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Review

A Bibliometric Analysis and Review of Building Information Modelling for Post-Disaster Reconstruction

Abdullah O. Baarimah [1], Wesam Salah Alaloul [1,*], M. S. Liew [1], Widya Kartika [2], Mohammed A. Al-Sharafi [3], Muhammad Ali Musarat [1], Aawag Mohsen Alawag [1] and Abdul Hannan Qureshi [1]

[1] Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar 32610, Perak, Malaysia; abdullah_20000260@utp.edu.my (A.O.B.); shahir_liew@utp.edu.my (M.S.L.); muhammad_19000316@utp.edu.my (M.A.M.); aawag_17006581@utp.edu.my (A.M.A.); abdul_19000967@utp.edu.my (A.H.Q.)
[2] Civil Engineering Department, Universitas Janabadra, Yogyakarta 55231, Indonesia; widya.kartika@janabadra.ac.id
[3] Department of Information Systems, Azman Hashim International Business School, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia; alsharafi@ieee.org
* Correspondence: wesam.alaloul@utp.edu.my

Abstract: Post-disaster reconstruction (PDR) is a dynamic, complex system that is chaotic in nature, and represents many challenges and issues. Recently, building information modelling (BIM) has been commonly utilized in the construction industry to solve complex and dynamic challenges. However, BIM has not been thoroughly considered for managing PDR, and there is a lack of comprehensive scientometric analyses that objectively examine the trends in BIM applications in PDR. A literature search was performed considering studies published from 2010 to March 2021 using the Scopus database. A total of 75 relevant studies were found to meet the inclusion criteria. The collected literature was analyzed using VOSviewer through scientific journals, authors, keywords, citations, and countries. This is the first study in its vital significance and originality that aims to investigate the current states of research on BIM applications in PDR and provide suggestions for potential research directions. The findings showed that "Reconstruction" and "Safety Management" have emerged as mainstream research themes in this field and recently attracted scholars' interest, which could represent the directions of future research. Five major research domains associated with BIM were identified based on the most frequently used keywords, namely "Disasters", "Earthquakes", "HBIM", "Damage Detection", and "Life Cycle". Moreover, a proposed conceptual framework of BIM adoption for PDR is provided. Accordingly, the outcomes of this study will help scholars and practitioners gain clear ideas of the present status and identify the directions of future research.

Keywords: BIM; post-disaster reconstruction; construction industry; scientometric analysis; visualization; PRISMA; review

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1. Introduction

Disasters can be defined as "an action that causes a threat to life, well-being, material goods, and the environment from the extremes of natural processes or technology" [1]. Natural and human-made disasters affect the built environment. The large-scale damages caused by infrastructures and houses are accompanied by injuries and fatalities, reversal or stagnation of the local economy, and mislaying of livelihood sources [2]. Post-disaster reconstruction (PDR) has been gaining more attention in the world because of frequent natural environment disasters, such as earthquakes tsunamis, and other activities, caused by human-made factors, such as conflicts and wars, which have raised the importance of PDR [3,4]. Following the increasing occurrence of major disasters, stakeholders are increasingly initiating reconstruction to reduce the effects of those disasters on the built environment; however, reconstruction projects are considered challenging to implement in

terms of capacity and resources [5,6]. Nevertheless, PDR is categorized as unpredictable, chaotic, complex, and dynamic; this indicates several difficulties due to its differences when compared to traditional construction [7]. Conventional construction has been used in reconstruction projects, whereas some features, such as a single lifecycle of project and inflexibility in aspects of creating a specified project duration, have proven unsatisfactory for the complications encountered in the aftermath of the disaster [8,9]. Reconstruction projects face immense challenges, such as time and cost overrun, and low quality, due to several factors during the implementation [10,11].

The main target of any PDR project is to attain high levels of beneficiary satisfaction. Nonetheless, PDR projects frequently fail in their pre-planned objectives; for example, only 20% of building requirements are fulfilled, with most buildings being constructed on a temporary instead of permanent basis [12]. Moreover, the efforts of reconstruction projects have lacked any suitable coordination mechanism and monitoring framework [13]. If not properly handled, those challenges can result in ineffective PDR project delivery and often a failure of the project [3,14]. Successful delivery of PDR projects is important to restore essential services and return to normalcy after disasters [15,16]. Controlling the cost, time, and delivery of the projects are the most significant factors in evaluating successful PDR projects, which will be heightened by utilizing one of the emerging technologies or processes that aim to enhance productivity and sustainability in PDR projects.

Building information modelling (BIM) is considered one of these technologies, and has altered the ways of the practices of architecture, engineering, and construction industries during recent years. It brings stakeholders in construction to a single productive platform [17]. Additionally, BIM is not only a technical facility but also an activity concept for efficient project delivery linked to advanced technology [18]. It utilizes information and communication technologies to enhance growth monitoring, increase performance, and boost productivity [19]. Consequently, numerous studies have been conducted on BIM within the construction industry from the perspective of the industry, organizations, and users [20,21]. Other studies have focused on BIM in terms of adoption, implementation, challenges, and benefits, as well as strategies and application [22,23].

In this regard, BIM is an intelligence tool that has a wide range of benefits, such as collaboration among parties, visualization of project execution, enhanced productivity and efficiency, enhanced communications, improved design quality, cost estimation, positive return on investment, enhanced sustainability, faster development while reducing the cost and rework, on-time delivery capabilities, clash detection, better contract documentation, life-cycle cost data management, and competitive edge [24–26]. These and other advantages have prompted governments, institutions, and organizations to implement BIM in their construction industries [27–29].

With the increasing significant challenges in PDR, it is necessary to apply BIM in reconstruction projects after disasters to overcome these challenges [30–33]. Despite some reported evidence on the benefits of BIM within the construction industry, the adoption of BIM for the PDR field has not received adequate attention. Moreover, there is a lack of adoption of modern methods for managing PDR that is a cause of low boost. However, a few studies have focused on utilizing BIM for PDR. For example, Dakhil and Alshawi [31] explored the BIM applications that supported building disaster management, including disaster planning, site planning, and existing condition modelling, and its advantages; they suggested that future research should empirically study all applications of BIM during the project life cycle and identify the advantages of those applications. Nawari and Ravindran [32] listed the potential advantages of BIM in conjunction with blockchain for post-disaster rebuilding. The authors presented a framework for an automated reconstruction permitting process by using Hyperledger Fabric; however, no evidence of actual implementation has been found. Messaoudi and Nawari [33] proposed a virtual framework based on BIM and a generalized adaptive framework for speeding up the permitting process of reconstruction in the aftermath of the disaster in Florida; however, this framework was limited to the time of the permitting process for rebuilding.

On the other hand, scientometric analysis is being used by a growing number of scholars to address subjective problems in literature reviews [34–37]. In contrast, there is a paucity of scientometric analysis in the current studies that explore trends of BIM applications in the PDR projects field. It is worth noting that the PDR in question is still in its early stages for BIM adoption. One of the challenges is determining the need to start setting the foundations for best frameworks and guidelines for promoting the BIM applications in PDR projects. Experience has shown that it is never too early to start preparing for reconstruction in the aftermath of the disaster. Accordingly, it is crucial to map the related literature in order to address this research gap. This study is unique because it explores trends of BIM applications in PDR from an objective standpoint.

Based on the researchers' knowledge, this is the first study that aims to investigate the current state of research on BIM applications in PDR and provide suggestions for potential research directions. To achieve the study aim, the present study analyzed the collected papers through scientific journals, authors, keywords, citations, and countries. In addition, a proposed conceptual framework was developed that underlines the relationship between PDR and BIM adoption, which impacts BIM adoption for PDR. Therefore, the outcomes of this study will assist scholars and practitioners in gaining clear ideas of the present status and identifying the directions of future research. It may promote BIM awareness and offer more opportunities for a positive perception of BIM implementation in reconstruction projects in the aftermath of future disasters.

2. Methodology

The present study used the PRISMA guidelines in order to review the current literature [38]. We followed the PRISMA guidelines without considering meta-analysis approaches. The scoping procedure was employed to extract the most related papers on BIM and PDR. The collected literature was retrieved from the Scopus database. Scopus includes more journals and scientific publications than any other available literature database (such as "Web of Science") [39,40]. A list of keywords relevant to disaster and reconstruction was created. These keywords, along with the keyword "BIM", were utilized for the literature search, with the following query string: TITLE-ABS-KEY (("BIM" OR "Building Information Model*") AND ("Disaster" OR "post-conflict" OR "post-war" OR "war" OR "earthquake" OR "flood" OR "landslides" OR "Tsunami" OR "storm" OR "cyclone" OR "tornado" OR "hurricane") AND ("construction" OR "reconstruction" OR "recovery" OR "rehabilitation" OR "repair" OR "rebuild*" OR "retrofitting" OR "restoration")). In addition, the time range was set from 2010 to March 2021. Initially, a total of 185 documents were displayed; these included research papers, reviews, book chapters, and other types of documents. The documents were limited to research articles, review papers, conference papers, and book chapters. As result, 150 papers were chosen in this stage as illustrated in Figure 1. Additionally, in the second stage, the data were transferred to an Excel sheet, and after assessing the documents and excluding irrelevant publications as well as non-English publications, a total of 75 papers were finally considered eligible to be included for further analysis. In the end, returned to the Scopus database to select those papers manually in order to export an Excel sheet file that was used for the scientometric analysis. Figure 1 illustrates the framework implementation of the current review.

Moreover, a scientometric analysis was conducted after the literature sample was obtained. With the rapid progress in technology, scientometric analysis can now be performed using a range of existing software. VOSviewer was selected in this study to draw science mappings, since it has remarkable text mining capabilities and is ideal for dealing with larger networks [41]. Currently, VOSviewer is increasingly being used in construction industry research to create science mappings, for example, BIM [42], system dynamics [36], and artificial intelligence [43]. The collected papers were examined through five aspects: scientific journals, authors, keywords, citations, and countries. In the literature review study, according to Ren et al. [44], those five aspects are considered as the main components of the scientometric analysis that can help researchers to grasp the current state of

research quickly. The most critical measurements include the citations, documents, average publication year, average citations, and average normalized citations [45], where the last three metrics are inextricably linked to each other. The average publication year mainly refers to the documents that are published in a certain year [42]. The average citations were determined by dividing the total number of citations by documents. Furthermore, average normalized citations indicate the normalized number of citations of a journal, author, keyword, document, and country. This was calculated by dividing the total number of citations by the average number of citations received during the given year; the higher the score, the greater the impact [45].

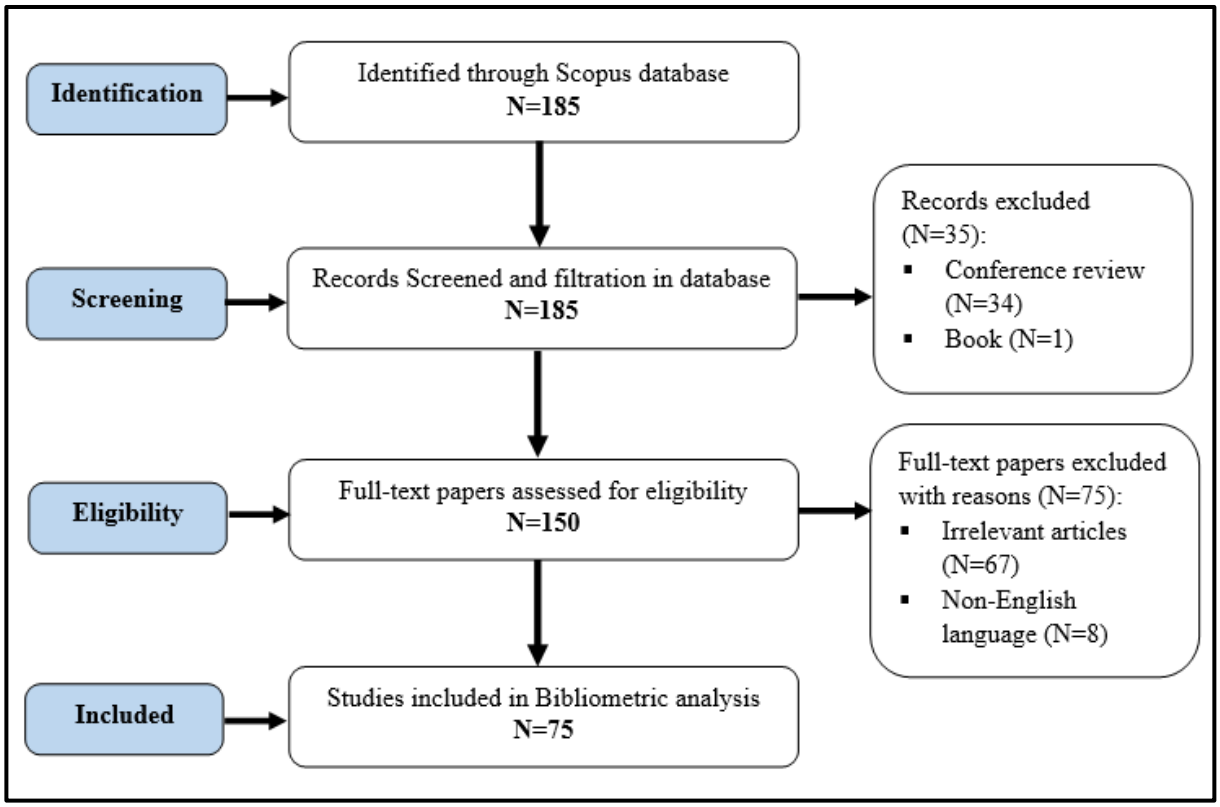


Figure 1. Study flowchart.

3. Results and Interpretation of Articles

This section analyzes the scientific journals, authors, keywords, citations, and countries active in the targeted research. It will provide a clear and succinct explanation of the experimental findings, their analysis, and the experimental conclusions that were reached.

3.1. Analysis of Published Journals

It is common for researchers to share and communicate their research findings through various published journals. In the current study, VOSviewer was utilized to find the source journals of the papers obtained, as shown in Figure 2. The minimum number of published documents and citations of a source was set at two and one, respectively. According to Jin et al. [45], there is no limit to setting the threshold value. Several attempts were made with various threshold values until the most appropriate values for determining the optimal range of sources were discovered. Accordingly, a total of 14 journals out of 58 met the thresholds. There was a total of 11 leading journals linked to each other, as shown in Figure 2. It was found that the nodes of "ISPRS Archives" and "Automation in Construction" were the largest in regard to the category of conferences and journals, respectively, and were linked to most other journals. This indicates that these two journals are leading journals in this research field.

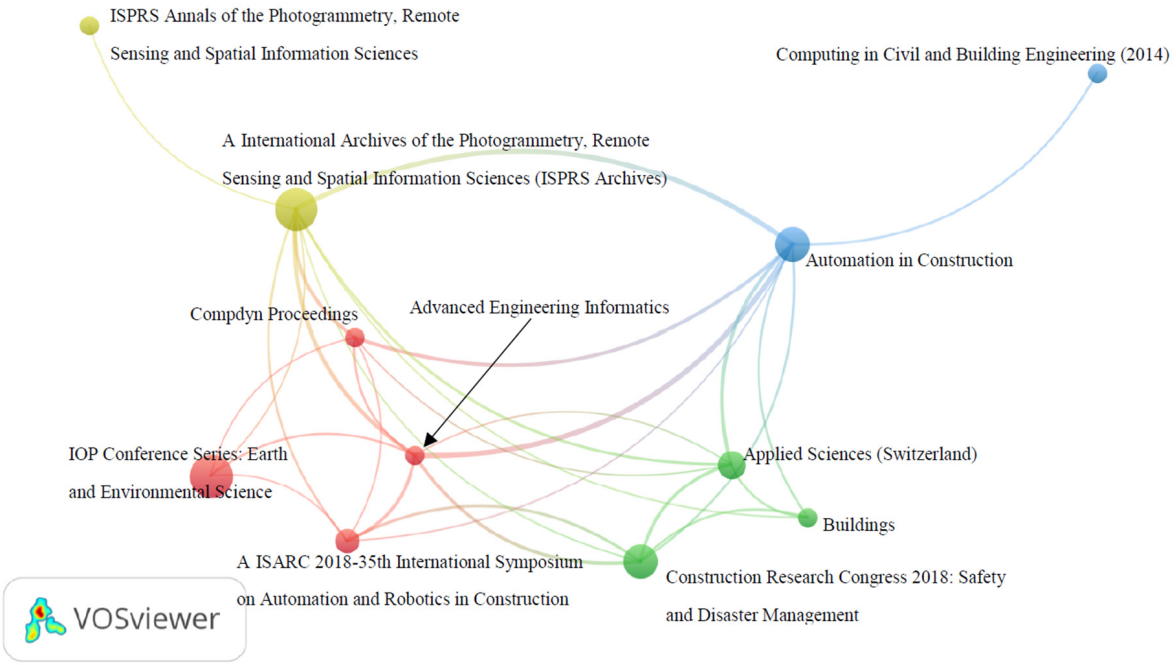


Figure 2. Mapping of published journals.

In Figure 2, the source journals are divided into different clusters in terms of colors. Therefore, these journals were grouped: "Applied Sciences", 'Buildings", and "Construction Research Congress 2018". The journals that appear in the same cluster have a greater level of interconnectedness, which means that articles from these journals cite each other more frequently. A quantitative summary of the journals can be obtained from Table 1.

Table 1. Details of published journals.

No.	Source Journal	Total Link Strength	Documents	Total Citations	Avg. Citations	Avg. Norm. Citations
1	"Advanced Engineering Informatics"	29	2	79	39.5	7.2
2	"Applied Sciences (Switzerland)"	16	4	12	3.0	2.2
3	"Automation in Construction"	36	6	111	18.5	2.3
4	"Buildings"	7	2	25	12.5	2.4
5	"Compdyn Proceedings"	15	2	1	0.5	0.1
6	"Computing in Civil and Building Engineering (2014)"	2	2	9	4.5	0.6
7	"Construction Research Congress 2018: Safety and Disaster Management"	16	6	19	3.2	0.6
8	"International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives)"	29	9	63	7.0	1.1
9	"IOP Conference Series: Earth and Environmental Science"	5	10	3	0.3	0.3
10	"ISARC 2018—35th International Symposium on Automation and Robotics in Construction"	12	3	4	1.3	0.3
11	"ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences"	1	2	9	4.5	0.9

The total link strength, number of documents, and total citations, which are all strongly connected can be used to assess the productivity of a given journal's research outputs. Moreover, the importance of a journal's contribution to the research community can be also evaluated through the average citation. The average normalized citation per document is not always linked to the number of documents. As shown in Table 2, it was found that "Advanced Engineering Informatics" is a top-ranked journal, with the greatest average cita-

tions and average normalized citations. Moreover, in terms of total citations, "Automation in Construction" showed incredible performance and recorded the maximum number of total citations. Other more significant journals in terms of average normalized citations included "Buildings", "Automation in Construction", and "Applied Sciences", which also have a strong potential influence on BIM applications for the PDR field.

3.2. Analysis of Co-Authorship

Scholars usually collaborate in academic research, which can improve productivity and access to expertise as well as prevent scholars from being isolated [46]. The minimum number of published articles and an author's citations in this study were set at one and ten, respectively. Thus, of the 219 authors, 27 met the thresholds. There was a total of 10 influential authors linked to each other, as visualized in Figure 3.

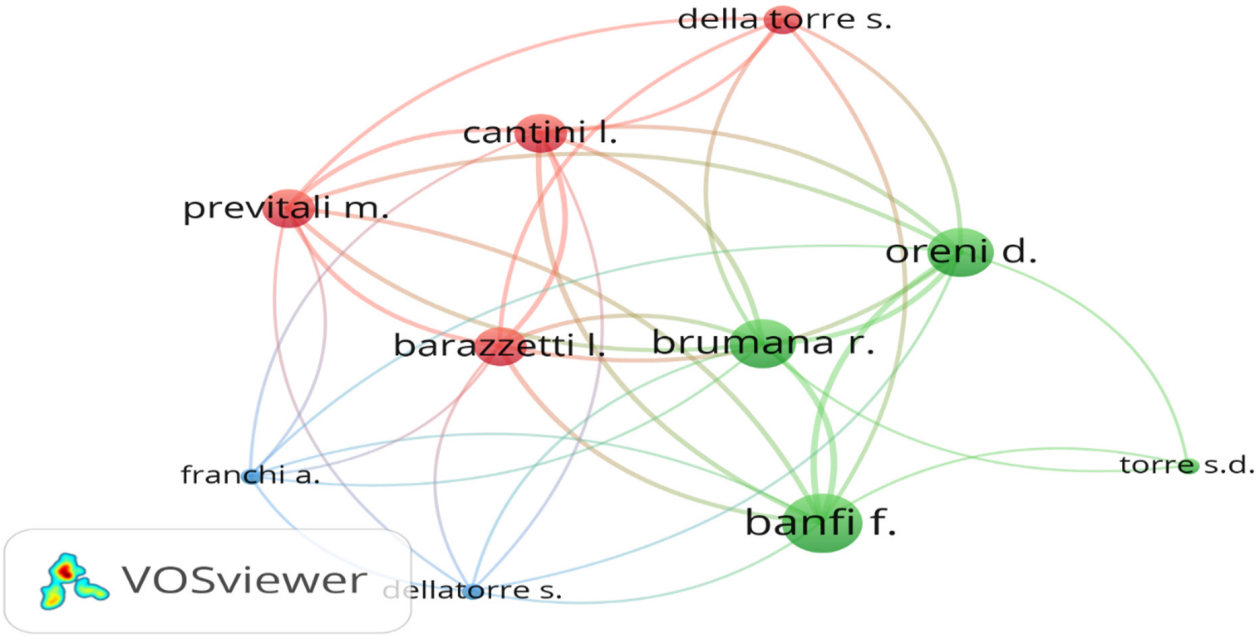


Figure 3. Mapping of co-authorship.

As shown in Figure 3, the authors were explicitly divided into three groups based on colors. Here, Previtali M., Cantini L., Della Torre S., and Barazzetti L. appeared in the same research group. Brumana R. was in the middle of this network and was connected with the other two groups of authors, suggesting that Brumana R. maintains strong academic cooperation with leading researchers in the field. Banfi F. has the largest node compared to other authors, and he collaborates closely with all authors, meaning that Banfi F. is considered one of the top scholars in this domain. The details of these productive authors are presented in Table 2.

Table 2 demonstrates that the most productive author is Banfi F., who published the largest number of documents. Regarding overall research significance, Banfi F., Brumana R., and Oreni D. ranked at the top by achieving 84 citations. In the aspects of collaboration links, again Banfi F., Brumana R., and Oreni D. had the best network of all researchers in this field, with a total link strength of 22. When it comes to average citations, Dellatorre S. and Franchi A. ranked first with 26 average citations, and the authors Barazzetti L., Cantini L., and Previtali M. ranked second with a recorded 24.7 average citations, suggesting their active influence in this field. According to average year publications, the emerging researchers listed in Table 2 have contributed to the research field and have recently linked BIM application to PDR, where the average year publications started from 2017.

Table 2. Details of co-authorship.

Author	Total Link Strength	Documents	Total Citations	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations
Banfi F.	22	5	84	2018	16.8	2.5
Barazzetti L.	19	3	74	2018	24.7	3.4
Brumana R.	22	4	84	2018	21.0	2.9
Cantini L.	19	3	74	2018	24.7	3.4
Della Torre S.	12	2	48	2018	24.0	3.3
Dellatorre S.	7	1	26	2017	26.0	3.5
Franchi A.	7	1	26	2017	26.0	3.5
Oreni D.	22	4	84	2018	21.0	2.9
Previtali M.	19	3	74	2018	24.7	3.4
Torre S.D.	3	1	10	2017	10.0	1.4

3.3. Analysis of Co-Occurring Keywords

Keywords help scholars understand mainstream topics and emphasize possible research directions [47,48]. The connection of keywords demonstrates the knowledge of the research domain in the aspects of intellectual organization, relationships, and development trends [49]. By setting the minimum frequency of keywords to three in this study, only 73 out of 746 keywords met the thresholds. Those keywords were filtered, and a few keywords that were not relevant to the study were removed. In consequence, a total of 38 keywords were selected and are represented in Figure 4.

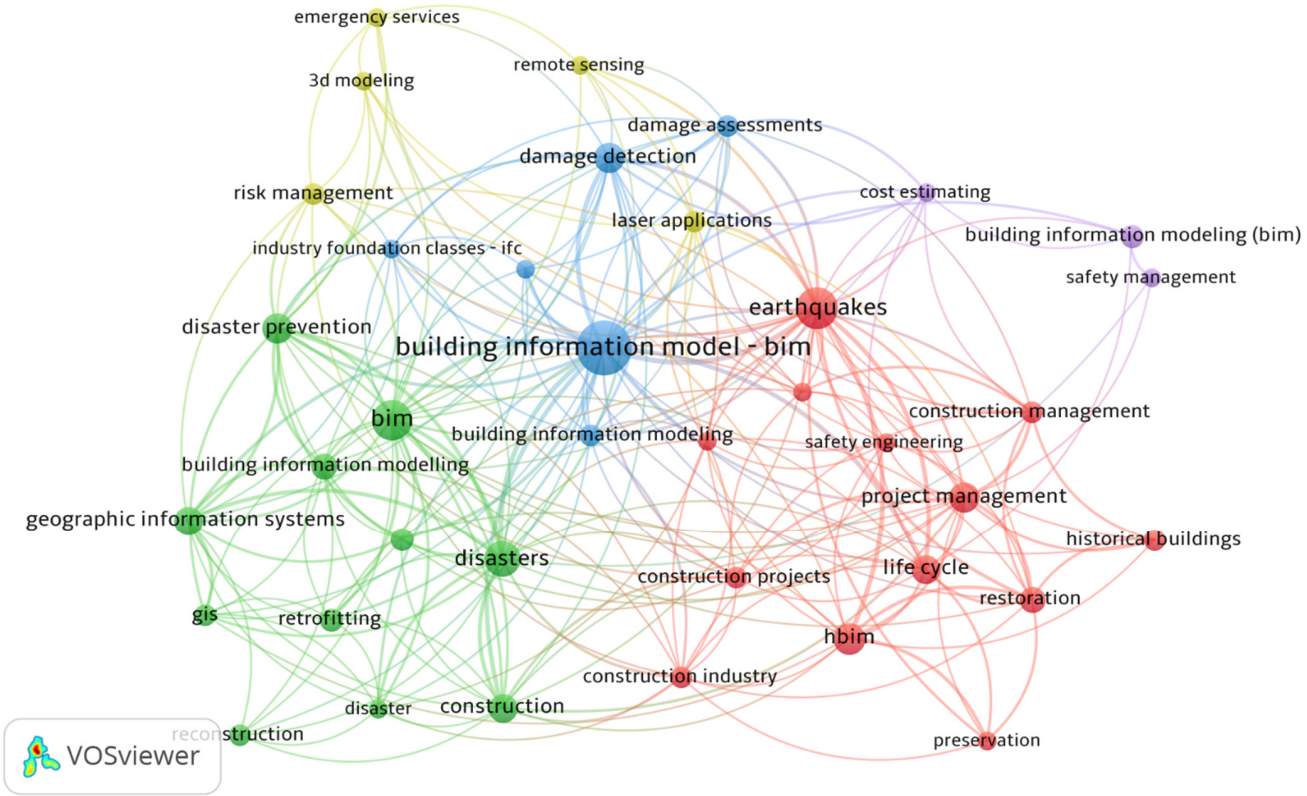


Figure 4. Mapping of co-occurring keywords.

Figure 4 depicts the research directions for the applications of BIM, and it is not surprising to see that "Building Information Model—BIM" was the most commonly listed research keyword. The other keywords associated with BIM, such as "Disasters" and "Earthquakes", indicate that BIM applications were primarily utilized in this field. A quantitative summary of keywords can be obtained from Table 1, and the frequency of

keywords conformed to those in Figure 4. It should be noted that "Damage Assessments", "Disaster Prevention", "Historical Buildings", "Reconstruction", "Repair", "Restoration", "Retrofitting", "Risk Management", "Safety Management", "Life Cycle", and "Virtual Reality" were included in the common research areas based on the frequency of keywords. Hence, it can be inferred that the characteristics of BIM applications can evaluate the impacts of different policies.

As shown in Table 3, the average citation and average normalized citation demonstrate the impact of the keyword in the academic community. Following the keywords "Preservation", "Restoration", "Historical Buildings", "Construction Management", and "Repair" attracted more interest according to average citations. Interestingly, the keyword "Preservation" was ranked at the top with 3.4 average normalized citations, suggesting its influence in this field. Besides, the average year publication indicates the novelty of those keywords. For instance, some articles relative to "Reconstruction" and "Safety Management" were published recently in 2020, meaning that they emerged as mainstream research themes in this field and spurred the interest of scholars recently, which could represent future research directions as well.

Table 3. Details of co-occurring keywords.

Keywords	Total Link Strength	Occurrence	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations
3D Modeling	8	3	2019	2.7	1.3
BIM	39	14	2018	3.6	1.3
Building Information Model—BIM	80	26	2017	3.7	0.9
Building Information Modeling	16	4	2018	8.5	1.2
Building Information Modeling (BIM)	7	5	2019	3.4	2.3
Building Information Modelling	22	6	2018	3.2	0.4
Construction	27	7	2018	1.6	0.4
Construction Industry	16	4	2019	6.5	0.9
Construction Management	15	4	2017	16.8	1.5
Construction Projects	14	4	2018	0.3	0.3
Cost Estimating	13	3	2015	4.3	0.8
Damage Assessments	20	4	2014	9.3	1.4
Damage Detection	34	8	2016	6.3	0.8
Disaster	15	3	2018	1.3	0.9
Disaster Prevention	32	8	2019	1.6	0.3
Disasters	42	11	2018	2.3	0.6
Earthquake	11	3	2018	5.3	0.6
Earthquake Engineering	11	3	2018	1.3	0.6
Earthquakes	55	15	2018	6.3	1.2
Emergency Services	8	3	2019	0.0	0.0
Geographic Information Systems	27	7	2018	2.6	0.5
GIS	14	4	2017	2.8	0.6
HBIM	23	9	2018	10.4	1.7
Historical Buildings	8	4	2017	17.0	1.2
Industry Foundation Classes—IFC	13	3	2017	11.3	2.0
Laser Applications	16	4	2017	7.0	0.9
Life Cycle	24	7	2018	4.6	0.9
Preservation	10	3	2018	24.7	3.4
Reconstruction	7	4	2020	1.5	0.6
Remote Sensing	9	3	2017	2.3	0.2
Repair	12	3	2018	10.7	2.3
Restoration	21	6	2017	17.8	1.7
Retrofitting	12	5	2017	2.6	0.5
Risk Management	12	4	2019	2.3	0.5
Robotics	10	3	2015	1.0	0.2
Safety Engineering	9	3	2019	6.3	1.4
Safety Management	3	3	2020	2.0	2.7
Virtual Reality	15	5	2019	2.0	0.6

3.4. Analysis of Article Citations

Researchers need to find publications that have significant contributions to the academic community. By setting the minimum number of document citations to four, only 26 out of 75 documents met the thresholds. There was a total of 14 crucial articles linked to each other, as presented in Figure 5.

As shown in Figure 5, the node of Biagini C. (2016) [50] was the largest, indicating the most cited papers. However, the node of Newari N.O. (2019b) [32] was small and in the middle of the network, which has strong connections with other most cited papers. The influence of each document was evaluated through the number of links, total citations, and normalized citations as detailed in Table 4.

It is interesting to find that the insightful research results were primarily published in the domain of applications of BIM, especially in the phases of disasters, from pre- to post-disaster. Hence, it can be inferred that the properties of BIM applications are capable of solving challenges related to PDR. It is expected that applications of BIM will be used more frequently in future studies within PDR.

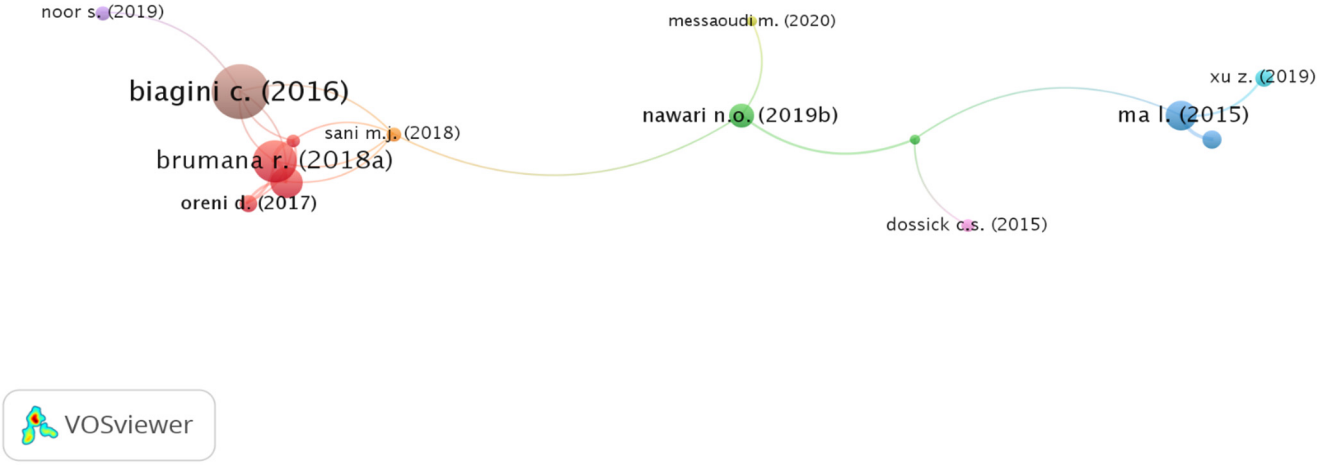


Figure 5. Mapping of article citations.

Table 4. Details of article citations.

No.	Article	Title	Number of Links	Citations	Norm. Citations
1	Messaoudi M. (2020) [33]	"BIM-Based Virtual Permitting Framework (VPF) For Post-Disaster Recovery and Rebuilding in the State of Florida"	1	4	5.4
2	Noor S. (2019) [51]	"Modeling and Representation of Built Cultural Heritage Data Using Semantic Web Technologies and Building Information Model"	1	7	1.4
3	Nawari N.O. (2019a) [52]	"BIM Data Exchange Standard for Hydro-Supported Structures"	3	4	0.8
4	Xu Z. (2019) [53]	"A Prediction Method of Building Seismic Loss Based on BIM and Fema P-58"	1	9	1.9
5	Nawari N.O. [32]	"Blockchain and Building Information Modeling (BIM): Review and Applications in Post-Disaster Recovery"	3	16	3.3
6	Brumana R. (2018a) [54]	"Generative HBIM Modelling to Embody Complexity (Lod, Log, Loa, Loi): Surveying, Preservation, Site Intervention—the Basilica Di Collemaggio (L'aquila)"	5	42	5.8

Table 4. *Cont.*

No.	Article	Title	Number of Links	Citations	Norm. Citations
7	Sani M.J. (2018) [55]	"GIS And BIM Integration At Data Level: A Review"	5	7	1.0
8	Brumana R. (2018b) [56]	"Scan to HBIM-Post Earthquake Preservation: Informative Model as Sentinel at the Crossroads of Present, Past, And Future"	5	6	0.8
9	Brumana R. (2017) [57]	"HBIM Challenge Among the Paradigm of Complexity, Tools and Preservation: the Basilica Di Collemaggio 8 Years After The Earthquake (L'aquila)"	5	26	3.5
10	Oreni D. (2017) [58]	"Survey, HBIM and Conservation Plan of a Monumental Building Damaged by Earthquake"	3	10	1.4
11	Biagini C. (2016) [50]	"Towards the BIM Implementation for Historical Building Restoration Sites"	5	63	4.2
12	Ma L. (2016) [59]	"Preparation of Synthetic As-Damaged Models for Post-Earthquake BIM Reconstruction Research"	1	11	0.7
13	Ma L. (2015) [60]	"Information Modeling of Earthquake-Damaged Reinforced Concrete Structures"	3	23	4.1
14	Dossick C.S. (2015) [61]	"Learning in Global Teams: BIM Planning and Coordination"	1	6	1.1

Besides research topics, the number of links mentioned in Table 4 demonstrates an article's influence within the academic community. The articles by Brumana R. (2018a) [54], Sani M.J. (2018) [55], Brumana R. (2018b) [56], Brumana R. (2017) [57], and Biagini C. (2016) [50] had the strongest number of links. Moreover, two articles from Biagini C. (2016) [50] and Brumana R. (2018a) [54] earned the highest citations and had the greatest normalized citations, respectively, in highly cited articles. Brumana R. had three out of the fourteen most cited papers regarding the number of citations; hence, this indicates that the author Brumana R. has led an important series of studies on BIM applications for PDR compared to other authors. Additionally, other researchers, including but not limited to Messaoudi M., Xu Z., Ma L., and Dossick C.S., have conducted the most influential research.

3.5. Analysis of Countries

The availability of information on outstanding countries in a research field can help scholars collaborate between them on projects, get grants, and share their findings [46]. In this study, diligent countries were also recognized according to their research contributions. VOSviewer was used to identify, evaluate, and visualize the source countries of researchers [41]. The minimum number of published articles and citations of a country was set at two and ten, respectively. Accordingly, out of 32 countries, 11 met the thresholds. There was a total of nine important countries linked to each other, as presented in Figure 6.

It can be observed in Figure 6 that the countries were classified explicitly into three groups based on colors, where the first group included Canada, South Korea, and the United States. It is interesting to note that Italy had the largest node, implying that Italian academics were the primary contributors to research on the applications of BIM to solve PDR problems. The details of these productive countries are provided in Table 5.

As can be seen in Table 5, Italy, China, and the United States were ranked higher in terms of total documents. Academics from Italy earned the highest total citations compared to the countries active in BIM applications for PDR research, showing that the utilization of BIM applications by Italy's academics was extremely enlightening and aided in the research area of PDR. Based on the average citation, which shows the importance of the study conducted in the country, Canada ranked first with 19.5 average citations, and Israel ranked second with 11.7 average citations recorded. Interestingly, academics from Canada, South Korea, Greece, and Cyprus recorded higher average normalized citations, indicating

that they are strongly competitive and provide important contributions to BIM applications for PDR research.

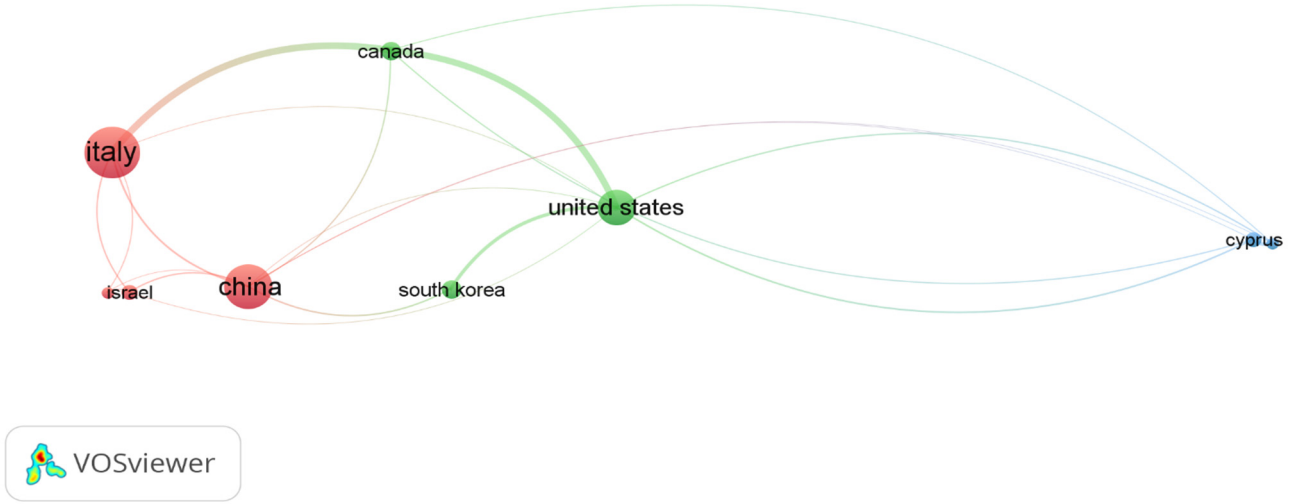


Figure 6. Mapping of countries.

Table 5. Details of countries.

Country	Total Link Strength	Documents	Total Citations	Avg. Pub. Year	Avg. Citations	Avg. Norm. Citations
Canada	196	4	78	2018	19.5	2.9
China	23	14	24	2019	1.7	0.7
Cyprus	40	3	21	2013	7.0	1.6
Germany	5	2	11	2016	5.5	1.1
Greece	37	2	11	2015	5.5	1.9
Israel	11	3	35	2015	11.7	1.7
Italy	114	17	168	2018	9.9	1.3
South Korea	30	4	12	2019	3.0	2.3
United States	126	10	30	2018	3.0	1.3

4. Discussion

Following the bibliometric analysis, this section summarizes the present status of the research and offers directions for future research.

4.1. Post-Disaster Reconstruction

The present study found various expectations for research regarding PDR, with the majority focusing mainly on short-term recovery and ignoring long-term reconstruction. Lyons [62] reported that PDR is primarily unsuccessful in achieving its pre-planned goals, where the failure rate of the reconstruction project is beyond 50% [63]. Delays in the process of reconstruction projects might reduce the effectiveness of the reconstruction and make achieving the goals more challenging [64,65]. Based on the work that needs to be carried out post-disaster, several other challenges can influence the timeframe of the work [8]. PDR mainly relies on economic, cultural, social, environmental, and political elements [66]. Various problems emanate because of inadequate supports from poor governance, local government, poor infrastructure, and insufficient knowledge and preparedness. Moreover, other elements that positively influence the reconstruction processes include addressing technical problems, integrated information, short and long-term approaches, and public participation in dealing with technical problems [67]. PDR is influenced by the locations of the destroyed areas because this influences the assigned funds, technical resources, and labors [5]. Despite the value of community contribution in PDR, it is important to ascertain timely information during the reconstruction period [68]. Moreover, although PDR offers

chances to lower vulnerability and enhance sustainability in disaster-affected communities, most reconstruction projects have failed to meet these objectives [69]. Hence, PDR is highly demanding and complex, and needs several well-coordinated and diverse actions.

Moreover, during the past few years, several studies have been conducted in this area to investigate various variables exerting either negative or positive impacts on a PDR project [3–5,9,10,68,70–72]. The unsuccessful outcomes of PDR projects are due to the following: inadequate availability of resources, delays in project implementations, inadequate coordination amidst participation organizations, corruptions, substandard quality of the reconstructed building, inadequate community participation, inadequate road access, inadequate government support, problems with land availability and acquisition, ineffective design, conventional 2D documentation, manual schedule and cost estimation, and inadequate extensive resource database. Meanwhile, available evidence shows that PDR has a discouraging record of performance in recent decades due to ineffective reconstruction strategies that do not consider the concept of collaboration among parties, have coordination procedures, and adopt modern communication technology.

Some examples of good reconstruction practices include the establishment of construction guidelines and permitting processes, as well as the certification of reconstructed housing to ensure safe building construction [33]. However, these practices have taken a long time to obtain approval. Since acting quickly is the priority in a post-disaster situation, the traditional manual cost estimation methods are not feasible. Based on previous studies, there is a need for a tool to calculate the construction cost of the proposed alternatives quickly and automatically [73]. Reconstruction requires avoiding disintegration between stakeholders, such as governments, emergency agencies, builders, relief organizations, designers, and disaster victims [7], and also demands the enhancement of delivery practices in order to provide higher value to stakeholders [6,16]. Moreover, non-participatory reconstruction practices by donors have caused conflicts and resentment among the local people [13]. This study found that the existing practices of reconstruction projects must be compiled and evaluated to determine whether the proposed conceptual designs satisfy construction codes. Accordingly, it is susceptible to personal mistakes, and any updates need to be performed manually, which causes budget overruns and schedule delays in reconstruction projects.

The current status of managing PDR mostly seeks to avert factors causing failures in the PDR projects. However, information about post-disaster management is ongoing, and most desire to learn from past failures. To overcome these challenges, PDR must integrate short and long-term reconstruction to guarantee that housing and infrastructure requirements are fulfilled throughout the short-term recovery phase, while lowering vulnerability and enhancing sustainability and resilience in the long-term reconstruction phase. As a result, the goal of efficient PDR may be attained by integrating the requirements of stakeholders with modern management practices and information technology. Therefore, to accomplish the PDR project on schedule, within the allocated cost and with a high standard of quality, there is a need for more objective studies to boost productivity and sustainability in PDR projects. Besides, it is necessary to adopt new developments in modern management practices and information technologies, such as building information modelling, that can enhance the competitive environment of PDR projects based on the improvement of product quality, on-time project delivery, and cost reduction.

4.2. Building Information Modelling (BIM)

BIM is a powerful tool adopted in construction projects to control project information and building design in digital form throughout the life cycle of buildings. This approach allows for information interchange and interoperability between parties [74]. BIM has been widely promoted as an nD modelling platform to improve collaboration and communication, and its scope has expanded from "geometric models (3D) to include time (4D), costs (5D), sustainability of the environment (6D), and facility management (7D)" [75]. Its significant advantages in terms of cost and time savings, as well as increased performance

and boosting of productivity, have compelled construction players to adopt and rapidly implement it within several fields [76]. A 3D building model that identifies the clash detection, improves the schedules of construction, and prepares construction site activities was shown to be useful in everyday operations [77]. Additionally, the utilization of BIM has provided significant benefits to the construction industry over the project's life cycle, from conceptualization to demolition [78]. Significant advantages found in the design phase of the project include improved visualization, efficiency, and productivity, whereas, during the construction phase, BIM can consist of cost analysis and auto-scheduling, allowing for improved project coordination and on-time delivery capabilities [79]. Accordingly, BIM encourages all professionals and stakeholders to contribute and collaborate to produce a high-quality output throughout the project.

Diffusion and implementation are two steps in the BIM adoption process. With effective BIM adoption and implementation, complexities and challenges in project management will be greatly minimized as and partnerships between stakeholders will be enhanced over the project life cycle [28,48,80,81]. The implementation of BIM is expanding rapidly in the international context [80]. The implementation of BIM has reached a significant level in several developed world countries, such as the UK, USA, Australia, and Canada [23,82]. However, there is a low rate of BIM adoption not only in developing nations but also in certain developed world nations. While BIM implementation in developing nations has fulfilled the criteria during the design stage, it is substandard during the construction stage, as highlighted by Memon et al. [83]. Due to the fragmentation in implementation, BIM applications are delayed, and the construction industry remains at a low level of BIM adoption. Numerous factors contribute to this fragmented activity, including a lack of understanding about BIM implementation activity, a lack of coordination and collaboration between different disciplines, a lack of practice standards and guidelines, resistance to changing current working practices, and a lack of skill in preparing BIM plans and the ability to use them with stakeholders effectively [84]. It can be noted that the studies centering on BIM in developing world nations have highlighted the dynamics of BIM adoption and are working to improve BIM maturity in these countries. The barriers to BIM adoption must be addressed, and the benefits must be explained adequately to achieve comprehensive adoption of BIM and avail its benefits. Thus, future studies concentrating on this research field should perform case studies in which real-life adoption of BIM is validated.

Moreover, the utilization of BIM applications has progressively appeared as an essential topic in the PDR field [31,33]. Despite some reported evidence on its benefits within the construction industry, the adoption of BIM for PDR has been limited, and stakeholders and decision-makers in the aftermath of the disasters are not excited to adopt and implement BIM into its reconstruction practices. Therefore, there is a need to transfer from traditional reconstruction practices to BIM-based practices. Using BIM applications in reconstruction projects for planning, design, and construction will create and manage support key data and reports. The application of BIM in reconstruction projects will result in more cost-effective design and enhance communications and collaboration among parties.

It can be concluded that several studies address BIM adoption in general; however, few researchers concentrate on BIM adoption challenges and factors that influence adoption without providing a comprehensive perspective and an in-depth understanding of issues for the adoption of BIM. Nevertheless, there is a lack of studies on factors influencing BIM adoption in various dimensions of BIM research.

4.3. Disaster Management and Building Information Modelling

The role of BIM applications in disaster management is evident through all phases, from pre- to post-disaster. For instance, Drogemuller [85] conducted a study on the benefits of BIM in disaster response. This study looked at a variety of scenarios in which BIM was used during several disaster stages, including prevention, preparation, reaction, and recovery. By employing augmented reality to simulate multiple disaster scenarios and the best method to cope with them, the BIM can aid disaster preparation. Facility managers can

utilize BIM to track key building data to undertake maintenance and prevent the failure of the building in the event of a disaster. Additionally, BIM can create 3D visualizations to assist stakeholders and decision-makers in comprehending the larger picture of a disaster's effect and speed up assessments of building damage. This could result in more effective planning and cooperation between stakeholders [85]. Dakhil and Alshawi [31] explored the BIM applications that support building disaster management, including disaster planning, site planning, and existing condition modelling, and their advantages; they suggested that future research should empirically study all applications of BIM during the project life cycle and identify the advantages of those applications. Based on the study by Kim and Hong [86], BIM information is a helpful tool for the response of disaster management. They presented a "BIM-based disaster integration information system" that allowed first responders to locate the event occurrence rapidly. In addition, Wang et al., [87] debated using a BIM-based virtual environment to assist the residents' building management during disasters. This suggested system employed BIM data and the game engine to design a real-time evacuation path for building occupants via a mobile device [87]. Moreover, Boguslawski et al., [88] proposed an algorithm for calculating evacuation routes during disasters. This method used a combination of BIM and geographic information system (GIS) to display the fastest egress route. According to Lyu et al. [89], BIM and GIS integration might be a valuable tool for city managers to identify flooding disasters.

Additionally, Sertyesilisik [90] emphasized the contribution of BIM to the resiliency of disaster from the pre- to the post-disaster stage, particularly by impacting the performance of the rescue operations, rebuild activity, and supply chain. Academic researchers and decision-makers play a vital role in encouraging and educating the public regarding the significance of BIM as a tool for improving the robustness of built environments throughout the disaster management process [90]. Moreover, Kermanshachi and Rouhanizadeh [73] developed a BIM-based automatic cost estimation methodology to aid in reconstruction by providing a precise estimate of the required budget. This tool is limited in that it can only estimate the cost of repairing a damaged structure. The tool has had one upgrade that allows it to reflect changes in estimated costs, although it still has limitations [73]. Furthermore, it was shown that very few studies on BIM integration with blockchain have been undertaken for PDR permits [32]. Nawari and Ravindran [32] listed the potential advantages of BIM in conjunction with blockchain for post-disaster rebuilding. The authors presented a framework for automated reconstruction permitting in any transaction by using Hyperledger Fabric. As a result, paperwork, additional processing fees, and the time it takes to obtain building permits, can all be reduced; however, no evidence of actual implementation has been found. Hence, more time is required to investigate blockchain in PDR. Thus, greater research into BIM and PDR combined with blockchain will provide a major boost in the PDR field.

Furthermore, Biagini et al. [50] recommended using BIM for historic building rehabilitation. The fundamental concern for historical building repair is on-site management. A detailed information plan for executing the restoration plan should be provided in order to provide effective on-site management. While conventional restoration techniques produce 2D maps with inadequate data, BIM allows users to create a 3D model of historic buildings and link it to a range of data. In the case of "Basilica di Collemaggio", which was harshly damaged because of a seismic event, BIM was used for a variety of purposes, including various scenario simulations for making decisions regarding the collapsed dome, structural analyses, and construction site management through various stages of the rebuild [57]. Xu et al. [53] established a BIM-based seismic damage evaluation based on FEMA P-58. Stakeholders can proceed through a virtual walkthrough to see how damage and loss are distributed, given that FEMA P-58 necessitates thorough information in order to forecast building damage. Furthermore, the BIM model for building components may be at various levels of development. Messaoudi and Nawari [33] proposed a virtual framework according to BIM and a generalized adaptive framework for speeding up the permitting process of reconstruction in the aftermath of the disaster in Florida. The fundamental procedure

of the framework was to determine the type of construction permission, apply the newly established permitting framework, and decide on the permit result. The framework was able to save around 18 h for each permit, though this framework only considered the time of the permitting process of reconstruction. Finally, Rad et al. [91] provided an integration of BIM and life cycle cost (LCC) to assess building resiliency following an earthquake all through the building service life. The proposed BIM-LCC approach mainly was employed during the conceptual stage. The suggested BIM-LCC approach has limitations in that it only addresses earthquakes as one of the potential events that can occur through a building's life cycle. Nevertheless, in order to completely assess the building resiliency, numerous events of a disaster may need to be examined, and the consequences of each on the structure explored, which might be a topic for future research.

According to the literature, the available evidence shows that utilizing BIM for PDR is still nascent. Even though BIM has a great deal of potential within the construction industry, the challenges of adopting BIM in PDR have not been extensively studied. Moreover, BIM applications in PDR, such as scheduling, communication and collaboration, project delivery, demolition process, and deconstruction have been neglected in past studies. The majority of previous studies on BIM for PDR have been conducted using a qualitative approach. As a result, further primary investigations should be undertaken to adopt BIM for PDR projects fully. We recommend setting the foundations for a better framework and guidelines for BIM adoption through the planning, design, and construction phases of PDR projects. We also suggest that the barriers to adopting BIM for PDR projects within the construction industry be identified. In addition, studies concentrating on this research field in the future should perform quantitative research approaches in which real-life adoption of BIM is validated, which will be helpful for decision-makers. Finally, we recommend the integration of BIM for PDR with blockchain and/or other technology, such as the Internet of Things (IoT), which will provide a significant boost in the PDR field.

5. Conceptual Framework

Based on the above discussions, this study developed the proposed conceptual framework of BIM adoption for PDR, as illustrated in Figure 7. The proposed conceptual framework comprises a variety of key elements, such as the current practices of PDR projects, benefits of BIM adoption, and barriers to BIM adoption. While the previous frameworks focused only on the adoption of BIM for conventional construction [20,21,92–94], and others focused on the management of PDR projects separately [3,12,14,68], our proposed framework is the first attempt to integrate BIM adoption for PDR projects. This framework also incorporates main stakeholders, such as governments, NGOs and donors, disaster victims, and construction players. Those components serve as the foundation for developing the conceptual framework of BIM adoption for PDR.

In contrast, the proposed conceptual framework is not static or complete; instead, it reflects the current knowledge on BIM for PDR. Therefore, it serves as a leading strategy from which future researchers can conduct more comprehensive studies to identify the advantages and disadvantages of the current practices of the PDR, as well as the role and responsibilities of each stakeholder participating in the reconstruction projects. Moreover, we suggest that the most important benefits of BIM adoption and its barriers within the construction industry be identified. Accordingly, the benefits of BIM will mainly be determined to overcome the disadvantages of the current practices of PDR. There is a relationship between PDR and BIM adoption, which impacts BIM adoption for PDR.

Furthermore, the proposed conceptual framework shows how the current practices of PDR and the benefits and barriers of BIM adoption, considering the relationships among the stakeholders, will affect the adoption of BIM for PDR, and how it can be led to success. It also demonstrates that the adoption of BIM in PDR projects occurs through the interactive relationships between stakeholders. As a result, the success of the PDR project is heavily reliant on stakeholder relationships, leadership, decision-makers, and decisions made individually by each stakeholder, who is influenced by the decisions of other stakeholders,

in conjunction with the mandatory adoption of BIM. Therefore, for a better understanding of this scenario, the proposed conceptual framework summarizes that the full adoption of BIM through the planning, design, and construction phases of PDR will lead to the success of reconstruction projects based on the success of their components, which is a part of the process of PDR. The proposed conceptual framework can assist to improve collaboration among reconstruction project stakeholders and offer more opportunities for a positive perception of BIM adoption in PDR in the future.

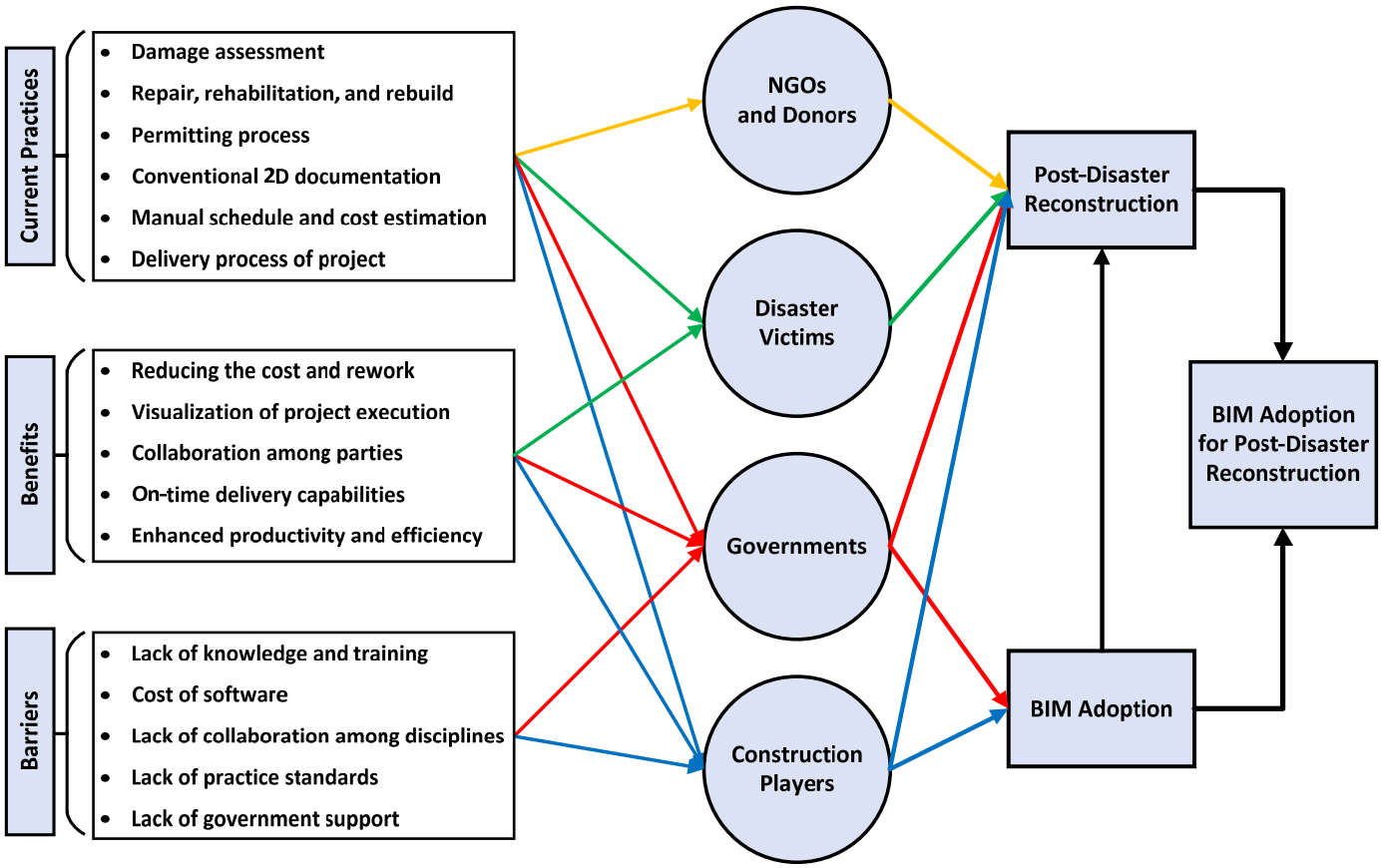


Figure 7. Conceptual framework.

6. Conclusions

Post-disaster reconstruction has been considered as a dynamic, complex system, and represents many challenges and issues. Recently, building information modelling has been extensively utilized in the construction industry due to its efficiency in solving complex and dynamic challenges. To provide a holistic overview of the present status, the current study used VOSviewer to visualize related papers published from 2010 to March 2021. The findings showed that "Automation in Construction" had an outstanding performance in BIM applications for the PDR field, and recorded the highest number of total citations. The analysis of keyword frequency showed that "Reconstruction" and "Safety Management" emerged as mainstream research themes in this field and recently attracted scholars' interest, which could represent the directions of future research. Five major research domains associated with BIM were identified, namely "Disasters", "Earthquakes", "HBIM", "Damage Detection", and "Life Cycle". Finally, a proposed conceptual framework was provided, highlighting the relationship between post-disaster reconstruction and BIM adoption, which impacts BIM adoption for PDR.

The outcomes of this study will assist scholars and practitioners in gaining clear ideas of the present status and identifying the directions of future research in this area. It will develop and open a new research area of BIM in the life cycle phases of PDR projects. Furthermore, while using BIM for reconstruction projects in the aftermath of disasters is still

nascent, further primary investigations should be conducted to adopt BIM for post-disaster reconstruction projects fully. We recommend setting foundations for a better framework and guidelines for BIM adoption through the planning, design, and construction phases of PDR projects. We also suggest that the barriers to adopting BIM for PDR within the construction industry be identified. In addition, we recommend the integration of BIM for PDR with blockchain and/or other technology, such as the IoT, which will significantly boost the PDR field. However, there are a few limitations to this research. For instance, this study followed the PRISMA guidelines, without paying attention to meta-analyses. Thus, future studies should be undertaken considering meta-analyses to support the analysis of this study. Moreover, the collected papers were only sourced from the Scopus database, meaning that other related papers may be missing. Thus, prospective studies could include articles from another database. In addition, only English papers were included; however, there could be related papers in other languages that should be considered in future studies to overwhelm these limitations.

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