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Analysis of Global Research Trends on BIM Studies in the Field of Architecture

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Abstract

This paper reveals the results of a bibliometric analysis on BIM and architecture to analyze and determine how the current research trends in BIM literature have evolved and diversified in the discipline of architecture. Although there are currently bibliometric analysis reviews of BIM in the literature, these studies take either the BIM process from a general perspective or the engineering-construction sectors, urban design scale. This state-of-the-art study explains a bibliometric analysis of the literature's relationship between architecture and BIM. Through analyzing the data including keywords, authors, journals, institutions, citation rate etc., the relationship between BIM and architecture in all times till today has been mapped and visualized by using Clarivate Analytics' Web of Science database and VOS viewer program. In addition, analyzing the current literature published between 2017-2022 was highlighted and the emerging fields in architectural research were revealed. Emerging fields today in architectural research under the scope of BIM have clustered according to the keywords and these keywords are mostly related to information technologies and automation. The goal of revealing these findings extensively is to inspire future research based on the gaps and missing information in the existing literature. The unique importance of this study is to generate a knowledge base for the relationship between BIM and architecture studies based on the data including keywords, authors, journals, universities, citation rate, etc., adopting the bibliometric approach. This study provides valuable information to BIM studies in architecture research for researchers and practitioners. The current state of the research field, trend topics, and the key scholars and universities were identified.

Keywords:
Architecture, bibliometric analysis, BIM, construction building technology, literature review

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INTRODUCTION

From the beginning of the design to the end of the construction process, especially in large-scale projects, stakeholders from many professional groups transfer data and try to implement the project. In this process, problems may be unnoticed during the design phase in data transfer, and construction mistakes can occur. In addition, it is known that some decisions to be made during the design phase can be beneficial to the sustainability of facility management after the project is built (Leite, 2020; Sacks et al., 2018; Garber, 2014). For these decisions to be made correctly during the design process, various simulations and analyses of the data and environmental impact assessments of the project should be made before the construction phase (Krygiel, Nies, 2008). Due to the evolving needs, traditional construction management and project delivery processes have changed, and information technology applications have entered our lives to be used throughout the project's life cycle (Gerrish, T., Cook, M., Ruikar, K., 2016).

NBIMS (National BIM Standards) (2007) defines BIM (Building Information Modeling) as the quantitative expression of the project's features of form and function and the process that ensures the transfer of information throughout the life cycle of the project and evaluates it in 3 dimensions:

A BIM model is a virtual representation of the project's form and function features with a data directory.

The BIM process is the process that covers the production and use of design, construction, and operational data that the project will have throughout its life cycle.

BIM management refers to the organization and control of the business process using BIM model data. Communication infrastructure is created to ensure efficiency and quality in management.

BIM is a process covering design, construction, facility management and technology that strengthens communication between architecture, engineering and construction industries (Leite, 2020; Deutsch, 2011; Lévy, 2019; Sacks et al., 2018). Khosrowshahi and Arayici (2012) support that BIM provides an improvement in the subjects of information management for the life cycle of the structure; increased efficiency for an improved design; reduced errors, rework and waste in design and construction; enhanced risk management; lean construction and design; gaining supply chain support in the production of documents; ensuring construction management with the use of technology. With BIM technology, a virtual model of the building is created using quantitative data before its physical construction (Azhar, 2011). This way, it is possible to analyze architectural, structural, electrical and mechanical details separately beforehand (Kymmel, 2008). During the architectural design phase, BIM helps the architect to visualize the building, estimate project costs, select and evaluate the material applied, adjust project

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inputs such as environmental comfort, and facilitate communication between professionals in the process (Amorim et al., 2009).

This study conducted a bibliometric analysis to determine how research trends related to BIM in the literature have evolved and diversified in architecture. For future research on BIM, there is a need to create networks for studies in the literature (Hosseini et al., 2018). The resulting findings raise awareness of the need to address identified gaps and neglected areas in the BIM literature; it allows specifically selected research to benefit practical life (Vilutiene et al., 2019). Although there are currently bibliometric analysis reviews of BIM in the literature, these studies take either the BIM process from a general perspective (Santos et al., 2017; Chihib et al., 2019; Babalola et al., 2021; Li et al., 2017; Zhao, 2017; Olawumi, Chan, & Wong, 2017; Oraee et al., 2017) or the engineering-construction sectors, urban design scale (Bastem, Cekmis, 2021; Shkundalov, Vilutiene, 2021; Wang, Pan, Luo, 2019; Vilutiene et al., 2019). It is believed that bibliometric analysis for the current relationship between architecture and BIM can guide authors for potential studies by giving general information about the area. The goal is to inspire future research based on the gaps and missing information in the existing literature. Therefore, in this study, bibliometric analysis and a comprehensive evaluation of published research were carried out to determine how researchers working at the intersection of BIM and architecture collaborate and where the gap and potential in the field lie.

METHODOLOGY

Bibliometrics is the measurement of documents depending on quantitative data. These documents can be exemplified as texts, books, records or information in different formats. Pritchard (1969) defines bibliometric studies as applying sequencing, mathematical and statistical techniques to different communication environments. Although most common in the library and information sciences, many research fields use bibliographic studies to explore research trends in their field and the implications of these trends. In these studies, data such as the number of citations of the publications, the changes in the content of the publications according to the years, the universities where the publications were studied and keywords can be used. Metric studies have increased in recent years. This increase is due to the progress in computer usage, statistical algorithms, databases and internet connections (Sajovic et al., 2018).

In this study, a bibliometric analysis was conducted to reveal the direction of the current trends and developments at the intersection of architecture and BIM. The flow chart of the bibliometric study is as follows:

Figure 1. Method Of The Study

In the study, publications of all times are gathered till February of 2023, when this study takes place. This study aims to identify the latest trends, so all research conducted in Web Of Science database until the start of the study has been considered. The search filter contains the keywords "Building Information Modeling" OR "BIM" as a topic in the subject area of architecture or construction building technology. These publications were examined according to years (publication and citation), research areas, document types, publication titles, publication numbers by countries, author and co-authorship analyses, publication numbers and citation analyses by universities and keyword analyses. With the search filter remaining the same, the most cited publications published between 2017-2022 and the direction of the trends are clarified.

Clarivate analytics' Web of Science database was used in this study for providing high quality data and allowing the option to enrich search queries. Web of Science is considered one of the world's preeminent research, scientific citation and analytical information platforms (Li et al., 2018; Chavarro et al., 2018).

3997 publications containing the keywords "Building Information Modeling" OR "BIM" as a topic was filtered in the Web of Science database, which are under the subject area of "Architecture or Construction Building Technology."

Science mapping techniques and algorithms are used in bibliometric studies to visualize similarities and differences in collecting data from one or more sources. Network analysis, consisting of algorithm sets and techniques while deriving from network theory, enables scientifically demonstrating of the interactions of research and research trends, supported by the advent and advanced use of the internet and computers (Smiraglia, 2015). With recent advances in computer technology, scientific indexes, and information visualization techniques, researchers can discover hidden connections and trends in the literature (Li et al., 2017).

Various tools such as VOSviewer, SankeyMATIC, Gephi, nodeXL and Citespace have been developed to support network analysis by visualizing the data and information for a better understanding. In this study used VOSviewer software, which also allows working with different databases.

With VOSviewer tool, bibliometric charts, maps and clusters are generated using network links and understandable visual graphics like circles and labels to imply the similarities and relationships of the gathered data (Van Eck, Waltman, 2014). Network links state the relationship between the elements. The clusters are expressed with different colors. VOSviewer software is widely used especially in graphical and metadata metric studies (Aghimien et al., 2019; Akinlolu et al., 2020; Wu et al., 2020).

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RESULTS OF THE BIBLIOMETRIC ANALYSIS

In the study, firstly, publications containing the keywords "Building Information Modeling" OR "BIM" as a topic within the subject area of "Architecture or Construction Building Technology" were filtered in the Web of Science database. Publication and citation numbers of 3997 publications by years, research areas they address in addition to Architecture or Construction Building Technology, document types, publication titles, publication numbers by countries, author and co-authorship analysis, publication numbers and citations by universities, and keyword analysis are presented. Applying the same filter, the 10 most cited publications published between 2017-2022 were presented in detail, and the direction of the research trend today was interpreted.

Number Of Publications And Citations By Year

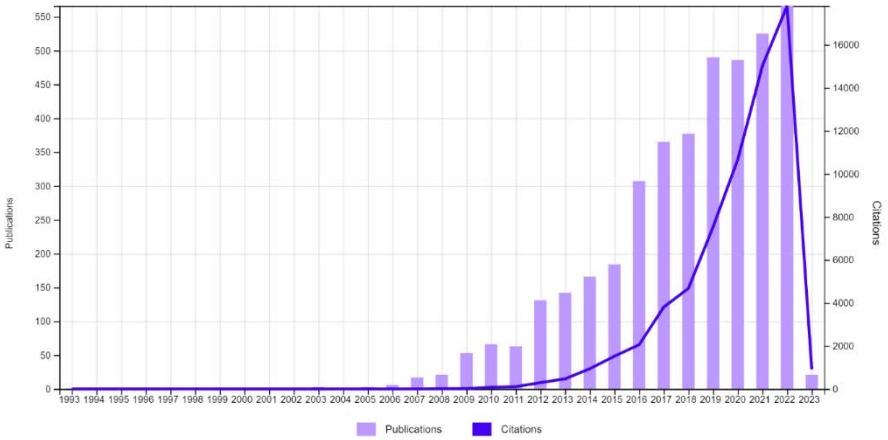

Figure 2. Number Of Publications And Citations By Years

Figure 2 shows the number of publications and citations of 3997 publications by year. The first publication was in 1993. It is stated that between the years 1993 and 2023 (until February when this study was conducted), 2022 (566 publications) is the year that has the highest publication numbers. 2022 is followed by 2021 with 525 publications. There has been an increase in the number of publications on the subject investigated from 1993 to the present day. The period in which the number of publications increased the fastest is between 2015-2016 and 2018-2019.

Citations always express an article's scientific impact (Guo et al., 2019). When Figure 2 is examined, it is seen that citations for publications have increased since 2010. The fastest increase was experienced between 2018-2022. According to Figure 2, 2022 was the most cited year with 17819 citations.

Research Areas

In the study, all publications were filtered to be researched in Architecture or Construction Building Technology. There are other fields in which publications fall within the subject range apart from architecture or construction building technology. In Table 1, the top 10 research areas of the publications are listed. These fields are engineering, computer science, science technology, materials science, energy fuels,

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urban studies, remote sensing and imaging science photographic technology. According to Table 1, research areas are identified with record counts and percentages as follows; 3345 publications (83.688% rate) in construction building technologies, 2589 publications (64.774% rate) in engineering, 856 publications (21416% rate) in architecture, 309 publications (7.731% rate) in computer science, 166 publications (4153% rate) in science technology, 134 publications (3.353% ratio) in materials sciences, 132 publications (3302% ratio) in energy fuels, 123 publications (3.077% ratio) in urban studies, 122 publications (3.052% ratio) in remote sensing and 88 publications (2.202% ratio) in imaging science photographic technology.

Table 1. Top ten research areas of the publications with record counts and percentages

Research Areas	Record Count	Percentage
Construction Building Technology	3345	83.688%
Engineering	2589	64.774%
Architecture	856	21.416%
Computer Science	309	7.731%
Science Technology	166	4.153%
Materials Science	134	3.353%
Energy Fuels	132	3.302%
Urban Studies	123	3.077%
Remote Sensing	122	3.052%
Imaging Science Photographic Technology	88	2.202%

Document Types

Document types are divided into 12 sub-titles in Web of Science database: articles, proceedings papers, review articles, editorial materials, book chapters, early access, news items, corrections, letters, books, book reviews, and art exhibit reviews. According to Table 2, most of the 3997 publications analyzed were published as articles (56.743% rate and 2268 articles) or proceedings papers (33.725% rates and 1348 articles). Apart from articles and proceedings papers, there are 232 review articles, 109 editorial materials, 74 book chapters, 58 early access, 34 news items, 8 corrections, 5 art exhibit reviews, 4 letters, 2 books, 2 book reviews among analyzed publications.

Table 2. Document types of the publications with record counts and percentages

Document Types	Record Count	Percentage
Article	2268	56.743%
Proceedings Paper	1348	33.725%
Review Article	232	5.804%
Editorial Material	109	2.727%
Book Chapters	74	1.851%
Early Access	58	1.451%
News Item	34	0.851%
Correction	8	0.200%
Art Exhibit Review	5	0.125%
Letter	4	0.100%

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Book	2	0.050%
Book Review	2	0.050%

Publication Titles

Document type analysis states that publications are mostly written as articles or proceedings papers. It is supported in Table 3 that 9 of the top 10 publication titles according to the record counts are journals and 1 of them is a proceedings paper. Automation in Construction Journal is in the first place with 798 publications (19.965%) which published the majority of articles in the research area of "Architecture" or "Building Construction Technology" containing the keywords "Building Information Modeling" or "BIM" as a topic. Buildings (284 publications, 7.105% rate), Journal of Construction Engineering and Management (167 publications, 4.178% rate), Procedia Engineering (131 publications, 3.277% rate), International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences (119 publications, 2.977% rate), Journal of Building Engineering (116 publications, 2.902% rate), Advances In Civil Engineering (97 publications, 2.427% rate), Bauingenifur (87 publications, 2.177% rate), Construction Innovation England (74 publications, 1.851% rate) IOP Conference Series Materials Science and Engineering (71 publications, 1.776% rate) and are among top 10 publication titles with the most record counts.

Table 3. Top ten publication titles with the most record counts.

Publication Titles	Record Count	Percentage
Automation in Construction	798	19.965%
Buildings	284	7.105%
Journal of Construction Engineering and Management	167	4.178%
Procedia Engineering	131	3.277%
International Archives of The Photogrammetry Remote Sensing and Spatial Information Sciences	119	2.977%
Journal of Building Engineering	116	2.902%
Advances In Civil Engineering	97	2.427%
Bauingenifur	87	2.177%
Construction Innovation England	74	1.851%
IOP Conference Series Materials Science and Engineering	71	1.776%

Number Of Publications By Country

Figure 3 shows the distribution of 3997 publications, according to the countries in which they were published. According to the data obtained, China (747 publications) and America (689 publications) are in the first two places among the countries with the highest number of publications. After China and America, England (358 publications), Italy (337 publications), Australia (309 publications), Germany (253 publications), South Korea (199 publications), Canada (169 publications), Spain (156 publications), Malaysia (107 publications), Singapore (77 publications), Netherlands (75 publications), Portugal (73 publications), Iran (68 publications), Finland (62 publications), Taiwan (62 publications),

Turkey (61 publications), Sweden (60 publications), Belgium (57 publications), Czech Republic (55 publications), Austria (52 publications), Brazil (51 publications), Norway (49 publications), Poland (49 publications) and Denmark (47 publications) follow the graphic.

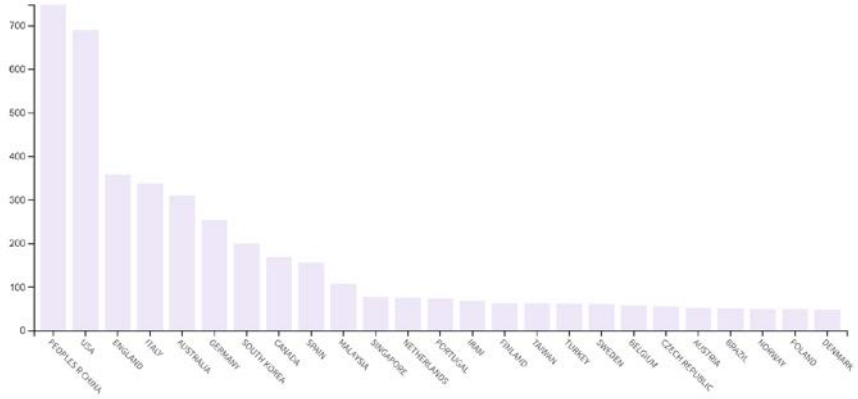

Figure 3. Number Of Publications And Citations By Years

Author And Co-Authorship Analysis

Co-authorship analysis assists in identifying and evaluating leading organizations, authors, countries and scientific collaboration trends (Fonseca et al., 2016). For author and co-authorship analysis, the minimum number of publications per author was set to 10 as a parameter in VOSviewer program. 62 authors met this criterion. Table 4 presents the list of the most productive 10 authors who have conducted research on the topic of "Building Information Modelling" or "BIM" in the field of "Architecture" or "Construction Building Technology." Accordingly, Cheng J. (41 publications, 1406 citations), Wang X. (32 publications, 2328 citations), Li H. (30 publications, 1247 citations), Lu W. (26 publications, 618 citations), and Luo H. (21 publications, 1097 citations) are the first 5 authors of the table. According to the table, the most cited author is Wang X.

Table 4. The most productive 11 authors and their document numbers and citations

Author	Documents	Citations
Cheng, Jack C. P.	41	1406
Wang, Xiangyu	32	2328
Li, Heng	30	1247
Lu, Weisheng	26	618
Luo, Hanbin	21	1097
Hosseini, M. Reza	20	867
Yan, Wei	20	543
Love, Peter E. D.	18	1204
Wang, Qian	18	598
Chong, Heap-yih	17	309
Leite, Fernanda	17	365

In Figure 4, a co-authorship network has been developed for authors. Lines between author names refer to collaborations and describe an author's connection with other authors (Van Eck & Waltman, 2010). 14 co-authorship clusters with 48 authors are identified in the table. Figure 5 visually represents the most productive years of the authors.

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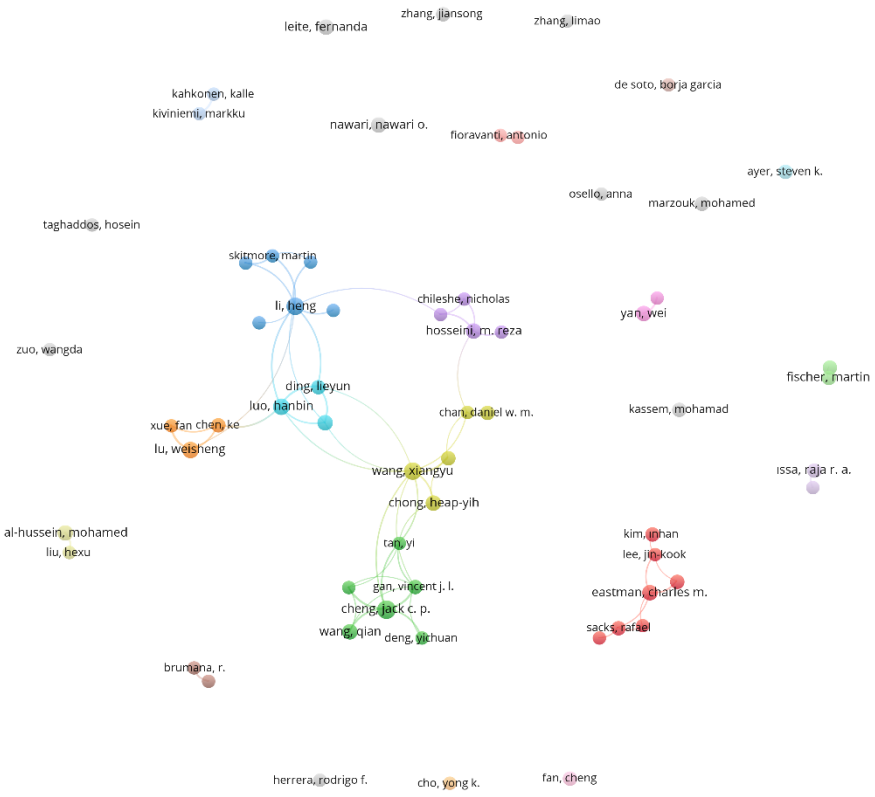

Figure 4. Co-Authorship Network / Author Collaboration

Figure 5. The Most Productive Years Of The Authors

Number Of Documents And Citations By Universities

Document and citation numbers of the universities are examined in this section. Among the universities where the filtered publications are done, those with at least 30 publications are listed in Table 5. Accordingly, Hong Kong Polytechnic University (97 publications, 4203 citations), Politecnico Milano (83 publications, 588 citations) and Georgia Institute Technology (68 publications, 3416 citations) are the first three universities considering the document numbers.

Table 5. Number of publications and citations by universities

Organization	Documents	Citations
Hong Kong Polytechnic University	97	4203
Politecnico Milano	83	588
Georgia Institute Technology	68	3416
Curtin University	67	3027
University Of Florida	60	1151
University Of Hong Kong	57	1581
Tsinghua University	54	1645
Tongji University	52	937
Hong Kong University Of Science And Technology	49	1432
Southeast University	47	399
Huazhong University Of Science And Technology	45	1711
Deakin University	44	1935
Shenzhen University	42	596
National University Of Singapore	41	939
Texas A&M University	39	844
Politecnico Torino	39	282
University College London	38	655
Kyung Hee University	35	2079
University Of New South Wales	35	475
Northumbria University	35	730
Hanyang University	34	838
Technic University Of Munich	33	424
University Of Alberta	32	639
Katholieke University Leuven	31	358
Cardiff University	31	832

Keyword analysis

Keywords mainly mirror the essence of a publication (Xiang et al., 2017). Keywords were obtained by analyzing the content of 3326 publications with the co-occurrence option in VOSviewer program. Co-occurrence means the common existence or closeness of similar keywords (Lozano et al., 2019).

In the study, the minimum repeat number of the keywords was determined as 10. The keywords listed with the co-occurrence option were filtered by considering their repetitions, and 143 were found. According to their relations in publications, these 143 keywords were divided into 8 clusters by VOSviewer program. Each cluster is represented with a different color in Figure 6. Figure 7 depicts cluster titles according to the subjects of the keywords.

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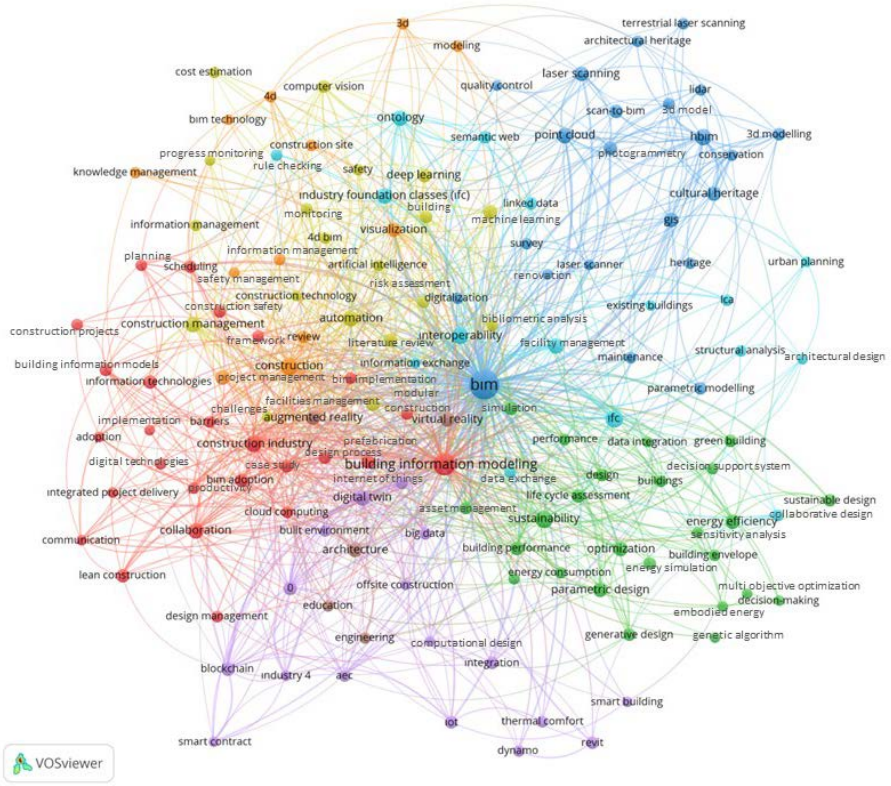

Figure 6. Keyword Network Analysis

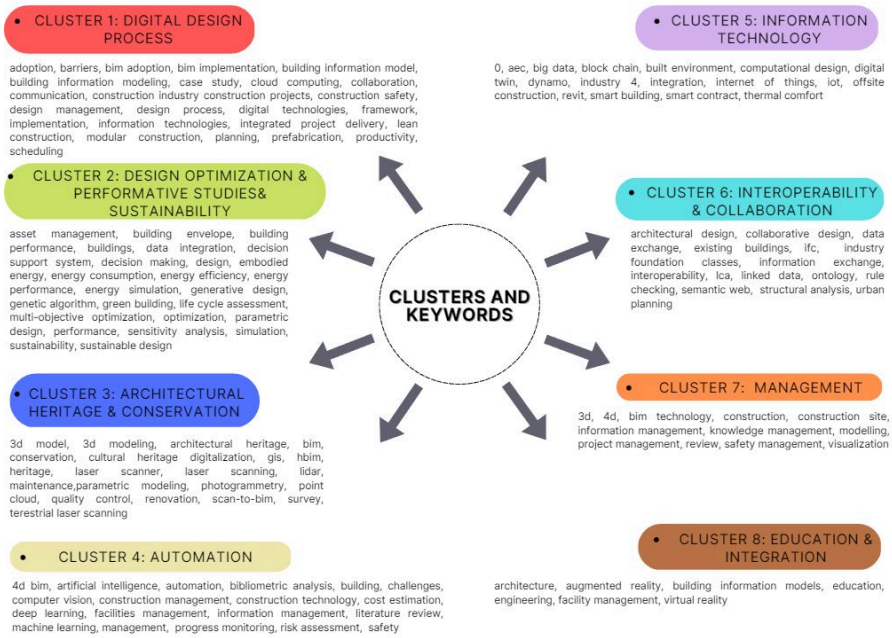

Figure 7. Generated Cluster Titles And Keywords

- **Cluster 1: Digital Design Process**

Building information modeling has significantly impacted how architects and engineers approach projects, promoting collaboration across disciplines (Harty, J., Kouider, T., Paterson, G., 2016). It has revolutionized the designer's relationship with the object they are designing, transforming the process from conception design to life cycle

maintenance, including detailed design and construction documentation (Marcos, 2017). Cluster 1 is shown in red in Figure 6. In the cluster, there are 26 keywords implying the *digital design process,* including bim adoption, bim implementation, design process, digital technologies, information technologies, and integrated project delivery.

- **Cluster 2: Design Optimization & Performative Studies & Sustainability**

BIM is not just a technological advancement but represents a new way of thinking about the entire lifecycle of construction, which has the potential to bring about a significant cultural shift in the industry (Vite, Morbiducci, 2021). To attain sustainable and efficient building design performance, stakeholders must make critical decisions during the early design phase. BIM can be used for energy performance simulations and can be integrated into the design process to improve the energy analysis process (Sherko, 2018). If BIM is not integrated into the design process, it can result in an inefficient design process (Cho, Chen, Woo, 2012).
Sustainable architectural design aims to reduce energy consumption and minimize negative environmental impacts while providing comfort for building occupants (Abdelhameed, 2017). To achieve this, passive and ecological building design criteria should be employed during design. These criteria aim to reduce energy consumption by optimizing heat losses and gains through the building envelope (Omrany, Marsono, 2016).

Cluster 2 is represented with 25 keywords in green. These keywords include building envelope, building performance, energy consumption, energy efficiency, energy performance, energy simulation, life cycle assessment, optimization, performance, sensitivity analysis, simulation, sustainability and sustainable design, which involves content for *design optimization & performative studies & sustainability.*

- **Cluster 3: Architectural Heritage & Conservation**

Building Information Modeling (BIM) is a widely used tool in the planning, design, and management stages of building construction. It offers a spatial and functional representation of structures through parametric objects. It has several features, such as visualization, data management, and cost calculation, making it useful for energy management, emergency management, and retrofit planning. Recently, BIM has been used to document existing structures, especially in maintenance, renovation, and the building's life cycle (Volk, 2014). When it comes to heritage buildings, the difficulty of matching traditional data with the real conditions of the building can lead to challenges in understanding and preserving the structure. In this regard, BIM is recognized as a valuable tool for documenting and restoring heritage buildings (Murphy et al., 2017; Bruno et al., 2019; Allegra et al., 2020). Heritage Building Information Modeling (HBIM) is a specialized

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adaptation of BIM designed to preserve architectural heritage. HBIM has emerged in the literature over the last decade and is used to express the use of BIM in the context of heritage buildings (Coşgun, Çügen, Arslan Selçuk, 2021).

There are 22 keywords in Cluster 3, shown in blue. These keywords include architectural heritage, bim, conservation, cultural heritage, digitalization, gis, lidar, photogrammetry, point cloud, and terrestrial laser scanning. This cluster can be examined under the title of *architectural heritage & conservation*.

- **Cluster 4: Automation**

The development of the Industry Foundation Classes (IFC) format in BIM software has enabled collaboration between construction parties and facilitated information exchange (buildingSMART, 2016). In this way, designs can be produced and controlled automatically. (Sacks et al., 2018). To ensure efficient automation in complex building quality assessment during the design phase, it is crucial to understand both the data structure of the IFC, which is widely used for buildings and the data structure of the assessment method used.

The complex quality of buildings is a significant concern in the construction industry. It encompasses a wide range of criteria, such as environmental quality and life cycle assessment, energy performance of buildings, durability, resilience, internal environment quality, architectural and functional quality, and social issues. Rating systems and assessment methods are effective, inspiring, and motivating tools in the design process to achieve complex building quality. However, the complexity of the rating systems and the many criteria and parameters required for the assessment presents a challenge in finding new ways to automate the process. By connecting BIM, which serves as a structured database of building parameters, with data workflows linked to the assessment scheme, it is possible to create an efficient tool for complex building quality assessment (Růžička et al., 2022).

Cluster 4 is identified in yellow with 19 keywords. The keywords such as artificial intelligence, automation, cost estimation, facilities management, information management, machine learning, progress monitoring, and risk assessment demonstrate *automation* in general.

- **Cluster 5: Information Technology**

Today, information technology applications are effective from the design phase of a project to the entire life cycle. BIM (Building Information Modelling) is a technology that enhances communication between architecture, engineering, and construction sectors, covering a process that includes design, construction, and facility management. Due to evolving needs, traditional construction management and project delivery processes have changed, and information technology

applications have entered our lives to be used throughout the life cycle of a project.

BIM is not just a technology but a process rich in information and centered on models. It can revolutionize project delivery and bring value to the entire life cycle of infrastructure assets, including planning, designing, building, and managing. BIM is a system of knowledge about how things are constructed. The technology enabling BIM gives it the potential to transform the construction industry. This technology allows for the creation and utilization of intelligent 3D models, connecting all project parties and stakeholders, enabling collaboration and seamless data flow about the design and construction process in a manner that the construction industry has never experienced before. (BIM for infrastructure the impact of today's technology on BIM, n.d.).

Cluster 5 is shown in purple in Figure 6. There are 17 keywords in the cluster, such as big data, blockchain, digital twin, internet of things, and iot that can be titled *information technology*.

- **Cluster 6: Interoperability & Collaboration**

From the planning stage of the building, many stakeholders (such as architects, engineers, contractors, owners, etc.) work together throughout the entire life cycle. The communication through which they exchange information is called collaboration (Ofluoğlu, 2014). According to a study by Wood and Gray (1991), collaboration occurs when a group of self-governing stakeholders in a particular field come together in an interactive process, using common guidelines, norms, and structures to address issues related to that field. Thomson et al. (2009) expanded on this definition in 2009 and stated that collaboration requires cooperation among all parties involved in creating rules and structures that benefit everyone involved. Different disciplines have different understandings of collaboration (Thomson et al., 2009, Bedwell et al., 2012). In fields related to management, collaboration is seen as a relationship structure that leads to successful management (Bedwell et al., 2012). Collaboration, closely tied to effective management, is crucial for success throughout the project lifecycle (van Gassel et al., 2014, Suprapto et al., 2015).

In Cluster 6, 15 keywords are expressed in light blue. The cluster containing the keywords data exchange, ifc, industry foundation classes, and semantic web can be analyzed under the title of *interoperability & collaboration*.

- **Cluster 7: Management**

The functions of BIM as a coordinator in a project system are comparable to those of a project manager. BIM facilitates communication among various disciplines, performs constructability analysis of project systems, calculates project costs and timelines using quantity take offs, creates a comprehensive view of projects through visualization, and fosters teamwork. These tasks are similar to those performed by a project

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manager on a larger scale throughout a project's lifecycle (Rokooei, 2015).

BIM is known for its well-organized information creation and exchange process. With numerous stakeholders involved in a project, who often have conflicting perspectives and objectives, properly managing information becomes crucial in project management. BIM provides the opportunity to improve project and information management by producing and utilizing high-quality information and represents both a challenge and an opportunity (Scheffer, Mattern, Konig, 2015).

Cluster 7 consists of 12 keywords shown in orange. These keywords involve information management, knowledge management, project management, and safety management. Cluster 7 is expressed with *management* as a title.

- **Cluster 8: Education & Integration**

Today, the use of BIM in architecture, construction, contractor and consultant offices is rapidly increasing and there is a need for graduates with the knowledge and skills to meet the needs of the industry (Arroteia et al., 2019; Tanko, Mbugua, 2021). Studies examining the evaluation of BIM in architecture education have indicated that BIM-supported virtual reality (VR), augmented reality (AR), and mixed reality (MR) are among the future research areas for both architecture and engineering education and can be applied to curriculum using various methods (Wang et al., 2018; Maharika et al., 2020)

Cluster 8 is expressed by 7 keywords in brown. In Figure 6, there are the keywords augmented reality, building information models, education, engineering, and virtual reality in this cluster. This cluster is referred to *education & integration* as a title.

The changes in the most used keywords in publications over the years are visualized in four categories in Figure 8. The categorization is made by using dark blue, turquoise, green and yellow as references.

Accordingly, specifying the keywords from the past to the present, the first category includes keywords such as; 3d, 4d, modeling, safety, rule checking, bim technology, cost estimation, information management, knowledge management, visualization, interoperability, survey, laser scanner, existing buildings, bim, simulation, ifc, parametric modeling, structural analysis, architectural design, urban planning, framework, planning, modular construction, building information models, information technologies, project management, design process, performance, design, sustainable design, collaborative design, decision making, energy simulation, parametric design, education, cloud computing, collaboration, communication, integrated project delivery, productivity, digital technologies, lean construction and ontology, building information model.

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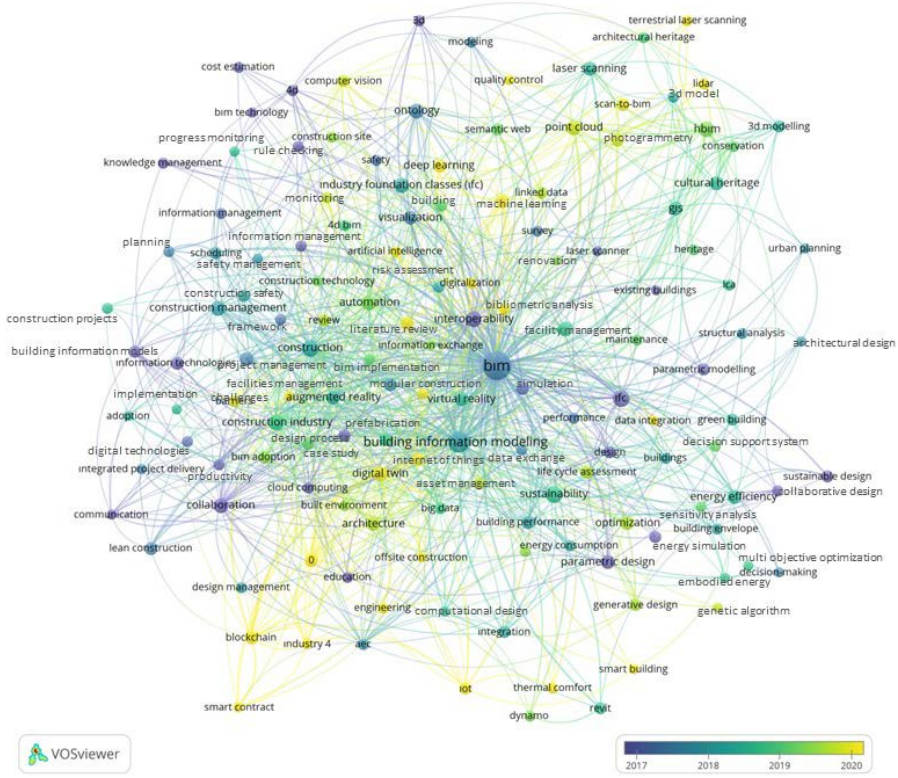

Figure 8. Change Of The Most Used Keywords Over Years

The second category consists of laser scanning, architectural heritage, 3d model, 3d modeling, cultural heritage, gis, heritage, lca, progress monitoring, semantic web, industry foundation classes (ifc), facility management, maintenance, 4d bim, risk assessment, scheduling, management, construction safety, construction management, construction projects, building information modeling, sustainability, design management, aec, revit, building performance, energy consumption, big data, data exchange, buildings, green building, energy efficiency, building envelope, adoption, implementation, prefabrication, computational design, integration, construction, safety management.

In the third category, the keywords are; hbim, renovation, conservation, building, embodied energy, multi objective optimization, genetic algorithm, generative design, dynamo, architecture, built environment, point cloud, photogrammetry, linked data, construction technology, computer vision, automation, review, construction site, bim implementation, information exchange, construction industry, bim adoption, case study, optimization, life cycle assessment, asset management, virtual reality, decision support system, energy performance, sensitivity analysis, augmented reality.

Keywords of the most recent publications include terrestrial laser scanning, barriers, engineering, lidar, scan-to-bim, quality control, machine learning, deep learning, artificial intelligence, digitalization, terrestrial laser scanning, bibliometric analysis, literature review, modular construction, facilities management, challenges, data

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integration, internet of things, digital twin, 0, offsite construction, blockchain, industry 4, smart contract, iot, thermal comfort and smart building.

When examining the changes in keywords according to the years, studies have been carried out on *digital design process, management, design optimization & performative studies & sustainability, interoperability & collaboration, and architectural heritage & conservation*. Currently, studies are frequently being carried out on integrating *automation and information technology* with BIM. It is believed that this is because various technologies can provide new solutions by integrating with BIM. Although there is a need for academic studies in the field of *education & integration*, it is stated that the least amount of research has been conducted in this area.

The Most Cited Publications Published Between 2017 And 2022

Finally, the most cited 10 publications between 2017 and 2022 among all analyzed sources were examined in the study. In Table 6, 9 out of 10 publications were published in Automation In Construction journal. 6 of these publications are reviews, 2 of them are scientometric and 1 of them is bibliometric analysis. In line with the results, it can be concluded that these studies on BIM tend to determine the potential study areas. On the other hand, Zhong et al. (2017) propose a BIM platform with the Internet of Things to achieve real-time visibility and traceability in prefabricated buildings with a case study. When the conclusion parts of the publications are examined, it is stated that the most researched topics recently are the development of BIM tools, the research of the adoption of BIM worldwide, energy simulation using BIM-based information, semantic web technology, ontology, interoperability, mobile and cloud computing (Zhao, 2017; Santos et al., 2017). According to these publications, potential fields of study were evaluated as optimization, collaboration, interoperability, and information technology (Tang et al., 2019; Guo et al., 2017; Pauwels et al., 2017). Academic case studies have been found to be rare to observe current practices and developments (Pärn et al., 2017).

Table 6. The most cited publications between 2017-2022

Publications	Citations
Critical Evaluation Off Offsite Construction Research: A Scientometric Analysis Hosseini, Mr, Martek, I, (...), Chileshe, N. 2018 | Automation In Construction 87, Pp.235-247	170
A Scientometric Review Of Global Bim Research: Analysis And Visualization Zhao, Xb. 2017 | Automation In Construction 80, Pp.37-47	162
Critical Review Of Bim-Based Lca Method To Buildings Soust-Verdaguer, B., Llatas, C., Garcia-Martanez A. 2017 | Energy And Buildings 136, Pp.110-120	158
Building Information Modelling (Bim) For Green Buildings: A Critical Review And Future Directions Lu, Yj, Wu, Zl, (...), Li, Yk. 2017 | Automation In Construction 83, Pp.134-148	154

The Building Information Modeling Trajectory In Facilities Management: A Review Parn, Ea., Edwards, Dj, Sing Mcp. 2017 | Automation In Construction 75 , Pp.45-55	145
A Review Of Building Information Modelling (Bim) And The Internet Of Things (Iot) Devices Integration: Present Status And Future Trends Tang, S, Shelden, Dr, (...), Gao, Xh. 2019 | Automation In Construction 101, Pp.127-139	139
Bibliometric Analysis And Review Of Building Information Modelling Literature Published Between 2005 And 2015 Santos, R. Costa, Aa., Grilo, A. 2017 | Automation In Construction 80 , Pp.118-136	131
Prefabricated Construction Enabled By The Internet-Of-Things Zhong, Ry, Peng, Y, (...), Huang, Gq. 2017 | Automation In Construction 76 , Pp.59-70	131
Visualization Technology-Based Construction Safety Management: A Review Guo, Hl, Yu, Yt; Skitmore, M. 2017 | Automation In Construction 73 , Pp.135-144	123
Semantic Web Technologies In Aec Industry: A Literature Overview Pauwells, P., Zhang, Sj., Lee, Yc. 2017 | Automation In Construction 73 , Pp.145-165	122

RESULTS, DISCUSSIONS AND FUTURE STUDIES

In this study, a bibliometric analysis of published documents was conducted to determine how researchers collaborate at the intersection of BIM and architecture and where the gap and potential are in the field. Data from 3997 publications that include keywords "Building Information Modeling" or "BIM" in the research area of "Architecture" or "Construction Building Technology" has been examined. The relationship between BIM and architecture over time was mapped, visualized, and described by analyzing the published data in depth and using keywords and a collaboration network analysis. Number of publications and citations by year, research areas, document types, publication titles, number of publications by country, author and co-authorship analysis, number of documents and citations by universities and keyword analysis are interpreted, respectively. The most cited 10 publications between 2017-2022 were determined and their contents were examined to observe research trends. The findings of this study will enable researchers and practitioners to benefit for future studies.

The results are as follows:

- Between 1993 and 2023 (until February, when this study was conducted), most of the publications were made in 2022. There has been an increase in the number of publications on the subject investigated from 1993 to the present day. The periods in which the number of publications increased the fastest are between 2015-2016 and 2018-2019. 2022 is also the year that has the highest publication numbers. This statement indicates that the topic is currently in the field being worked on. Therefore, it is important to identify existing gaps in the area, which is the purpose of the study.
- Other fields in which publications fall within the range of topics apart from architecture and construction building technology are engineering, computer science, science technology, materials

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science, energy fuels, urban studies, remote sensing and imaging science photographic technology. It is possible to say that engineering field involves most of the publications. Thus, this field is mostly suitable for more technical studies.

- Most of the 3997 analyzed publications are in the type of article or conference proceedings. This situation proves the current existence of the issue as the latest studies are presented as conference proceedings before converting into articles.
- According to the number of publications, nine of the top ten references are journals and one is a proceedings paper. BIM is a technology and process encompassing technical subjects such as optimization in design and construction, management processes in architecture, so it can be stated that journals working in this field are primarily listed in the article.
- Approximately 20% of the reviewed publications were published in the journal Automation In Construction because it is a subject that entirely fits the journal's scope. Apart from this, other references also publish on technical issues. It is worth mentioning that the list did not include any journal or conference that specifically focuses on architecture.
- When the number of publications is analyzed by country, China and America are in the first two places among the countries that publish the most on the researched subject. The reason for this can be a possible subject for future studies.
- The most productive 5 authors between searched years in the studied field are Cheng J., Wang X., Li H., Lu W., Luo H. and the most cited author is Wang X. 14 co-authorship clusters were identified with 48 authors. Authors who have made the most recent publications include Zhang, L., De Soto, B., Taghaddos, H., Sepasgozar, S., Xu, Z., Chileshe, N., Daniel, W., Zuo, W., Tan, Y., Chen, K., Vincent, J.; Wang, Q., Deng, Y, Herrera, R., Fan, C. For new studies on BIM, it is recommended to examine the studies of these authors working on the most recent publications.
- According to the number of documents, Hong Kong Polytechnic University, Politecnico Milano and Georgia Institute Technology are in the first three places. It was wondered what path the listed schools followed in their education about BIM. Given the need for research in the field of education, it is believed that this topic can be an intriguing area for investigation.
- For keyword analysis, 143 keywords are divided into 8 clusters. Clusters are titled according to the subjects of the keywords. These titles include; *digital design process, design optimization & performative studies & sustainability, architectural heritage & conservation, automation, information technology, interoperability & collaboration, management and education & integration.*
- Examining how keywords have evolved over the years reveals that research has been conducted in areas such as *digital design process, management, design optimization & performative studies*

& sustainability, interoperability & collaboration, and architectural heritage & conservation. Much research is being conducted on integrating *automation and information technology* with BIM, as it is believed that integrating various technologies with BIM can offer new solutions. However, despite the need for academic studies in the field of education and integration, it is noted that the least amount of work has been done in this area.

- The most cited 10 publications in the last 6 years present that studies on BIM in recent years aim to identify potential study areas.

In conclusion, recent research on BIM and architecture specifically, has identified key technologies such as laser scanning, lidar, scan-to-bim, machine learning, deep learning, artificial intelligence, internet of things (IoT), digital twin, blockchain, smart contract, smart building, etc. This demonstrates that BIM can be integrated with new technologies to address different issues and that further studies are needed. How these technologies work together is an open research topic, and studies in this scope are expected to be conducted soon. Moreover, academic studies on suitable approaches in design-construction processes and architectural education about BIM technology are limited, and there is a requirement for further research on these subjects.

Although this study contributes to the literature, it also has some limitations. First, the analysis is based on the dataset from the Web of Science database. For this reason, BIM-Architecture interaction has been reflected in the literature within the boundaries of the Web of Science database in terms of scope. Second, the analysis includes English literature using a specific set of keywords for search. A more comprehensive study can be done by adding publications in different languages.

Furthermore, this study focused on providing a broad picture of the available literature on BIM for architecture through bibliometric analysis of citation networks and less on in-depth content analysis of existing studies. Also, it would be beneficial to compare the bibliographic results of BIM research centered on architecture with other bibliographic research related to BIM. Despite this, there is a qualitative analysis of the most cited articles between 2017-2022. A complementary study to analyze the content of existing studies can provide a more comprehensive insight into research trends on the subject.

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Resume

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