several participants to cooperate to complete different components of BIM model production at various locations and times, successfully reducing the duration of BIM model creation. On the other side, collaboration creates a plethora of practical complications.

According to [2], collaborative effort for the development of BIM models raises the following critical practical issues: (1) ineffective mechanisms for managing collaborative work, (2) inability to manage BIM model conception problems and modifications effectively, (3) difficulty sharing and observing relevant changes to related BIM engineers, (4) inability to control BIM model creation self-inspections and findings efficiently, (5) inability to control BIM model construction versions effectively during the process where the BIM model must be revised and updated continuously, and (6), despite extensive research and development efforts in the academic and professional BIM literature, there is a dearth of research on BIM collaboration management (CM), notably for BIM model production. Numerous publications have been published on a variety of subjects relating to BIM usage in relation to various nations and adoption trends. A comprehensive examination of BIM is required to elicit diverse viewpoints on various user perceptions and experiences. Additionally, it is necessary to capture emerging trends, generate research findings, and propose opportunities for future research directions related to the use of BIM to enhance building process management and service delivery. While several studies [3–5] have conducted bibliometric analyses on the use of BIM for specific applications such as use in international construction projects and the evolution of BIM, this study examines the importance of collaborative and risk mitigation and the practice of rapidly evolving building information modeling (BIM). Moreover, it includes an investigation and additional examination of existing materials in order to identify potential solutions to present issues associated with increasing BIM acceptance and utilization.

This was accomplished via the use of a range of current samples and selection criteria set through the bibliometric analysis of disaggregated research on BIM and construction industry research themes. This study aims to use bibliometric and systematic review analysis to answer the following research questions:

RQ1. What are the most relevant keywords in collaboration and risk in BIM studies?
RQ2. Which are the most important journals and productive authors on collaboration and risk in BIM studies?
RQ3. What are the most prevalent themes of collaboration and risk in BIM between scholars?
RQ4. What are the future trends of publications on collaboration and risk in BIM studies?

This review research intends to improve our understanding of BIM cooperation and risk, particularly in the growing worldwide construction sector. This research will also help academics propose future research suggestions by studying Web of Science WOS database articles in the construction project. A systematic review analysis is a "quantitative examination of science, science communication, and science policy." [6]. The systematic review analysis covers methodologies for analyzing citation inter-relationships, measuring research effect, and investigating the influence of academic publications and research institutes in a certain field of knowledge [7]. Recent construction studies, such as construction engineering and management (CEM) and building information modelling (BIM), have used a systematic review approach [5]. This research includes a systematic review that analyses and maps the literature on construction project management using the systematic review method (CPM). This paper's conclusions highlight the key subjects in the BIM literature and give a better grasp of current research paths. This study is organised into four sections: methodology, results and interpretations, discussion of numerous issues and challenges elaborated in addressing the research questions, and the conclusion.

2. Research Methodology

Academic papers relevant to building information modelling (BIM) were gathered from an online dataset to reach the objectives of this review research. As a result, the Web of Science database was queried for a list of scholarly papers. Drawing the study field's boundaries is critical to overcoming the challenge of searching for every linked article [8]. In this paper, a systematic methodology is used, as well as a science mapping approach, to perform bibliometric and systematic review analysis using the Web of Science online database as a data source. The methodological process framework for this study is depicted in Figure 1.

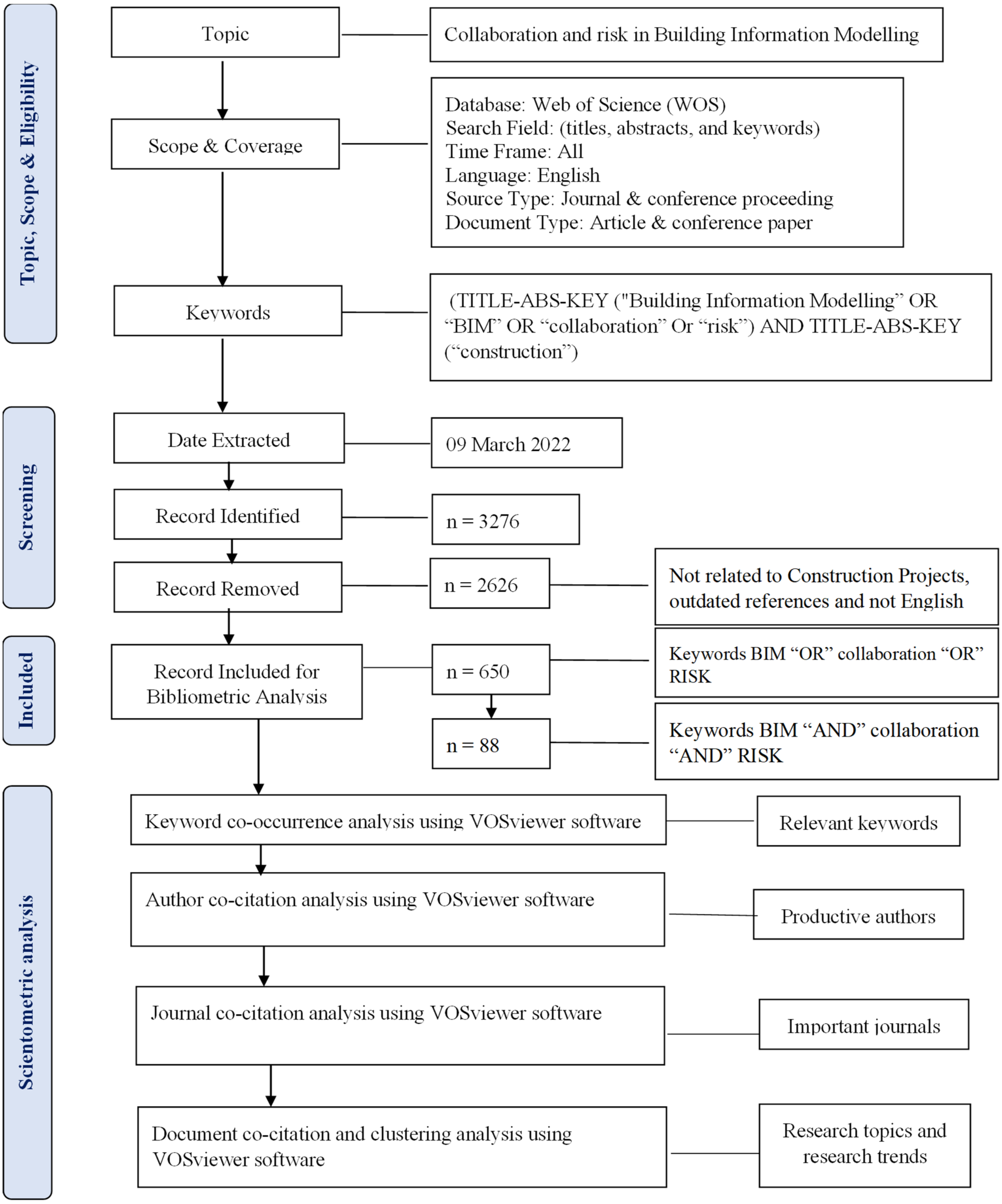

Figure 1. Flow diagram of the search methodology.

3. Bibliometric Analysis

Bibliometric search retrieves data for required academic documents [9]. Web of Science is a database that is one of the most comprehensive available [10]. As a result, the Web of Science database was chosen to conduct a review of the current literature on project BIM in the construction industry in this paper. Additionally, the Web of Science database includes the most recent documents published [11]. Moreover, the Web of Science database is among the most significant sources of peer-reviewed literature and the widest range of peer-reviewed journals, with the highest number of citations and abstracts [10,12]. The Web of Science database was chosen for this review article because it contains the most academic research on construction compared to other databases such as Google Scholar, Scopus, and PubMed [13]. For a comprehensive literature review, articles related to project BIM in the construction industry were retrieved using the following keywords: ("Building Information Modeling" OR "BIM" OR "Collaboration" OR "Risk") AND ("construction") and the search was conducted within the code of (titles, abstracts, and keywords). The research subjects were limited to Engineering, Business Management and Accounting, Decision Sciences, Social Sciences, Economics, Econometrics and Finance, Multidisciplinary, which are related to the construction domain. Only English journal and conference proceedings papers were selected for this review.

Research query was carried out on 9 March 2022 with the following final string: (TITLE-ABS-KEY ("Building Information Modeling" OR "BIM" OR "Collaboration" OR "Risk") AND TITLE-ABS-KEY ("construction")) AND INCLUDED "ENGINEERING CIVIL" OR "CONSTRUCTION BUILDING TECHNOLOGY" OR "ENVIRONMENTAL SCIENCES" OR "ENGINEERING MULTIDISCIPLINARY" OR "GREEN SUSTAINABLE SCIENCE TECHNOLOGY" OR "ENVIRONMENTAL STUDIES OR ARCHITECTURE". EXCLUDED "ENVIRONMENTAL STUDIES" OR "ENGINEERING INDUSTRIAL" OR "MATERIALS SCIENCE MULTIDISCIPLINARY" OR "PHYSICS APPLIED" OR "CHEMISTRY MULTIDISCIPLINARY" OR "COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS" OR "ENGINEERING ENVIRONMENTAL" OR "MANAGEMENT" OR "REMOTE SENSING" OR "EDUCATION SCIENTIFIC DISCIPLINES" OR "COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE" OR "GEOSCIENCES MULTIDISCIPLINARY" OR "IMAGING SCIENCE PHOTOGRAPHIC TECHNOLOGY" OR "GEOGRAPHY PHYSICAL" OR "ENERGY FUELS OR GEOGRAPHY" OR "PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH" OR "URBAN STUDIES" OR "TRANSPORTATION SCIENCE TECHNOLOGY" OR "COMPUTER SCIENCE INFORMATION SYSTEMS" OR "ENGINEERING GEOLOGICAL" OR "REGIONAL URBAN PLANNING" OR "ARCHAEOLOGY" OR "ART" OR "ENGINEERING ELECTRICAL ELECTRONIC" OR "MATERIALS SCIENCE COMPOSITES" OR "AUTOMATION CONTROL SYSTEMS" OR "COMPUTER SCIENCE THEORY METHODS" OR "ENGINEERING MECHANICAL" OR "WATER RESOURCES" OR "COMPUTER SCIENCE SOFTWARE ENGINEERING" OR "TRANSPORTATION OR MATERIALS SCIENCE CHARACTERIZATION TESTING" OR "DEVELOPMENT STUDIES OR ECONOMICS" OR "EDUCATION EDUCATIONAL RESEARCH" OR "HISTORY PHILOSOPHY OF SCIENCE" OR "INSTRUMENTS INSTRUMENTATION" OR "MATHEMATICS APPLIED" OR "OPERATIONS RESEARCH MANAGEMENT SCIENCE" OR "OPTICS OR PUBLIC ADMINISTRATION" OR "SOCIAL SCIENCES INTERDISCIPLINARY" OR "THERMODYNAMICS" OR "BIODIVERSITY CONSERVATION" OR "BUSINESS" OR "ERGONOMICS" OR "MARINE FRESHWATER BIOLOGY" OR "MATHEMATICS INTERDISCIPLINARY APPLICATIONS" OR "METEOROLOGY ATMOSPHERIC SCIENCES"). The other assessment process involved reviewing the titles and abstracts of documents to identify only those that were relevant to the field of building information modelling. Following an exhaustive manual filtering process, the final dataset contained 650 documents, including 594 journal and review articles and 55 conference papers.

4. Systematic Review Analysis

The authors of [14] define systematic review analysis as "a quantitative study of research on the development of science". It is a technique for assessing the impact of research and examining citation relationships in order to map a specific body of knowledge using trends extracted from academic databases. While a manual review of the literature can provide a comprehensive map of a particular research area, it is still subject to bias and limited to subjective interpretation [15]. Thus, in this study, the systematic review technique is used to analyse BIM projects within the construction domain in order to visualize and map the knowledge area [16]. The bibliometric analysis method generates a network model from systematic review data and identifies research subjects [17]. Systematic review analysis generates network models that depict the intellectual perspective on a particular body of knowledge, assisting researchers in answering their research questions and achieving their research objectives [18]. Visualizing the building information modelling field as a network will aid researchers in perceiving overall research patterns and identifying research trends.

The abstract and keywords succinctly summarise the contents of publications. As a result, keywords are used as a unit of analysis to create clusters corresponding to the research area's most salient components. A bibliometric search was conducted in this review paper using the title, abstract, and keywords codes to conduct a comprehensive review of the literature on building information modelling. To ascertain the research pattern, the following analyses were conducted: keyword co-occurrence, author co-citation, burst identification, journal co-citation, and document co-citation and clustering. Prior to clustering analysis, keyword co-occurrence and author co-citation analysis provide a broad description of the research area. Burst aides in determining research trends over time and navigating recent trends in building information modelling. Document co-citation analysis employs clustering techniques and assigns abstract terms to clusters in order to denote research areas. This strategy has been proposed previously for conducting a systematic review of the literature [19,20].

5. Selecting the Appropriate Tool for the Analyses

Choosing the most suitable analytical tool, the term "network analysis" refers to a group of advanced methods and algorithms generated from network theory and accelerated by the emergence and widespread usage of the internet and computers. Its objective is to objectively establish the impact of social networks on research and research trends [21]. Numerous tools have been created to help with network analysis, visualization, and an increased understanding of enormous volumes of data and information through database analytic procedures, including Citespace, Pajek, VOSviewer, nodeXL, Gephi, and Citespace. The VOSviewer programme was used in this investigation. The VOSviewer programme has grown in popularity and use among construction management researchers in the industry, especially in studies including graphical and metadata metrics [22–25]. Additionally, VOSviewer enables the simultaneous usage of numerous databases in a single research study.

VOSviewer is a free, graphical application for constructing and displaying bibliometric graphs and maps that depict the similarities and connections between bibliographic entries. The programme is capable of graphically representing massive networks in an attractive manner [26]. Additionally, VOSviewer was used to perform the required analysis and generate a bibliometric map. VOSviewer is a data generation and visualization programme that enables the analysis of graphical and metadata metrics. Software can handle a vast number of bibliometric networks and data with enhanced accuracy [13]. The web of science core collection database was used to extract data for this research, which was analyzed using VOSviewer version 1.6.15. The research focused on co-authorship analyses and keyword co-occurrence. In the VOSviewer output, circles and labels identify the entities in the visualization network. The hyperlinks demonstrate the strength of the items' connections. Cluster analysis of keyword co-citations makes use of the line-log normalization approach to establish the items' colouring and cluster assignment.

6. VOSviewer Colour Code

The colours of clusters are stored in a cluster colours file, which is a text file. In a cluster colours file, each line corresponds to a cluster. The first line is the lone exception. This is a header line in a cluster colours file that indicates what is in each of the columns. There must be four columns in a cluster colours file: a cluster column, a red column, a green column, and a blue column. Cluster numbers are listed in the cluster column. This column can only contain numbers between 1 and 1000. The red, green, and blue columns represent the red, green, and blue hues of clusters, respectively. These columns can only contain numbers between 0 and 255. A score colours file is identical to a cluster colours file, only it features a colour value column instead of a cluster column, with values ranging from 0 to 1. If items have been assigned scores, they can be coloured by converting their scores to colour values and matching these colour values to the colour values in the score colours file's colour value column. In most cases, exact colour matching is not achievable, thus the colours in the score colours file are interpolated. A score colours file and a density colours file are the same thing. The colour of a point on a map in the item density visualization is determined by converting the density of items at that place into a colour value and matching that colour value with the colour values in the density colours file's colour value column. In most cases, exact colour matching is not achievable, thus the colours in the density colours file are interpolated.

7. Data Acquisition

Academic documents, journals, and conference papers related to building information modelling were extracted using the keyword search strategy from the Web of Science database. The Web of Science database allows to browse and sort required documents by subject area, and statistics display that 62% was related to Construction & Building Technology and 22.9% was related to Engineering, Civil, as shown in Figure 2.

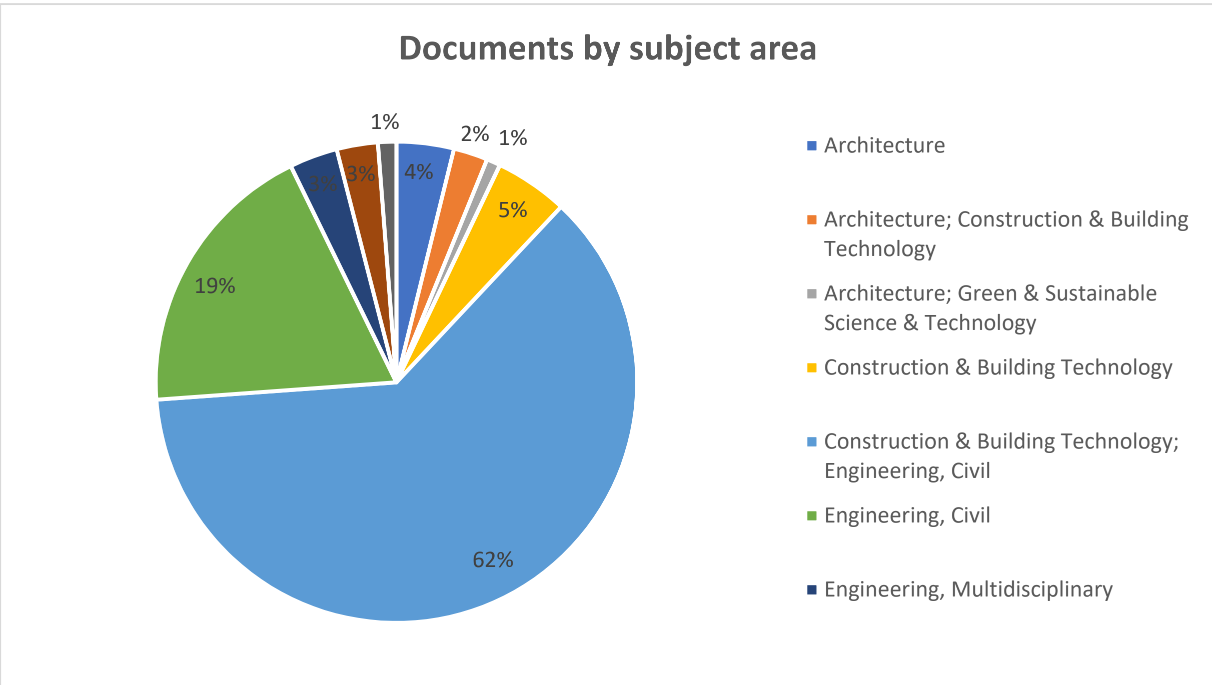

Figure 2. Documents by subject area.

Figure 3 shows the number of published documents each year. Publications in building information modelling exhibit an upward trend between 2000 and 2021, and the highest number of publications occurred in the years of 2021 and 2020, with 81 and 76 published documents, respectively. The following figure shows the extent of researchers' interest and the increase in the number of research in the field of BIM as well as its relation to collaboration and risk in recent years and the multiplicity of areas that can be researched and contribute to promoting the uses of BIM in the field of construction projects.

Although, notably, this study covers publications for only three months of the year 2022, records in 2022 would be estimated at around 84 publications, if linear regression is applied to extend the statistical graph.

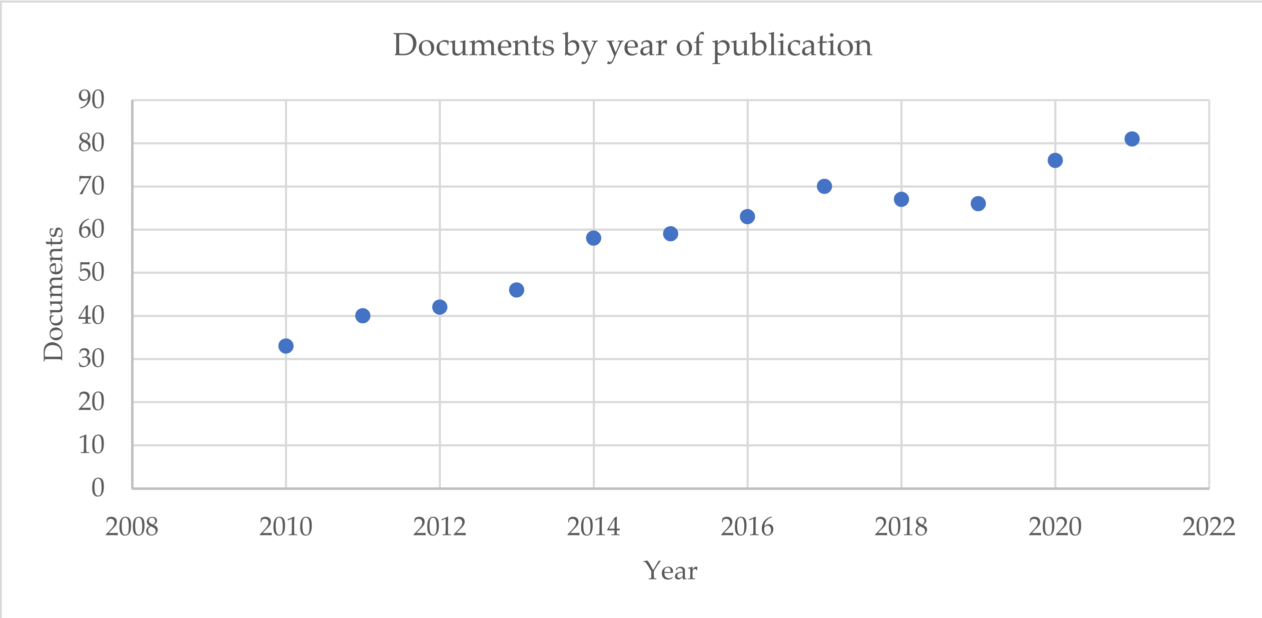

Figure 3. Documents by year of publication.

The publishing profiles of the top ten nations in the BIM research topic throughout the world's regions are shown in Figure 4. Asia (China 934, South Korea 191, and Malaysia 161) had a combined output of 1286 published documents, North America (USA 579 and Canada 163) had a combined output of 742 published documents, and Europe had a combined output of 915 published documents, including 402 from England, 209 from Germany, 154 from Italy, and 132 from Spain. While Australia has 325 papers, Brazil has the most in Latin America with 46 papers. While not complete, this list illustrates the nations and continents where BIM research is currently being conducted.

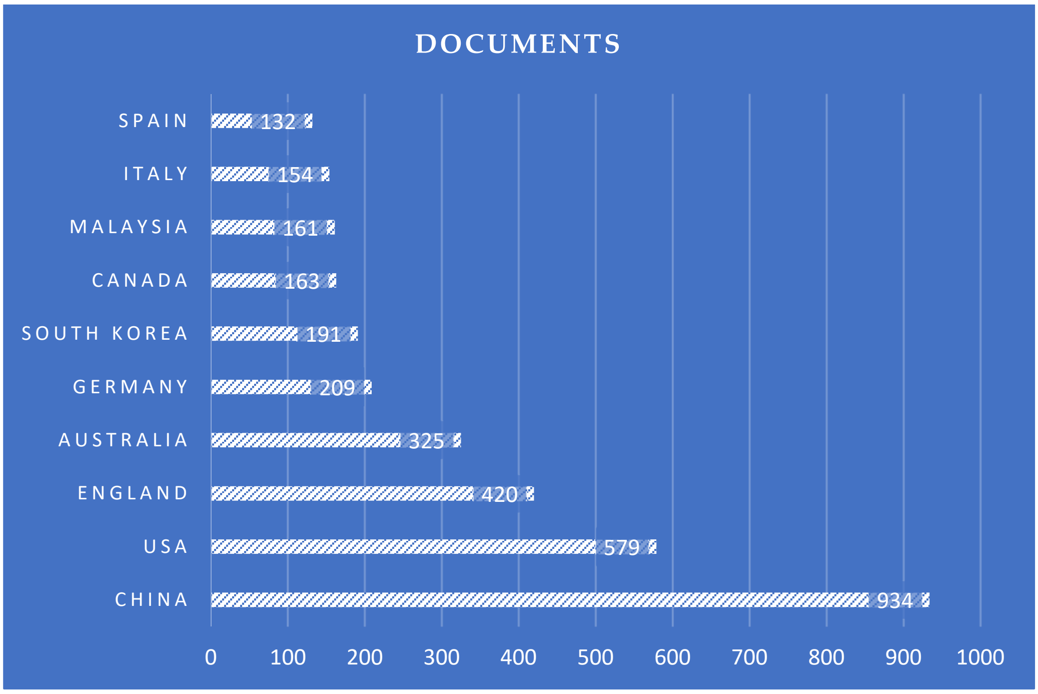

Figure 4. Top publications per country.

8. Keyword Co-Occurrence Analysis

Keywords are words or phrases that reflect overall document content and express the researched area inside the domain boundaries [27]. In this study, VOSviewer software performs keyword co-occurrence analysis and creates networks based on the data from the Web of Science database. Generated map is a distance-based network, and the space between nodes indicates the strength of the relationship between the keywords [28]. The closer distance between nodes generally represents the more robust relationship between the keywords, and node size is directly proportional to the number of documents containing that keyword. VOSviewer tool provides a clustering technique to set related keywords in the same group with the same colour [29]. Only keywords with high occurrence numbers are selected to map the network, therefore the threshold was set at 5, and 42 keywords remain from 665 total keywords. For example, Figure 5 shows keywords co-occurrence network with cluster #1, (bim) 649 links, and a total link strength of 4690; for cluster #2 (construction), with 510 links, and a total link strength of 3441; cluster #7 (risk management), with 42 links, and a total link strength of 62; cluster #11 for collaboration, with 225 links, and a total link strength of 768. Table 1 summarises the most frequent keywords with occurrences, mean year published, links, and full link strength.

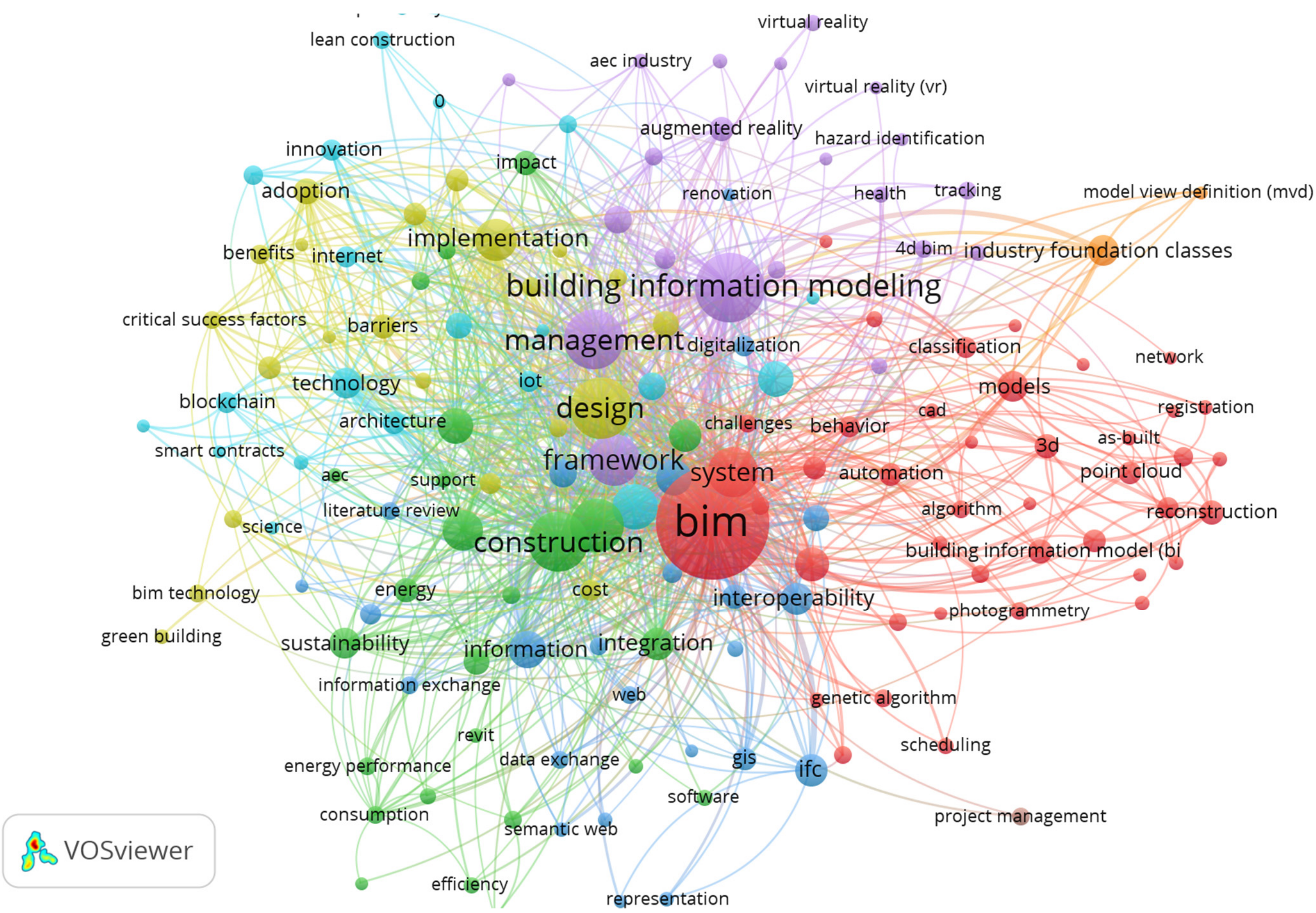

Figure 5. Keyword co-occurrence network.

According to VOSviewer statistical technique, Table 1 shows that the term (bim) is the most frequent author keyword in the literature, and the word (building information modelling) is the second. However, the word (BIM) is mentioned implicitly in different phrases such as building information modelling BIM, building information model (bim), bim implementation, and bim technology. Aggregating frequencies of those items will result in 582 occurrences. Thus, the term (bim) can be considered the most mentioned author keyword in the literature, and the word (construction) is the second. The mean year of publication indicates the average period researchers have used this keyword in their documents. For instance, documents that include collaboration received more attention in 2020, while publications that include risk, integration, and uncertainty have received more attention in 2017, 2019, and 2021. The links represent the number of connections between a particular node and other nodes, while total link strength represents the overall strength of links connected to a given node (Van Eck and Waltman, 2018). For example, the entire link strength of the keyword (bim) is 176, which is the highest among other nodes, and suggests the strongest inter-related keyword to BIM project.

Table 1. Selected keywords with network parameter.

Keyword	Occurrences	Total Link Strength
bim	276	176
building information modeling (bim)	123	62
building information modelling (bim)	72	35
building information modeling	34	25
building information modelling	33	25
construction	18	15
sustainability	18	17
building information model (bim)	16	6
blockchain	11	10
bim implementation	10	7
bim adoption	9	5
bim technology	9	2
gis	9	9
parametric design	9	8
collaboration	8	6
construction industry	8	8
construction management	8	8
facility management	8	8
lean construction	8	8
project management	8	7
scheduling	7	7
green building	6	6
integration	6	6
simulation	6	6
asset management	5	4
barriers	5	5
bridge engineering	5	5
construction projects	5	4
deep learning	5	5
design	5	4
infrastructure	5	5
last planner system	5	5
machine learning	5	5
model view definition (mvd)	5	5
modular construction	5	4
point clouds	5	5
process mining	5	4
productivity	5	5
renovation	5	5
smart contract	5	5
social network analysis	5	4
virtual reality (vr)	5	4

9. Author Co-Citation Analysis

The VOSviewer tool is capable of analysing and visualising a scientific research field in order to logically comprehend a cohesive and organised knowledge structure. This method is widely recognised as a useful systematic review approach for revealing hidden implications in massive amounts of data. Additionally, VOSviewer is a powerful tool for mapping the knowledge domain and generates various network maps in a systematic manner [30]. As a result, VOSviewer is used to generate a network of co-citations and perform abstract clustering analysis in this systematic review. Kleinberg created VOSviewer in 2003, and the application has since been updated to include a burst detection algorithm. The author co-citation network diagram illustrates the relationship between authors whose works are cited in the same document. The author's co-citation network is depicted in Figure 6, which contains 650 nodes and 122,821 links. As previously recommended, network pruning was performed using the pathfinder function to eliminate superfluous links [31]. Thus, node size represents each author's co-citation frequency, and connections between nodes reflect citation relationships created by the number of citations. The top-ranked author is [32], with citation counts of 377. The second one is [33], with citation counts of 337. The third is [34], with citation counts of 313. The fourth is [35], with citation counts of 289.

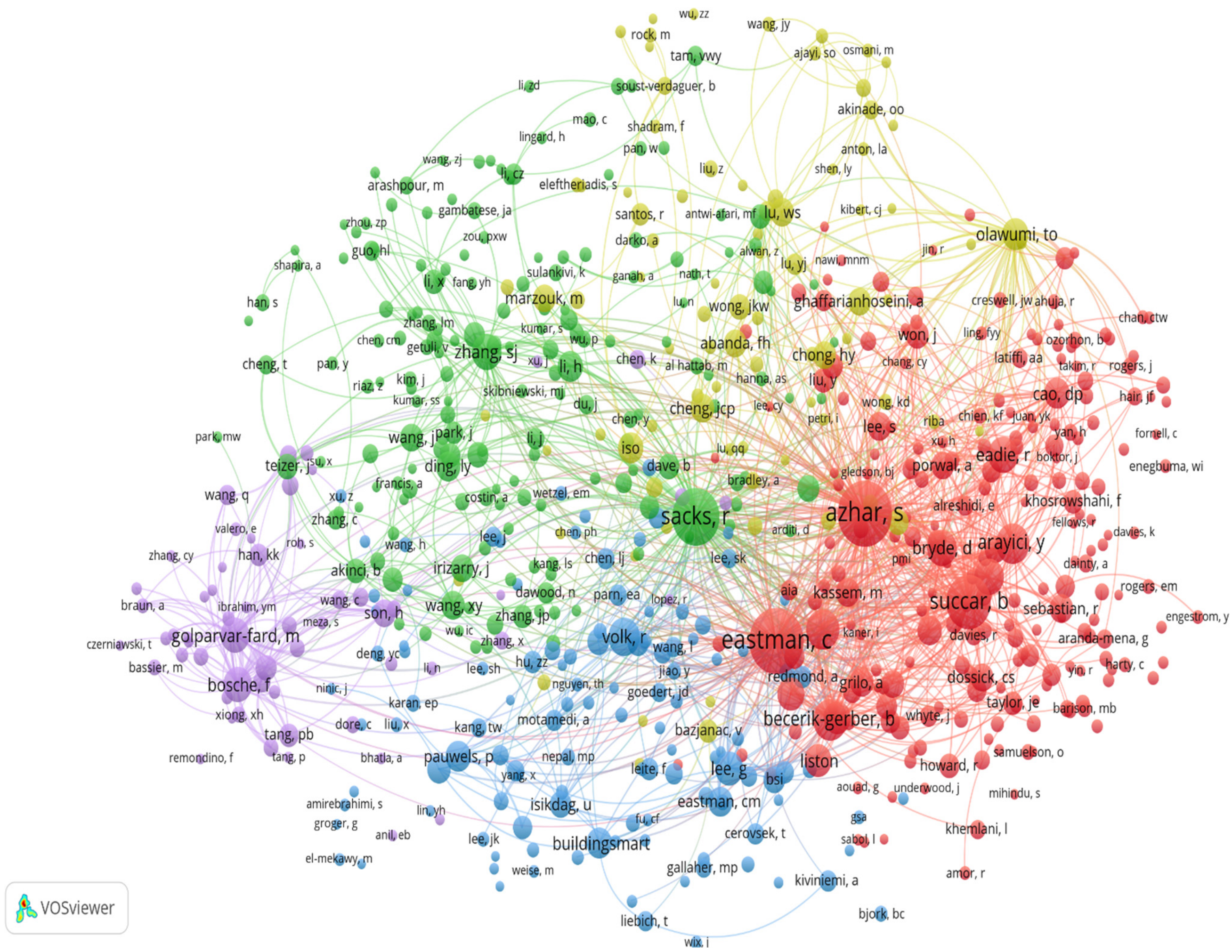

Figure 6. Author co-citations network.

The fifth is [35], with citation counts of 252. The sixth is N. Gu and London, 2010), with citation counts of 247. The seventh is [36], with citation counts of 186. The eighth is [37], with citation counts of 182. The nineth is [38], with citation counts of 168. The tenth is [39], with citation counts of 155. Authors with the most robust citation bursts, who received a sudden increase in the number of citations during a short time, are identified and sorted as shown in Figure 7.

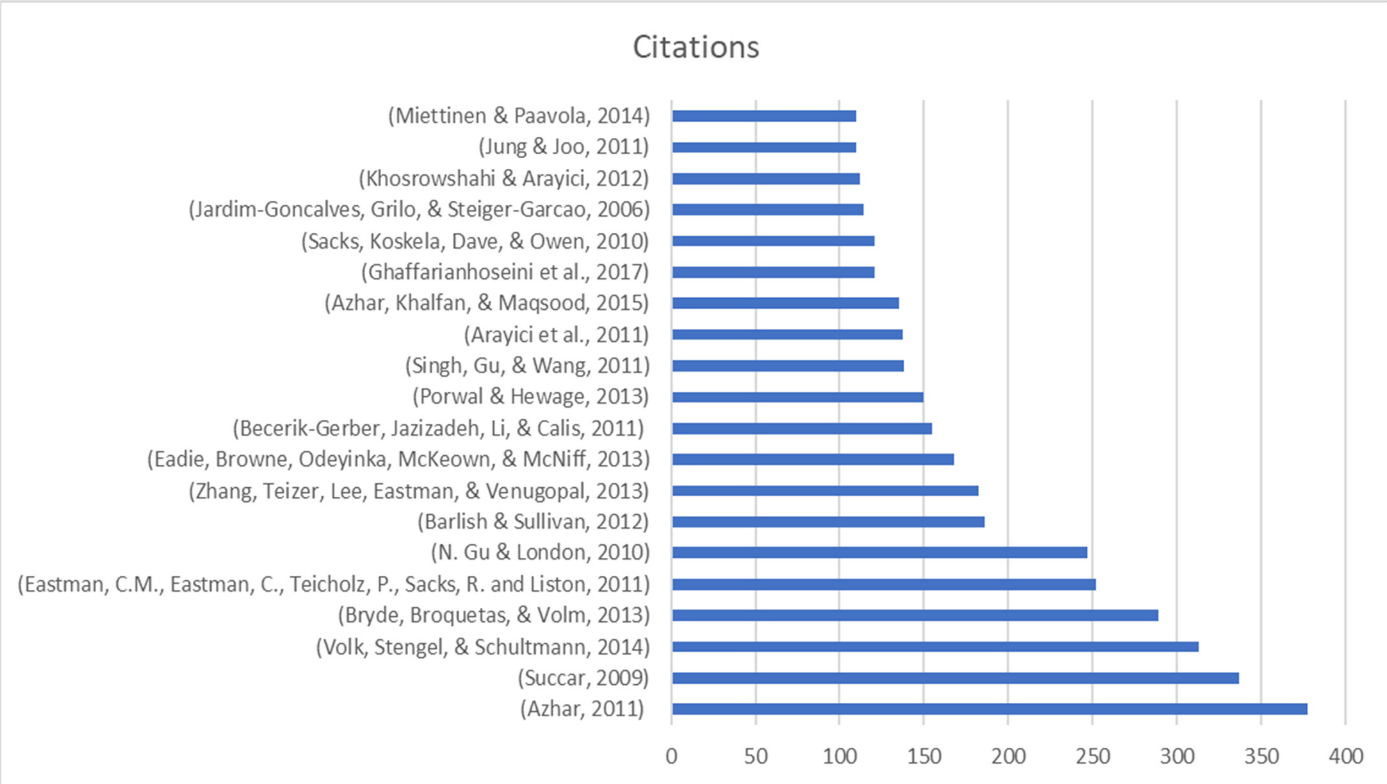

Figure 7. Authors with the strongest citation bursts.

10. Journal Co-Citation Analysis

Table 2 shows the list of top sources (journals and conference proceedings) of academic documents related to building information modelling.

Top sources of academic publications for building information modelling were identified from the Web of Science database statistics and extracted in Table 2. Journals that include the most publications are Automation in Construction, Journal of Information Technology in Construction, Engineering Construction and Architectural Management, Sustainability, Journal of Construction Engineering and Management, eWork and eBusiness in Architecture, Engineering and Construction, and Applied Sciences-basel. Similarly, conference proceedings that contribute the most to the research field of BIM are Construction Research Congress, 7th International Workshop on When Social Science Meets Lean and BIM, and 6th International Symposium on Project Management Ispm.

Journal co-citation analysis using the VOSviewer was carried out, and a journal co-citations network was created with 116 nodes and 1721 links. As shown in Figure 8, the node size represents citation frequency, as the most cited journals offer more significant nodes on the network. The top-ranked journal by citation counts is the Automation in Construction, with citation counts of 15,658. The second is the journal of information technology in construction, with citation counts of 1826. The third is the journal of construction engineering and management, with citation counts of 1810. The fourth is international journal of project management, with citation counts of 1306. Finally, the fifth is advanced engineering informatics, with citation counts of 1273. It is noticeable that all of the most cited journals are also among the top source journals publishing articles for building information modelling.

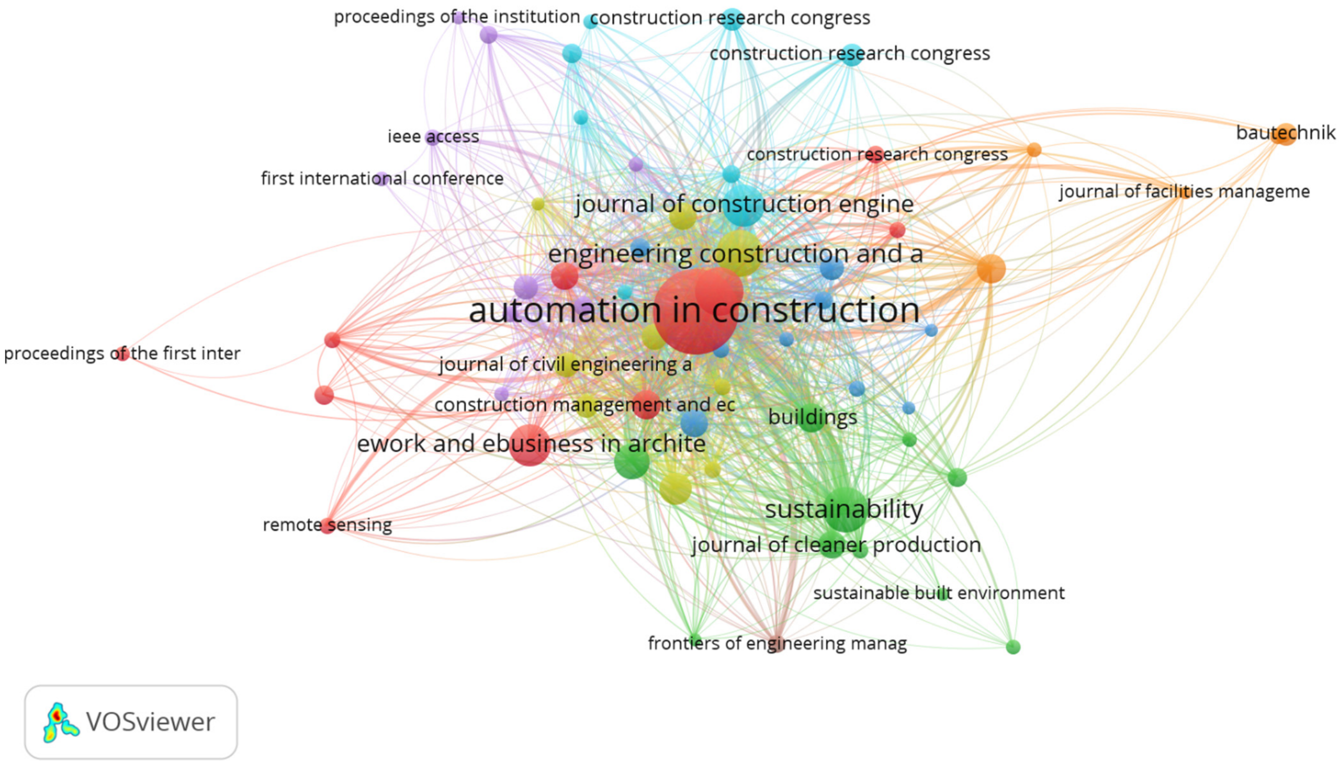

Figure 8. Journal co-citations network.

Table 2. Top sources of academic documents of building information modelling.

Journal Title	Relevant Published Articles	% Total Publication
automation in construction	381	16%
journal of information technology in construction	126	5%
engineering construction and architectural management	116	5%
sustainability	104	4%
journal of construction engineering and management	95	4%
ework and ebusiness in architecture, engineering and construction	89	4%
applied sciences-basel	66	3%
international journal of construction management	53	2%
advances in civil engineering	47	2%
buildings	45	2%
advanced engineering informatics	43	2%
journal of management in engineering	42	2%
journal of computing in civil engineering	40	2%
journal of building engineering	38	2%
journal of cleaner production	38	2%
architectural engineering and design management	34	1%
construction innovation-england	33	1%
journal of civil engineering and management	31	1%
built environment project and asset management	30	1%
Conference Titles	Relevant published articles	% Total publication
Construction Research Congress.	12	1.84
7th International Workshop on When Social Science Meets Lean and BIM.	7	1.074
6th International Symposium on Project Management Ispm.	6	0.92
12th European Conference on Product and Process Modelling Ecppm.	5	0.767

Table 2. *Cont.*

Journal Title	Relevant Published Articles	% Total Publication
Construction Research Congress Crc on Construction Research and Innovation to Transform Society.	5	0.767
34th International Conference on Passive and Low Energy Architecture Plea Smart and Healthy Within the Two Degree Limit.	4	0.613
13th International Conference on Modern Building Materials Structures and Techniques	2	0.307
9th International Conference on Sustainable Built Environment Icsbe.	2	0.307
Awam International Conference on Civil Engineering Aicce.	2	0.307
17th International Forum on World Heritage and Legacy Culture Creativity Contamination.	1	0.153
19th International Workshop on Computer Science and Information Technologies Csit.	1	0.153
33rd International Symposium on Automation and Robotics in Construction Isarc.	1	0.153

11. Document Co-Citation and Clustering Analysis

The network of document co-citations aids in mapping the research field and grouping documents based on citation relationships between publications. In this section, a document co-citation network with 650 nodes and 6418 links is built, as shown in Figure 9. Each node represents a document, and the size of the nodes indicates the frequency of co-citation. The co-citation relationship between publications is represented by links between nodes. VOSviewer's essential metrics for determining network structural properties are mean silhouette (S) and modularity (Q). When Q is greater than 0.3, it indicates that the network is divided into loosely coupled clusters [40]. When the silhouette score is greater than 0.5, it indicates that network clustering is heterogeneous [41].

As shown in Figure 10, a co-authorship network was formed based on writers who have made important contributions to BIM research and trends. The software function required a minimum of five papers to be deemed noteworthy, with a minimum citation of five. A total of 296 of the 8213 authors of 2890 documents fulfilled the relevance criterion. Table 2 shows a list of the most prolific writers in this field of study. The number of publications, citation scores, and link strength were used to determine the research impact.

Among the 655 publications that met the requirement, there were a total of 1881 authors, including both lead authors and contributing authors. The analytical algorithms in the VOSviewer programme were adjusted to require a minimum of five documents and five citations per author; 181 authors met this criterion. The following table summarises the top authors who have made the most significant and intellectual contributions to BIM research. A cursory examination of the most prolific authors reveals that Wang, Xiangyu. (45 documents, 1860 citations), Li, Heng. (29 documents, 822 citations), Chong, Heap-Yih. (28 documents, 327 citations), Lu, Weisheng. (27 documents, 677 citations), and Hosseini, M. Reza. (24 documents, 577 citations) all made significant scientific contributions to the research. Eastman, CM. (19 documents, 1190 citations) is also well known in the field, notably for the number of his citations. Co-citation clusters analysis of building information modelling shown in Table 3.

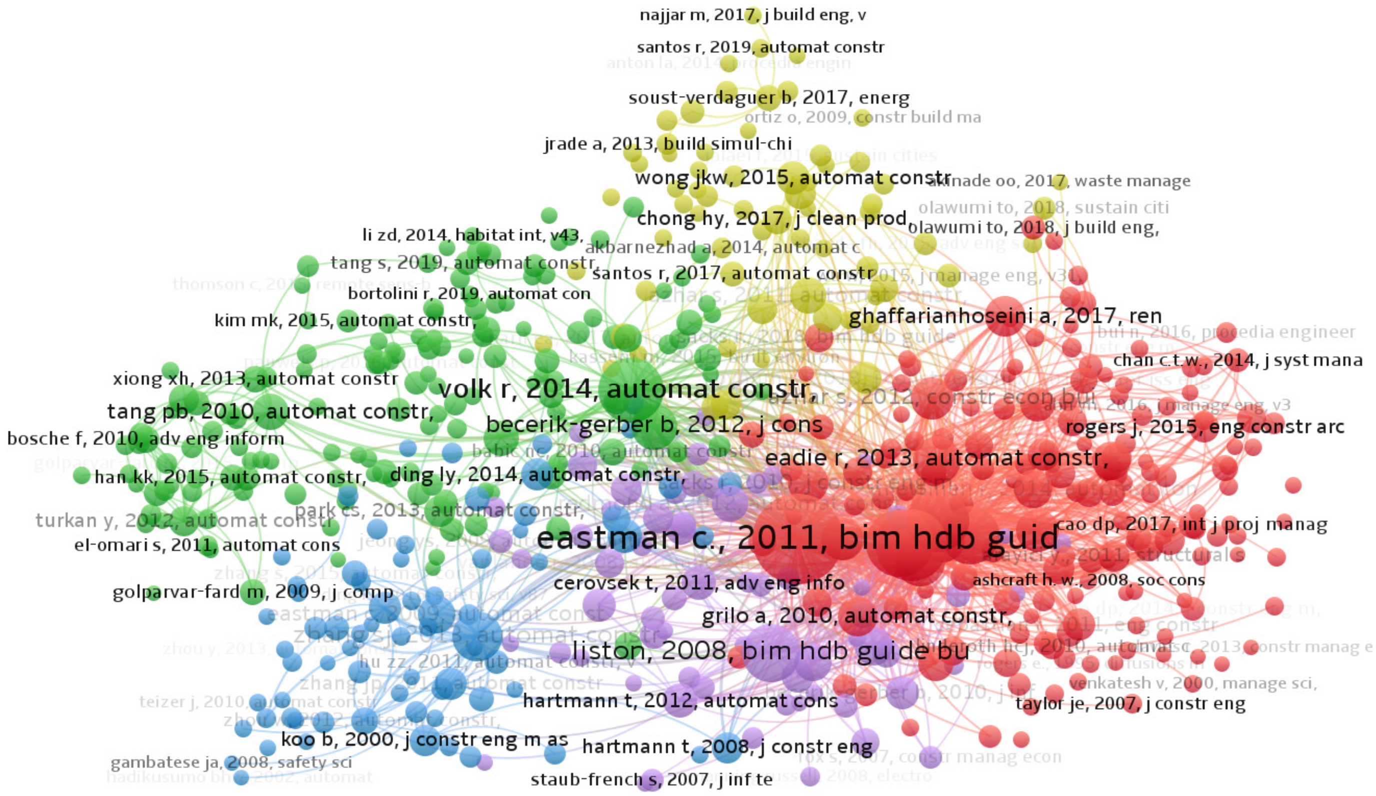

Figure 9. Network of document co-citations analysis.

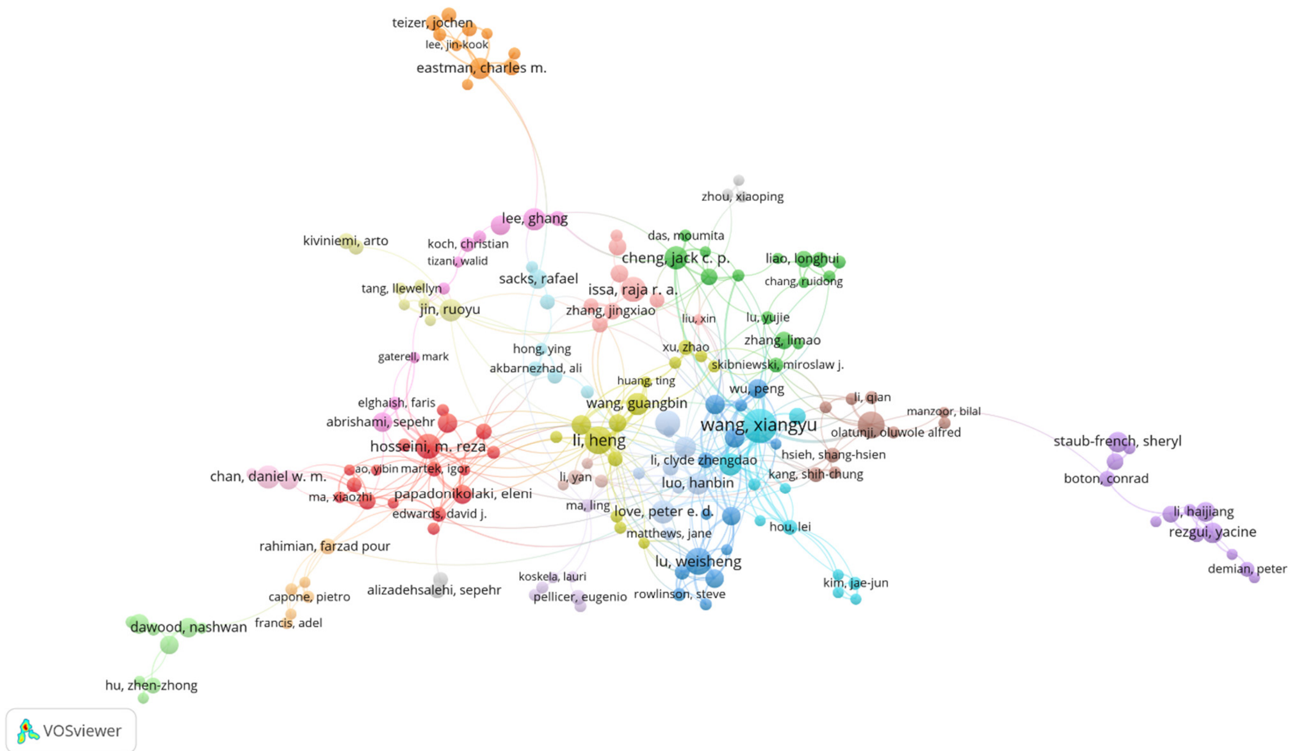

Figure 10. Network visualization of co-authorship network.

Table 3. Co-citation clusters analysis of building information modelling.

Author	Documents	Citations	Total Link Strength
wang, xiangyu	45	1860	89
li, heng	29	822	60
chong, heap-yih	28	327	30
lu, weisheng	27	677	44
hosseini, m. reza	24	577	51
issa, raja r. a.	24	561	5
leite, fernanda	23	324	1
cheng, jack c. p.	21	773	31
chan, daniel w. m.	20	407	19
love, peter e. d.	20	756	30
jin, ruoyu	19	356	27
wang, guangbin	19	372	30
lee, ghang	18	640	10
luo, hanbin	18	526	37
wang, jun	18	374	35
ding, lieyun	17	507	38
eastman, charles m.	17	1190	31
golparvar-fard, mani	17	309	3
rezgui, yacine	16	438	18
staub-french, sheryl	16	328	9

12. Discussion and Findings

This study examined the geographical locations of innovation in BIM research and the publication trends of organizations and individuals. The majority of the study's trends were channeled to North America, Asia, Europe, and Australia in that order. Africa and South America are absent from the corpus of the research. This is consistent with the results of [42,43], who claim that African nations continue to struggle with adoption issues, rather than BIM innovation issues.

As illustrated in Figure 11, this study has captured significant and current achievements in BIM research, establishing connections between innovations and existing issues related to BIM use, with the goal of demystifying technical jargon, identifying patterns, and promoting the enhanced comprehension of recent breakthroughs and research trends. This provides stakeholders and researchers in the building industry with a comprehensive picture of the intellectual landscapes and future research horizons in BIM.

Bibliometric data can provide the necessary information to evaluate a particular field's performance in literature, assist research institutions in managing policies regarding fund allocation, and evaluate scientific inputs and outputs [44]. Moreover, findings obtained from the bibliometric analysis can also uncover the main factors that increase contribution in a specific field of study and direct researchers to carry out more studies effectively [45]. This review studies a refined search query to find 650 documents from the Web of Science database related to collaboration and risk in BIM in the construction industry. Statistics display that 53.9% of the collected documents are related to engineering and 32.9% are related to business and management. Publications in this area exhibit an upward trend between 2010 and 2017, and the highest number of publications were in 2018 and 2022. The first research question of this study was regarding the identification of the most popular keywords in the field of building information modelling, which can be seen in the keyword co-occurrence network generated using the VOSviewer tool. The top keywords were identified from the Web of Science documents ranked by high occurrence frequency and are shown in the Table 1. The second research question was to identify the most important authors and journals. Therefore, citation metrices were used and found the following authors: Wang, Xiangyu; Eastman, Charles M.; Teizer, Jochen; Zhang, Sijie, who are from the top 10 authors in the field of collaboration and risk in BIM. Additionally, the most cited journals are: Automation in Construction; Journal of Information Technology in

Construction; Engineering Construction and Architectural Management; Sustainability, Journal of Construction Engineering and Management.

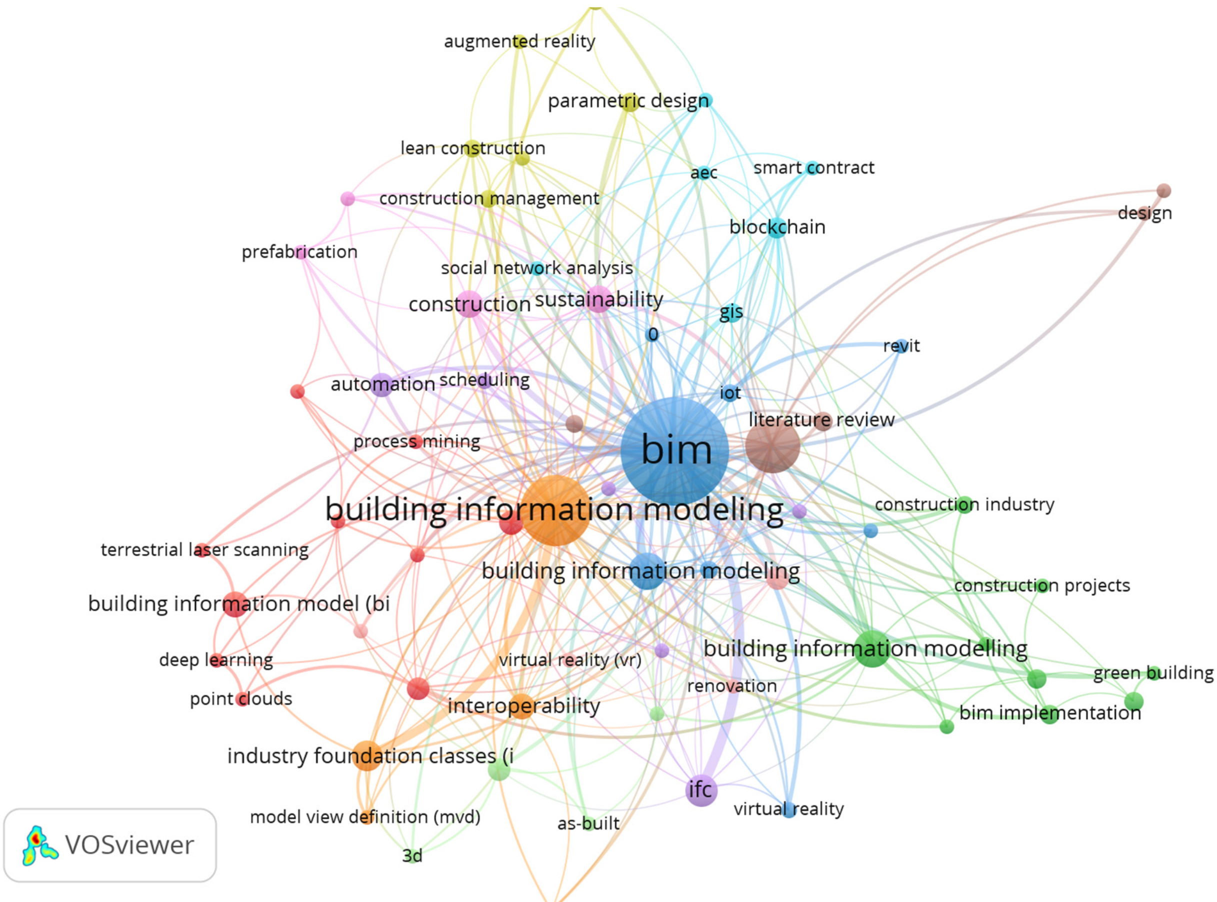

Figure 11. Network visualization map of most related topics in BIM.

The key study subjects in the literature for building information modelling were discovered using document co-citation and clustering analysis for the third research question, which addressed the most prominent themes of building information modelling. Literature of collaboration and risk in BIM was classified into six main groups: collaborative in BIM, integration of BIM, GIS, and IoT, barriers to the integration of BIM, sustainability and BIM, and risk assessment and uncertainty. Finally, this study addressed the fourth research direction regarding the current trends in building information modelling literature and the future research directions. According to [44], bibliometric analysis can evaluate research productivity and publications in a specific literature topic and explore research trends. From this study, research movements tend towards digital twin technology, integration of BIM and AI, and Augmented Reality (AR) and Virtual Reality (VR) in BIM.

13. Common Research Topics in Building Information Modelling

This section discusses the clusters presented and reviews the most cited documents mentioned in each group. Then, research topics are analyzed based on the most relevant publication and ordered according to the number of publications in the research areas.

14. Collaborative and Risk in BIM

Managing BIM project is one of the critical strategies to improve project performance and enhance successful project delivery. Measuring BIM collaboration and risk are vital practices to manage project complexity in the construction industry. Assessing risk enables managers to identify difficulties and allocate scarce resources efficiently in complex construction projects. Thus, many research studies were conducted to develop measurement models and evaluate project BIM from different perspectives [29,46]. Figure 9 illustrates that cluster #2 and cluster #7 are closely located in the networks, and cluster #7 and cluster #8 cover the same area of research in measuring project risk in BIM. Cluster #8 is the largest cluster in the network, including 276 publications, while cluster #17 is more minor, containing ten publications.

A total of 88 documents out of 650 papers examined in this study were directly related to collaboration and risks in BIM, and the increase in interest in this topic in recent years can be seen in Figure 12.

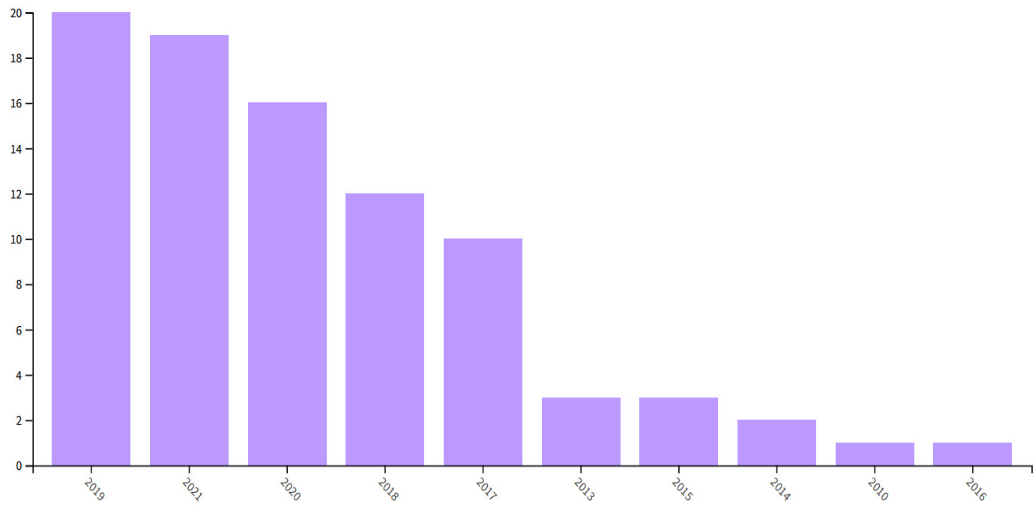

Figure 12. Trends of collaborative and risk in BIM recently.

For cluster #0, the most cited document was published by [47], which developed a building information model (BIM) for existing buildings, and [48] analyzed building information modelling in use, namely how to evaluate the return on investment. Ref. [29], discussed collaboration in BIM-based construction networks, namely through a bibliometric-qualitative literature review. Finally, [49] created a framework for a collaborative BIM-AR system that enables users to communicate in a synchronous manner. The study reveals that collaborative practices mitigate the negative impact of project risks that arise from the scope of uncertainty, communication, and large numbers of stakeholders. We also still need more in-depth studies on the possibility of developing cooperation in BIM and the relationship with risks in construction projects.

15. Integration of BIM, GIS, and IoT

Throughout the history of the construction business, complexity has been the primary cause of poor performance and project failure in terms of cost overruns, schedule delays, bad quality, and even safety issues. As a result, the use of tools and technology considerably aids in mitigating the impact of all of the aforementioned factors on the effectiveness of the building project [50–53].

BIM and GIS enable digital representations of architectural and environmental elements. BIM focuses on micro-level building representation, whereas GIS provides macro-level building environment representation. With BIM and GIS, building planning becomes more efficient, rational, and standardized. BIM and GIS have been mostly concentrated on their own fields, with little integration. Because these two technologies overlap, they may supply integrated data for building projects and their surroundings, which is beneficial to the construction industry's growth. Analyzing building characteristics in isolation is neither comprehensive nor scientific. Because BIM and GIS data are developed, handled, analyzed, stored, and presented differently, there exists incompatibilities between the two data sets [54]. The Internet of Things (IoT) is a network of physical "things" linked to the Internet and each other to exchange and exploit numerous services and assist various research fields. Its ability to translate centralized solutions and tools into new and advanced technology has not hampered its potential to innovate in practically every field [55]. There has been an increased interest in Internet of Things (IoT) solutions that use BIM platforms to deliver a unified view of rich contextual building information and real-time sensory data [56]. Using IoT systems, real-time data collecting about physical world items and circumstances is possible. As a result, combining BIM databases with IoT environmental sensor data has gained popularity [57,58].

16. Barriers to the Integration of BIM

Collaboration and risk have a significant impact on project integration. Therefore, BIM systems design improvement must be more integrated and flexible, delaying complexity issues [42]. Ref. [1] published the most referenced paper in cluster #3; they discovered that systems integration is the primary obstacle in completing complex projects. Organizations reduce the complexity of projects by segmenting them into interconnected subsystem components. To sustain stability in dynamic and unpredictable changing environments, organizations must comprehend the whole system of components and manage flexible interactions between individual components. Ref. [59] analyzed the methods used to manage structural and dynamic complexity in two successful construction megaprojects. The research discovered disparities between the two methods in their coping with structural and dynamic complexity; nonetheless, similar elements that aid project managers in successfully managing complex projects were found. Ref. [60] underlined the need for developing specific dynamic competencies (strategic behaviour and collaborative procedures) for executing complex, risky, multi-stakeholder projects. Ref. [61] did empirical research to determine the most effective methods and tactics for managing project barriers and increasing the likelihood of success. Ref. [62] created a model for assessing the integration of the BIM of large-scale projects by considering dynamic and emergent impacts.

17. Sustainability and BIM

Utilizing building information modelling (BIM) data created during the design and construction phases of a project allows quicker, safer, and more efficient construction, as well as more cost-effective, sustainable operation, maintenance, and ultimate decommissioning [52,63]. Coordination of BIM information from all project parties benefits sustainability in several ways; by combining technical, operational, construction, and manufacturing expertise, value engineering and optimization may be achieved at every step of the delivery and operation [64]. Changes to the design made while the project concept is still fluid may be addressed without incurring additional costs or time penalties [65]. When one party makes a modification, the other disciplines become aware and may adjust their contribution or discover a different answer [66]. Automatic conflict detection enabled by BIM eliminates the need for ad hoc solutions, resulting in the saving of material, time, and cost. Coordination of design, cost planning, manufacturing, and construction enables correct material and equipment ordering, hence avoiding waste and rework [67].

18. Risk Assessment and Uncertainty

Uncertainty and risk management methods are associated with perceived success in complicated initiatives [68]. Uncertainty refers to any divergence from expected project performance, and the complexity of the project is a significant contributor to the uncertainty. Thus, knowing the three notions of complexity–uncertainty–performance and modelling the nonlinear interactions between them is crucial for designing an effective approach for risk and complexity management in construction projects [69].

For cluster #16, the most cited document was published by [70]; by examining the usage of qualitative risk analysis approaches in large construction projects, the research concludes that qualitative risk analysis is insufficiently employed to identify the inherent risk in building projects, which results in time and expense overruns. Qualitative risk analysis is a critical aspect in determining the degree of project complexity for stakeholders. Stakeholders benefit from identifying and managing complexity in major construction projects by streamlining the planning process and ensuring effective project execution. Ref. [71] conducted a survey of the literature to identify all artificial intelligence (AI) approaches used to assess cost risk in construction projects in order to understand complexity and uncertainty. According to the survey, fuzzy hybrid approaches are the most often utilized because they can quantify both complexity and underlying uncertainty. Ref. [72] studied the complexity–risk link in large-scale building projects. A qualitative method was used to build a conceptual framework, and the qualitative approach was used to verify the linkages. As a result, an integrated risk assessment approach was developed to assist in developing risk management strategies for mega-construction projects. Ref. [73] developed a matrix-based risk propagation model for evaluating risk propagation in engineering projects with a high degree of complexity. The model quantifies and prioritizes risks based on their effect on the project's risk network.

19. Future Research Directions

While the preceding part highlighted current key topics in the field of building information modelling, the next section covers anticipated future research trends in the field of building information modelling, including the following:

20. Developing towards Digital Twin Technology

Building information modeling (BIM) is an intelligent and adaptive digital twin modelling technique that may assist building lifecycle activities such as design, construction, operations, and maintenance [1]. Digital twin technology is a simulation-based planning and optimization idea that has the potential to revolutionize the construction sector [74]. The digital twin is a cyber-physical system for modelling, simulation, analysis, prediction, and optimization. A practical loop consists of three components: a physical object, a virtual entity, and data connections [75]. In a digital twin, there are two approaches to mapping dynamically. On the one hand, physical inspection data are gathered and then transported to the virtual world for analysis. While the virtual model learns data from numerous sources, it can simulate, anticipate, and optimize the realistic process, allowing it to adapt to the changing environment [76]. Incorporating BIM, IoT, and data-mining tools into the digital twin has gained popularity [77]. Furthermore, web-based IoT integration captures vast amounts of data to augment BIM.

21. Integration of BIM and AI

The construction sector is undergoing significant transformation throughout the whole value chain, from planning to operation and maintenance. Artificial intelligence (AI) is the bedrock upon which effective digital efforts in construction engineering and management may be built [78]. AI is a subset of computer science that enables computers to perceive and learn human-like inputs for perception, knowledge representation, reasoning, problem-solving, and planning. Notably, BIM has led the way in digitalizing the construction sector, going well beyond 3D modelling to give a pool of information on the whole project lifecycle [79]. For real-time communication and cooperation, BIM offers a platform for not only gathering vast amounts of data about the project, but also for sharing, exchanging, and evaluating it. To automate and optimize the building process, AI algorithms carefully analyse enormous volumes of BIM data. BIM and AI can help transfer paper-based work online [80]. It can give the most efficient and effective information to keep the project updated. It may also use BIM data to do real-time analysis, allowing for fast replies to simplify complex workflows, save costs, minimize risk, and optimize staffing. By using symbolic AI approaches such as rule-inferencing, BIM is limited to basic prescriptive phrases [81].

22. Augmented Reality (AR) and Virtual Reality (VR) in BIM

Virtual Reality (VR) enables large-scale training scenarios, while AR is quickly becoming a standard tool in the building and construction industry [82]. Early AR applications in construction emphasized the use of see-through glasses as a ubiquitous technology for construction workers [83]. With the advent of BIM and the widespread usage of 3D computer graphics in the design, building, and operation stages of a project, the possibility of employing geometric information in AR has arisen [84]. Using AR may help architects and engineers understand a project up to 20% better than a 3D virtual model alone [85].

23. Conclusions

Building information modelling has exploded in popularity in recent years, drawing increased attention from academics and practitioners. A systematic review technique is proposed in this study for conducting a topical literature review for BIM and navigating potential research areas. Although a review of the BIM literature has previously been published, this is the first complete research to use a systematic review technique and include 650 academic publications in order to map the BIM literature. The frequent keywords, productive authors, top journal sources, and current research topics in the BIM literature were identified; simultaneously, future trends for building information modelling were proposed. The prominent research topics in the literature of BIM are: collaborative in BIM, integration of BIM, GIS and IoT, barriers to the integration of BIM, sustainability and BIM, and risk assessment and uncertainty. This review's conclusions have theoretical and practical consequences for researchers and practitioners. From an academic standpoint, studying and organizing the BIM literature will give academics more systematic information and a wider grasp of the subject topic. From a practical aspect, construction practitioners should evaluate the review's conclusions and assess the influence of cooperation and risk in BIM, which will aid in boosting organizational performance. Despite the fact that this research adds to the body of information, there is still one restriction to the research. The study focuses only on academic publications acquired from the Web of Science database, limiting the scope of the evaluated literature pertaining to building information modelling. For future research, it would be intriguing to undertake a comparable analysis using a greater spectrum of BIM literature from other databases such as Scopus, Google Scholar, and PubMed. This review would be supplemented by monitoring the progress of research in building information modelling.

The results of the analysis in the research found that there were only 88 papers focused on cooperation and risks in building information modelling, and there is a clear trend in the increase in these research studies in recent years due to the importance of the topic. Technological development in recent years, such as artificial intelligence and the Internet of things, facilitates a lot of cooperation between stakeholders in the construction project and provides information and the latest updates on the project model, thus mitigating the risks resulting from a lack of understanding of the project team resulting from the lack of information they have.

Author Contributions: Conceptualization, M.A.K., K.N.A. and H.H.A. Methodology, M.A.K., K.N.A. and H.H.A.; validation, M.A.K., K.N.A. and H.H.A.; formal analysis, M.A.K., K.N.A. and H.H.A.; writing—original draft preparation, M.A.K.; writing—review and editing, M.A.K., K.N.A. and H.H.A.; visualization, M.A.K., K.N.A. and H.H.A.; supervision, K.N.A. and H.H.A.; project administration, M.A.K., K.N.A. and H.H.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universiti Teknologi Malaysia (UTM) Research Grant Vot No: 02M84, FRGS/1/2020/SS0/UTM/02/2 and 05E79.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data sets during and/or analyzed during the current study available from the corresponding author on reasonable request.

Acknowledgments: The authors are grateful to Universiti Teknologi Malaysia (UTM) Research Grant Vot No 02M84, FRGS/1/2020/SS0/UTM/02/2 and 05E79 for supporting this research and providing research facilities.

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

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