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Utilizing AI for BIM An Analysis of Bibliographic Coupling and Citations Based on Country and Document

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Abstract

Cognitive and behavioral technologies are highly associated with the AECO/FM business, which means that industrial operations are generally more productive. Given these considerations, the AECO/FM sector incorporates the BIM platform to further boost productivity and complete construction projects in a safe, timely, and cost-effective manner. The AECO/FM sector benefits from ideas like artificial intelligence (AI) that provide new and rapid solutions, even though the BIM platform is compatible with a wide variety of applications and systems. The primary objective of this research is to identify patterns in the use of AI in building information modeling (BIM) studies conducted by different academics in different nations. Research on the integration of AI and BIM is surveyed using a bibliometric search, followed by scientometric analysis and mapping using document-based citation analysis, country-based citation analysis, and country-based bibliographic coupling analysis. Research on artificial intelligence (AI) in building information modeling (BIM) has been compiled by screening and analyzing papers taken from the Scopus database. The findings show that AI in building information modeling is impacted by decision support systems, genetic algorithms, neural networks, knowledge-based systems, machine learning, and deep learning. The present state and link between AI and BIM are analyzed and shown in this study, which adds to the AECO/FM literature. Hence, the results draw attention to the tendencies and voids in research on AI and BIM, and also suggest avenues for further investigation.

Keywords: Artificial Intelligence (AI), Building Information Modelling (BIM), Scientometric Analysis, Scientometric Mapping

1. Introduction

Site accidents, inaccurate complicated schedule and cost planning, mistakes due to poor planning, and a lack of teamwork are just a few of the many challenges that construction projects encounter. Architects, engineers, contractors, operators, and facility managers (AECO/FM) have used building information modeling (BIM) to tackle these challenges. When it comes to the AECO/FM industry's usage of computer-aided technology, BIM takes a completely different tack in terms of design knowledge and methodology. In order to achieve more efficiency, less waste, and shorter project durations, building information modeling (BIM) must be integrated into all aspects of a construction project. From inception to finalization, every project follows a predetermined path called a project lifecycle. As time goes forward, more and more AECO/FM companies are using BIM. The outcome has been a shift in the approach to facilities management and the delivery of the construction project [1]. In this way, the BIM platform facilitates administration and interoperability while also delivering rapid solutions. Products, systems, or business processes may cooperate to complete a shared task when they are interoperable [2]. But, a solid work plan and procedures are necessary for BIM to provide correct results [3]. In order to provide more automated and quicker solutions, the BIM platform should be connected to emerging technologies like the internet of things (IoT), immersive technologies, artificial intelligence (AI), and machine learning.
The goal of artificial intelligence (AI) research in computer science is to create systems that can learn and perceive the world as humans do, as well as store and retrieve large

amounts of data. With its focus on improving ICT and RT, artificial intelligence (AI) is a significant field of technology that supports everyday social life and activities. A.I. builds intelligent beings with perception, goal-setting, and environmental awareness. It advances in a regular pattern and accomplishes its aims via analytical and intuitive actions. Due to its usefulness in solving a variety of technical and scientific challenges, artificial intelligence (AI) research has been on the rise since the middle of the twentieth century. Classification of large datasets, model explanation and interpretation, and visualization are all areas where AI systems excel during the deep learning phases. Access to this area is provided by information theory, which explains and interprets how to change the problems between these models. Probabilistic programming, optimization, data compression, and automatic modeling occur with this access. Data science, machine learning, and cognitive science all contribute to this area. Analyzing, cleaning, converting, and modeling data are all parts of scientific data analysis, which aims to uncover valuable information, explain the outcomes, and help decision making. The field of study known as "machine learning" focuses on the study and development of algorithms that can learn from many kinds of data, including data collected by computer sensors or stored in databases. The field of cognitive science is multidisciplinary in nature, and its primary focus is the study of intelligent systems and how they work. As a programming paradigm, probabilistic programming allows for the automated inference of given probability models. There are a variety of choices that may be considered when trying to maximize or minimize certain functions with respect to a set. If you want your data to take up less space, you may compress it by altering, encoding, or converting its bit structure. In order to find three nonlinear dynamic benchmark processes, an automated model generation approach is used. Correct strategic decision-making, improved risk management, and new innovations are all possible outcomes of big data analysis when done properly. The field known as "data mining" focuses on discovering actionable insights within massive datasets. The recording medium is an integral part of digital storage technology, which employs computer components to safeguard digital data. Data science encompasses a wide range of disciplines that work together to extract value from both organized and unstructured data sets via the use of scientific methodologies, procedures, algorithms, and systems. The term "knowledge-based engineering" (KBE) refers to software that can build or query databases of information. One approach to reasoning that mimics human thought is Fuzzy Logic (FL). Inspired by the way the human brain processes information, artificial neural networks (ANN) are a kind of information technology. In quest of the optimal holistic solution, genetic algorithms (GE) use a survival-of-the-fittest principle in a complicated multi-dimensional search space, much like the natural evolutionary process. One way to prepare data for usage in an unfamiliar context is via a learning algorithm. Adopting a system to perform a certain input-output transformation job is the main objective. Language, computer programming, formal logic, and semiotics are all areas that fall within the purview of semantics, a branch of philosophy and language study. Words, phrases, signs, and symbols are examples of indicators; the things they represent and the connections between them are also indicators. Efficiency gains have been the primary goal of AI implementations in the AECO/FM sector. Improving the building process to save project resources by creating plans, maps, and blueprints with the use of autonomous, environment-aware equipment that surveys the site and gathers data. AI is also used for job monitoring and control, best-alternative selection, process and result optimization, and system and equipment automation [4,5, 10]. Dangerous and perilous conditions may also be tackled by robots improved with AI and machine learning. When it comes to building and running the facility, IoT integrated technologies provide safer and more efficient procedures.

With the advent of building information modeling (BIM), the AECO/FM sector underwent a sea change, and now it can include AI-powered innovations like the ones listed above. Computational research fields including data science, digital storage, big data, and data mining may help the AECO/FM business tackle the digital data problems that arise in modeled projects. The AECO/FM sector makes use of AI in project planning tools and analyses of construction designs. Semantics, genetic algorithms, learning algorithms, neural networks, fuzzy logic, knowledge-based engineering (KBE), and other AI methodologies' tools are also a part of it. With the help of AI, a wide variety of designs and project submissions may quickly get results, and the field offers a wealth of alternative alternatives. Improvements to the planning, building, maintenance, and operating procedures are possible because of these options. The AECO/FM sector has been slow to embrace digitization. Nevertheless, have the ability to provide industry-leading solutions. Benefits may be achieved via the integration of AI algorithms into the BIM platform for construction applications. This paper reviews the existing literature on artificial intelligence (AI) in building information modeling (BIM) and offers key research directions for the AECO/FM sector, including a review of recent developments, recommendations for further study, and analysis of existing data. Smart energy systems[8], Internet of Things (IoT) integration[6], Historical Building Information Modeling (HBIM) [7], safety, decision support systems[9], and countless more [10] are just a few examples of the practical AECO/FM industry activities that have already incorporated AI on the BIM platform.

2. Methodology

This article uses bibliometric search, scientometric analysis, and mapping to survey and comprehend the current state of AI use in building information modeling (BIM) studies conducted by academics in the AECO/FM sector across nations. To back up the claims made using natural language processing on the data collected from articles in the bibliometric search, which were then used in the scientometric analysis and mapping method to conduct an empirical analysis of the relevant literature, the bibliometric search and scientometric analysis and mapping method were chosen. Utilizing document-based citation analysis, country-based citation analysis, and country-based bibliographic coupling analysis, the scientometric analysis was conducted. There is currently no tool available to reliably merge data collected from several databases, hence it is recommended to do the bibliometric search in a single database. Consequently, Scopus, a leading search engine for academic research outputs, was used to conduct a bibliometric search of AI and BIM papers. Other databases that are well-known, extensive, inclusive, and widely-used also exist. On the other hand, compared to other sources, the Scopus database includes a greater number of journals and articles [11]. The Scopus API has a search mechanism that use Boolean Syntax to narrow the search by combining operators with keywords, resulting in aggregated and relevant results. Research policies and procedures may be assessed via the use of bibliometric data using scientometric mapping, which is an aspect of scientometric analysis [12]. In order to illustrate the structural and dynamic features of a research area, scientometric mapping defines the links across domains, publications, and disciplines [13]. VOSviewer is a popular tool in scientometric research for visualizing big networks using text mining and natural language processing methods [14]. Using bibliometric data collected by grouping and sequencing combinations of things like documents and countries, this study entails scientometric mapping and analysis. It examines the AECO/FM industry's use of AI in building information modeling (BIM) via visualisation, computation, analysis, and exploration. The Boolean Syntax, in conjunction with the combination of terms shown in Figure 1, was used to conduct a bibliometric search in the Scopus database. The investigation has yielded 199 findings. After further filters were applied, such as those pertaining to the English language and certain scientific fields, the total number of files was reduced to 195.

{artificial intelligence} OR {AI} AND {building information modelling} OR {building information modeling} OR {BIM} OR {building information model} (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA, "MATE") OR LIMIT-TO (SUBJAREA, "ARTS") OR LIMIT-TO (SUBJAREA, "MULT"))

Figure 1. Bibliometric search input

The VOSviewer software was developed to generate and display scientific measurement results and maps by utilizing natural language processing algorithms based on keyword, journal, author, and document data. In this research, the VOSviewer software was used to analyze and calculate Scopus data using for AI in BIM research. Country-based citation analysis was done to reveal the links of the countries in which the articles were prepared. The minimum number of documents of a country was set to 5, and the minimum number of citations of a country was set to 1. The threshold was reached by 13 countries out of 41. Country-based bibliographic coupling analysis was performed to indicate common references in articles of countries. The minimum number of documents of a country was determined as 5, and the minimum number of citations of a country was set to 1. The threshold was reached by 13 countries out of 41. Document-based citation analysis was done for published articles and trends of the articles and their belonged cluster was determined. The minimum number of citations of a document was determined as 19 The threshold met by 12 documents out of 185.

A network of items was established in VOSviewer by natural language processing algorithms to explore the relationship between them and to organize the knowledge by using clustering methods [15]. The items were clustered by VOS clustering technique and color-coded in Figures 2, 3, and 4. The color of an item symbolizes the cluster to which it belongs. The clusters are presented in Tables alongside their constituent items (country, document). There can only be one link between two items. The strength of a link is denoted by a positive value. The lower the strength, the weaker the link; the higher the strength, the stronger the link. The strength of a link represents the number of papers in which two items occur together. The meanings of the column headings in Tables are explained below.

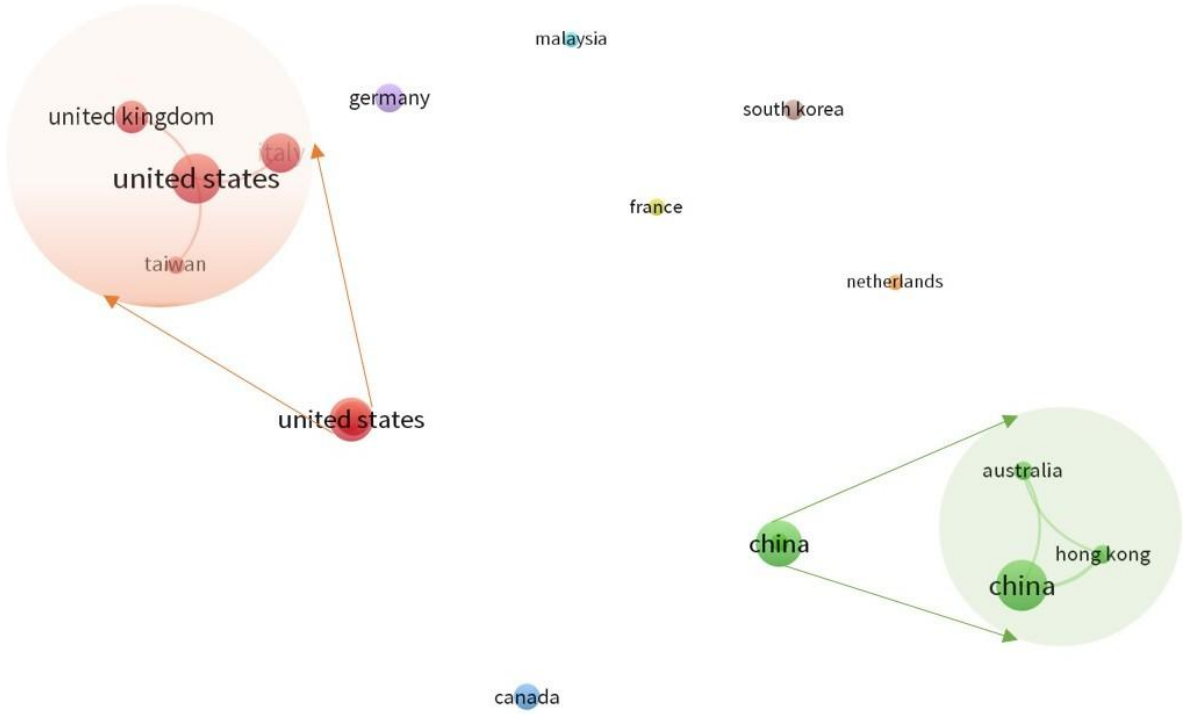


Figure 2. Network visualization map of the country-based citation analysis of AI in BIM research (detailed visual representation of linked countries was zoomed in).

• The number of links between a keyword and other keywords represents the relatedness between the keywords.

• Total link strength demonstrates the strength of the relationship between keywords.

• Average publication year of the papers in which a keyword occurs displays the chronology of a keyword's appearance in the related literature. The more recent the average year published, the newer the keyword is and so is the research subject.

• Average citation represents the total number of citations received by all the papers in which a keyword occurs, divided by the number of papers in which this keyword occurs.

• Average normalized citation indicates the average of the normalized citation for all documents in the set. Normalized citation is calculated by dividing the total number of citations of a paper by the number of citations of papers of the same type. The higher the average normalized citation, the higher the impact on the literature.

3. Findings

3.1. Results of The Country-Based Citation Analysis

Combining AI with BIM is a strategy that is evolving in response to research in many nations. Figure 2 displays the literature filtered by nation using VOSviewer, and the scientometric map that emerged from the citation analysis is shown in Figure 3. Eight groups have emerged from the investigation. A unique color has been assigned to each of the clusters. Representing the connection between the nation pairings are the ties among circles, colors, and distance. While some of the clusters are close together, such as the red and green ones, others are more spread out. Tabulated in Table 1 are the results of the analysis. U.S., Italian, and Chinese publications on "AI in BIM research" are in that order. The total connection strength measures how well one country's research is connected to that of other nations. In terms of overall link strength valued, the US, China, and Hong Kong are the top three nations. Comparing studies conducted in these three nations reveals extensive use of cutting-edge technological resources, including computers, sensors, learning systems, information management, automation, and semantic analysis.

Table 1. The country-based citation analysis of AI in BIM research.

Cluster	*Link*	*Total Link Strength*	*Document Numbers*	*Average Publication Year*	*Average Citations*	*Average Normalized Citations*
Research Region 1						
Italy	1	1	19	2017.68	5.16	1.26
Taiwan	1	1	5	2018.20	0.20	0.11
United Kingdom	1	1	14	2016.86	5.29	1.17
United States	3	3	28	2015.68	11.68	1.41
Research Region 2						
Australia	2	2	6	2017.00	6.67	5.61
China	2	3	30	2016.53	7.93	1.17
Hong Kong	2	3	6	2014.50	32.00	2.61
Research Region 3						
Canada	0	0	12	2016.42	4.75	0.73
Research Region 4						
France	0	0	7	2015.71	3.43	0.54
Research Region 5						
Germany	0	0	15	2015.47	8.47	1.86
Research Region 6						

Malaysia	0	0	5	2014.40	9.00	1.49
Research Region 7						
Netherlands	0	0	5	2015.60	1.20	0.20
Research Region 8						
South Korea	0	0	8	2014.88	5.62	0.58

3.2. Results of the country-based bibliographic coupling analysis

The bibliographic coupling demonstrates the conflict in the reference lists. If there is a common citation in both articles, these two articles are bibliographically related. The common reference number of the two articles reflects the strength of the bibliographic match relationship between articles. In this section, bibliographic matching analysis of the countries was applied to see the bibliographic matching relations of the countries. As a result of the analysis, the network visualization map was produced (Figure 3). As seen in the analysis the 3 different colors shown on the map represent the 3 clusters formed. The links and distance between circles represent publishing relations between country couples. The data obtained as a result of country-based bibliographic coupling analysis are listed in Table 2. The total link strength value indicates the strength of the publication relationship between the two countries. The three countries with the highest total link strength value are the China, Germany, and the United Kingdom. Looking at the three most publishing countries are China, United States and Italy, respectively.

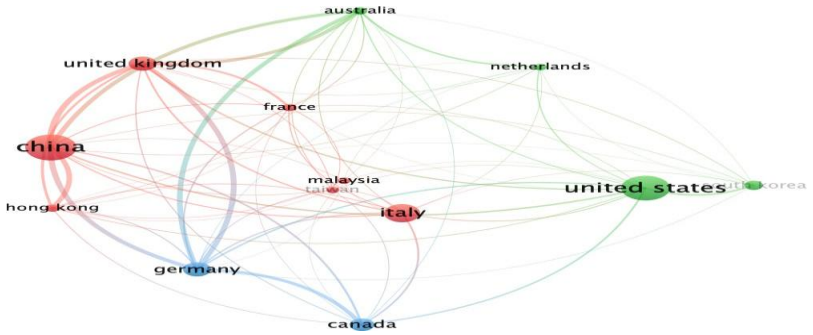


Figure 3. Network visualization map of the country-based bibliographic coupling analysis of AI in BIM research.

Table 2. The country-based bibliographic coupling analysis of AI in BIM research.

Cluster	*Link*	*Total Link Strength*	*Document Numbers*	*Average Publication Year*	*Average Citations*	*Average Normalized Citations*
Research Region 1						
China	12	903	30	2016.53	7.93	1.17
France	11	114	7	2015.71	3.43	0.54
Hong Kong	11	272	6	2014.50	32.00	2.61
Italy	12	139	19	2017.68	5.16	1.26
Malaysia	9	17	5	2014.40	9.00	1.49
Taiwan	10	44	5	2018.20	0.20	0.11
United Kingdom	11	764	14	2016.86	5.29	1.17
Research Region 2						
Australia	12	589	6	2017.00	6.67	5.61
Netherlands	9	61	5	2015.60	1.20	0.20
South Korea	9	73	8	2014.88	5.62	0.58
United States	12	229	28	2015.68	11.68	1.41
Research Region 3						
Canada	10	257	12	2016.42	4.75	0.73
Germany	12	786	15	2015.47	8.47	1.86

3.3. Results of the documents-based citation analysis

The network visualization map was obtained from document-based citation analysis of AI in BIM research, Figure 4 presents the image from the VOSviewer. The lines, colors, and distance between circles show the relationship between the documents' mutual quotes and document pairs. The size of the circle and the fonts show additive of the document to the research area. The large circle reflects that the document contributes more to the research topic. The link, citation, normalized citation and publication year data obtained as a result of the document-based citation analysis are shown in Table 3. The link values represent interconnected articles. The number of

citations explains results of the number of times the article was cited as a source in documents to be published by an author. In Table 3, the 12 documents revealed in the analysis are interconnected. The three most cited documents are "Golparvar-Fard et al., 2015" [21], “Chen et al., 2015” [20], and “Teizer, 2015” [27] (Fig. 3 and Table 3).

Golparvar-Fard et al. [21] investigates automated progress monitoring using unordered daily construction photographs and Industry Foundation

Classes-based (IFC-based) building information models. This study shows a new automated understanding of the recognition of physical progress according to the two main sources of information that have emerged. The first is unordered daily construction photo data, collected almost free of charge at all available construction sites. The second is the BIM designs, which are increasingly becoming the binding components of architectural, engineering and construction contracts.

Chen et al. [20] investigates the relation between bridging BIM and building and provides a conceptual structure for bridging the BIM and the building, which emphasizes the importance of real-life information synchronization. The prepared structure is presented in more detail with the prefabricated residential construction in Hong Kong.

Teizer [27] studies the status quo and open challenges in vision-based sensing and tracking of temporary resources on infrastructure construction sites. This study provides an overview of the vision-based sensing technology available for resource monitoring in infrastructure construction sites. Second, it provides research applications by highlighting the case study. Third, it opens a discussion about the current advantages and limitations of visual perception and monitoring.

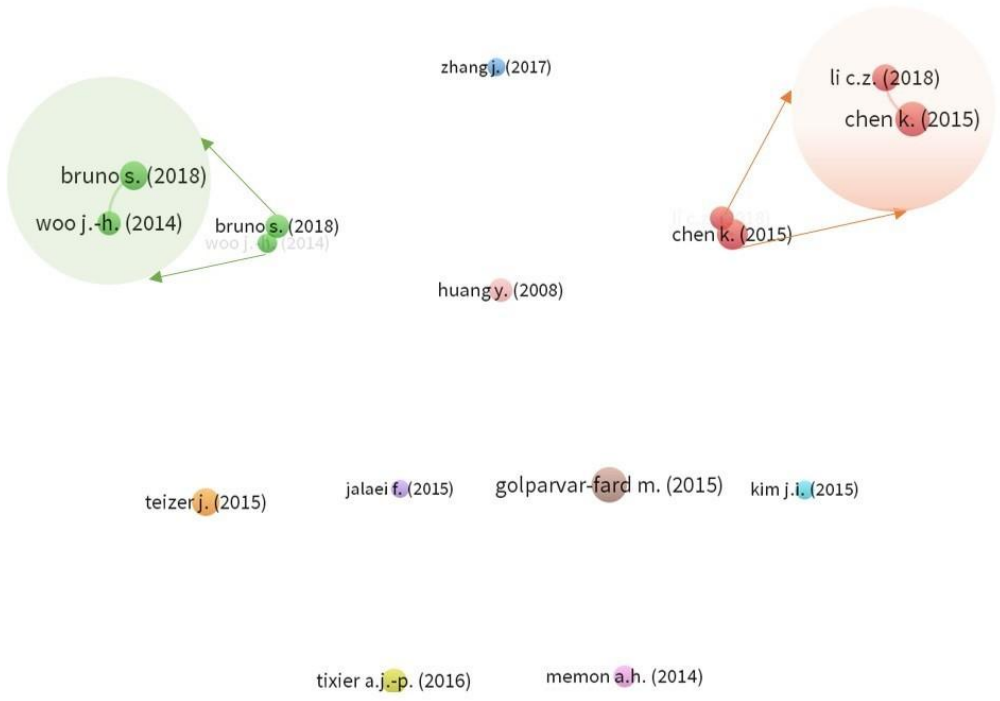


Figure 4. Network visualization map of the document-based citation analysis of AI in BIM research.

Table 3. The document-based citation analysis of AI in BIM research.

Documents	*Link*	*Citation*	*Normalized Citation*	*Publication Year*
Bruno et al., 2018 [31]	1	41	7.88	2018
Chen et al., 2015 [32]	1	81	3.03	2015
Golparvar-Fard et al., 2015 [33]	0	117	4.37	2015
Huang et al., 2008 [34]	0	40	1.67	2008
Jalaei et al., 2015 [35]	0	21	0.78	2015
Kim et al., 2015 [36]	0	24	0.90	2015
Li et al., 2018 [37]	1	42	8.07	2018
Memon et al., 2014 [38]	0	33	4.12	2014
Teizer, 2015 [39]	0	59	2.20	2015
Tixier et al., 2016 [40]	0	47	7.66	2016
Woo et al., 2014 [41]	1	26	3.25	2014
Zhang et al., 2017 [42]	0	21	6.52	2017

4. Discussions

BIM model development and intervention require multiple software use and integration. Considered as a for the AECO/FM sector, the BIM model necessitates better system integration. Research on artificial intelligence in building information modeling (BIM) is attracting a lot of attention from academics because of the potential impact it might have on the rate of BIM adoption in the AECO/FM sector. Rapid advancements in BIM model technology have been driven by stakeholder requirements, and as a result, ideas like AI are now a part of more and more BIM models in the AECO/FM business.
At the moment, computer-aided design is where most BIM studies are concentrated. The AECO/FM sector places a premium on the BIM model's evolution from a 3D data repository to a nD multi-information platform. Given its significance, it is expected to provide results in AECO/FM industry management-based research, since cognitive technologies have been used in construction project management as of late. In project management, the integration of AI technologies with the BIM model becomes very intriguing. Project information is better used all through a project's life cycle when building information modeling (BIM) is integrated with real-world, real-time building data. Accordingly, AI integration, such as the use of IoT sensors, may make the BIM model and the integration of building information a reality.

Research in building information modeling (BIM) focuses on information processing and IT studies that examine

AI integration via interoperability [11]. Thanks to these advancements in integrability, GIS integration is now available.

that are extensively used in the BIM model in conjunction with deep learning algorithms. The emphasis of recent studies has been on the use of information for decision-making systems, and the created models have been helpful in this regard. Smart building designs that reduce energy consumption have been appearing more often in recent publications, which is a direct result of the building automation made possible by the AI integrated systems of the BIM model [16].

5. Conclusion

In this study, it is aimed to reveal the scientific tendency related to the AI in BIM research and to explain the research orientation in different countries. Combining and developing AI and BIM research areas reduces cost, time, and increases productivity [16]. Therefore, a scientometric analysis and mapping of bibliometric data have been done by country-based citation analysis, document-based citation analysis, and country-based bibliographic coupling analysis thanks to VOSviewer software. As seen in the analysis of the countries, 8 regions were revealed. There are 12 documents found as the result of document-based citation analysis. The analysis revealed that interconnected documents study in similar areas and 8 independent documents contain publications from different specialties. The idea of the integrated operation of BIM and AI is the idea of creating intelligent systems that can help learn and solve problems quickly. In the AECO/FM industry, AI provides advantages to deal with complex engineering, management, and implementation issues, unlike solutions based on traditional computing and design methods [4, 5, 6, 7, 8, 9, 10, 16, 17, 18]. As a result of these advantages, it aims to solve many problems faster by integrating into the BIM platform throughout the design, construction, operation, and facility management processes throughout the project life cycle. In many countries, mainly China, the USA, and Italy actively use BIM and AI with a processable structure

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