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Investigating AI Applications in Construction Industry: A Systematic Review

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Abstract

Artificial Intelligence (AI) has become popular in all industries recently and provides numerous opportunities by simulating human intelligence processes. As a mainstream technology of an inevitable digital transformation in Industry 4.0, AI applications are hot research topics to deal with the different problems of several industries. The construction industry is no exception, but its main characteristic is resistant to new technologies and innovations. However, the construction industry has several challenges such as being a highly competitive arena, abundant participants, high financial risk, long-term periods of projects, and uniqueness of projects. Therefore, its productivity and performance growth level show relatively a poor increasing trend. This study aims to examine the contributions of AI to handling these challenges by performing both bibliometric and scientometric analysis using the PRISMA protocol. In this regard, this study presents the current state of adapting AI in the construction industry and its future directions.

Keywords: Artificial Intelligence; AI; Bibliometric Analysis; Construction Industry; Scientometric Analysis.

1. Introduction

Construction is a globally noteworthy industry that employs millions of people and contributes massively to the GDP of individual nations and the global economy (Shawney et.al., 2020). On the one hand delays, cost overruns, rework, safety issues, miscommunication problems could not be coped with by the industry professionals sufficiently (Ajmal et.al.,2022; Abioye et. al. 2021; Egwim et.al. 2021) On the other hand, the complexity of buildings (Amen & Nia, 2020Amen, 2021, Aziz Amen, 2022, Amen et al., 2023)has been increasing in the era of Industry 4.0 as being smarter, more sustainable and cost effective, the need for improving the construction processes arises drastically.

The implementations of Artificial Intelligence (AI) has been expanding rapidly in various industries since it has the potential to provide solutions in uncertain and complicated conditions (Owolabi et al., 2022; Eber, 2020). In the McKinsey Global report dated 2022 within all sectors AI adoption globally is 2,5 times higher than 2017 (URL 1). Essentially, this is mostly associated with technological advancements such as increased data volumes, advanced algorithms, and improvements in computing power and storage. AI has brought revolutionary results in improving labor efficiency, reducing labor costs, optimizing the structure of human resources (Duan et. al., 2019). Moreover, AI technologies provide practicality, applicability and fastness in figuring out engineering problems (Momade et. al.,2021).

As many researchers pointed out that the construction industry is one of the least digitized sectors (Abioye et al., 2021; Shawney et.al., 2020; Newman et.al. 2021) Bosch-Sijtsema et. al. (2021) in their study on hype factor of digital technologies stated that it is likely to expect the construction industry will enter the different phases of the Gartner hype curve later compared to other industries. Young et. al. (2021) pointed out the essential technologies that will affect the construction industry in a short time as; information communication technology (ICT), internet-of-things (IoT), big data analytics, blockchain, and AI. Besides, some previous studies mentioned about the valuable potentials of AI but its application in the construction industry globally is still limited (Boileau, 2019). However, there are restricted number of review studies that search for the causes for the low-degree AI implementations in the construction industry (Regona et. al., 2022). Moreover, obviously there are indeterminate territories in the research tendency of AI implementations, future potentials to utilization in the construction industry (Abioye, 2021). Additionally, Yaseen et.al. (2020), indicated that there is a lack of understanding in the construction industry due to the lack of research and development in AI. In this context, the goal of this study is to present existing researches' approaches and focus to investigate how to utilize from AI in building design and construction processes in the industry. For this purpose, a systematic review which involves bibliometric and descriptive analyses was performed. Bibliometric analyses are useful for decoding and mapping the accumulating scientific knowledge and developmental nuances of thorough areas by making understandable of abounding unstructured data in meticulous ways (Donthu et. al. ,2022).

There are some previous review studies focusing the AI research within the construction industry in the literature. However, those mainly emphasized on the engineering and management perspective. However, this study aims to investigate the whole building construction process, which covers building design and architectural engineering along with the construction operations and management on the site and company level.

2. Literature Review

According to a report about productivity of construction industry by McKinsey Global Institute, 98% of construction projects face cost-overruns or delays (URL 2). Contractual misunderstandings, inadequate communication, insufficient risk management and poor organization were highlighted among the main contributors of productivity problems in the construction industry in the same report. Moreover, Sanni-Anibire et. al. (2022) presented that poor planning, poor site organization, delay in approvals are among the factors causing delays and low-productivity. By performing a meta-analytical review. Therefore, over time to explore the solutions for these factors the researchers showed interest in Construction 4.0 technologies, particularly AI as the manufacturing industry benefits well.

One of the earliest publications on AI within the construction industry was by McGartland and Hendrickson (1985) describing potential applications of knowledge based expert systems for construction project monitoring. Later on, the last decade the studies have increased on the usage of AI technologies to handle specific problems of the construction industry. In this direction Faghihi et.al., (2015) focused on AI as it can help the construction industry by automating operation and digitalizing processes to boost productivity, safety, and quality. Besides, Abioye (2021) put forth some applications of machine learning for safety, cost estimation, supply chain processes and risk prediction. While Egwim et.al (2021) stated that AI/ML which best explains the factors that can influence an occurrence like delay depend on its predictive features have been extensively in use within other sectors, they developed an applied AI model for predicting construction projects delay. Several studies have been conducted on cost estimation using neural network, regression or stochastic techniques, as they developed in relation to cost overruns (Shoar et. al. 2022) Accordingly, a model utilizing ML to predict engineering services' cost overruns was developed by Shoar et.al (2022). Also, Mahmoodzadeh et. al. (2022) proposed a ML model predicting cost and duration for tunnel projects.

There are also some review studies in the literature focusing on different issues in relation to the construction research area. Pan, Y., & Zhang, L. (2021) revealed that construction engineering and management benefited from AI with regard to automation, risk mitigation, high efficiency, digitalization, and computer vision. Bang and Olsson (2021) reviewed AI in construction projects between the years 2015-2020. Besides, Darko et.al (2020) reviewed the literature by retrieving data from Scopus in terms of Architecture, Engineering and Construction (AEC) industry between 1974 to 2019 August. On the other hand, Akinosho et. al. (2020) systematically reviewed the literature focusing particularly DL applications in the construction industry. From a different perspective, the present study focuses on the last ten-year construction industry AI technologies usage and research trends to be able to give a big picture.

3. Material and Methods

In order to search the literature within AI and construction industry interrelation and perform scientometric analysis the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) adopted as a part of systematic literature review. The methodology of analyses was based on descriptive and bibliometric analysis to be able to present the interrelation between AI technologies and construction industry research. Descriptive analyses presented an overview of the included publications. Bibliometric analyses were performed through Excel and VOSviewer software focusing on the co-occurrence of keywords, country-based, source and citation analyses.

Figure 1 explains the data collection process through the PRISMA approach. The literature sample was retrieved from Web of Science (WoS) database which is considered to be one of the largest peer-review databases (Aghaei Chadegani et al., 2013). Since this study focused on AI technologies in the construction industry, the rule formulated in the topic field which applies the search in the title, abstract and keywords of a publication as follows; TOPIC ("construction*" OR "construction industry" OR "building design" OR "building construction" OR "architectural engineering") AND ("AI" OR "ARTIFICIAL INTELLIGENCE" OR "ML" OR "MACHINE LEARNING" OR "DEEP LEARNING" OR "DL" OR "computer vision" OR "natural language processing" OR "NLP" OR "cognitive computing"). Selected keywords emphasize the main concepts of this study in two groups. One group is about building construction and design to describe the construction industry. The other is related to AI and its main subfields.

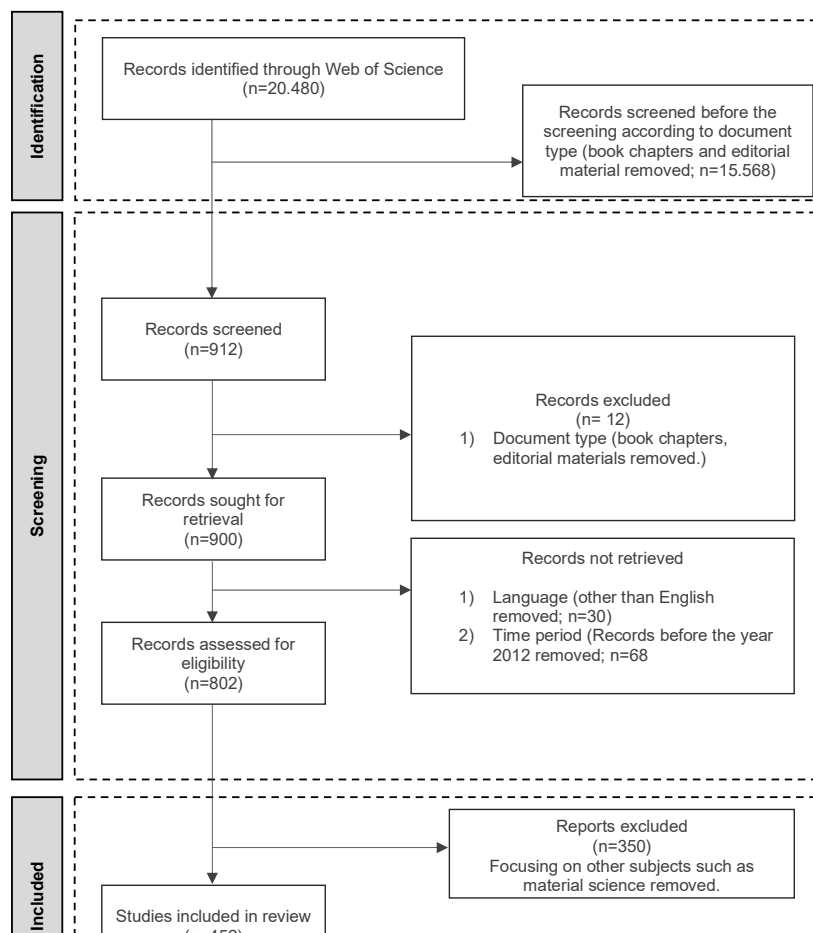


Figure 1. Publications retrieval process based on meta-analysis: PRISMA 2020 (Developed by Author)

Consequently, the first retrieval resulted in the identification of 20.480 publications from WoS since the term “construction” has usages in various other fields. To be able to reach the targeted publications particularly in relation to the construction industry, firstly WoS categories were selected as “architecture”, “construction building technology” and “engineering civil” in the identification phase of the PRISMA protocol. The number of publications to be screened defined as 912. The screening phase involved the document type filtering by removal of book chapters, book review and editorial materials. Only articles, review articles, proceeding papers and early access ones were included. The number of excluded publications were 12. The publications were continued to screened according to language, other than English language ones were excluded as 30 in number. Then, time period defined as 2012-2023; the publications dated before 2012 were eliminated. The number of publications considered was 802. The last phase was inclusion, a review of abstracts performed to eliminate the ones which were irrelevant to the aim and scope of this study. Finally, at the end of the PRISMA protocol, the search results generated 452 documents (Figure 1). The data for bibliometric analyses was downloaded in “plain text” file format from WoS. Then it was imported to VOS viewer to map and analyze the literature in relation to AI implementations in the construction industry.

4. Results

Results of descriptive and bibliometric analyses of a total of 452 publications were extracted from WoS are presented respectively.

4.1 Descriptive Analyses

Descriptive analyses of retrieved publications involve the analysis of the number of papers per year, and the analysis of publications by country of origin subsequently.

Publications throughout the years

The number of publications by year illustrated in Figure 2 showing the significant rise since 2012, it was increased by 20 times in the year 2022 comparing to 2012. In fact, the number of publications AI within the construction

domain began to increase markedly starting from 2016. As the year 2023 continues, the publications of the years 2021 and 2022 makes up the 50% of all since 2012. This strengthens the expectation of an increasing trend in the coming years.

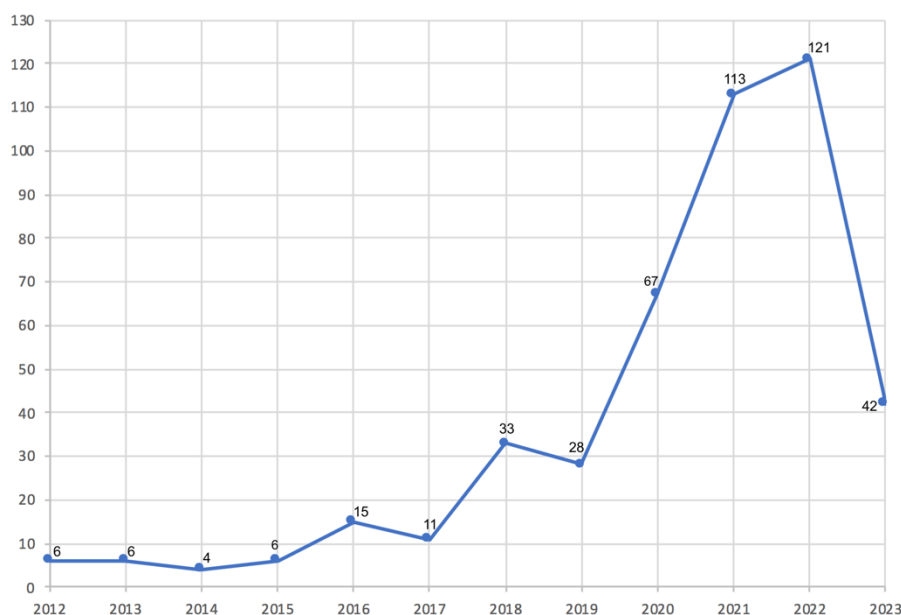


Figure 2. Number of publications per year between the years 2012-2023 (Developed by Author)

Publications by country

The number of publications per country can be seen in Figure 3 which shows the highest number of 15 countries between the years 2012-2023. Since there are countries from all over the world, a global trend can be mentioned here. China and USA are the leading countries on the research area with a rate of %28 and %23 respectively. Subsequently, Australia, South Korea and England comprises the first five with 52, 45 and 35 publications accordingly. These are followed by Canada (34), Taiwan (21), Italy (15) and Iran (12).

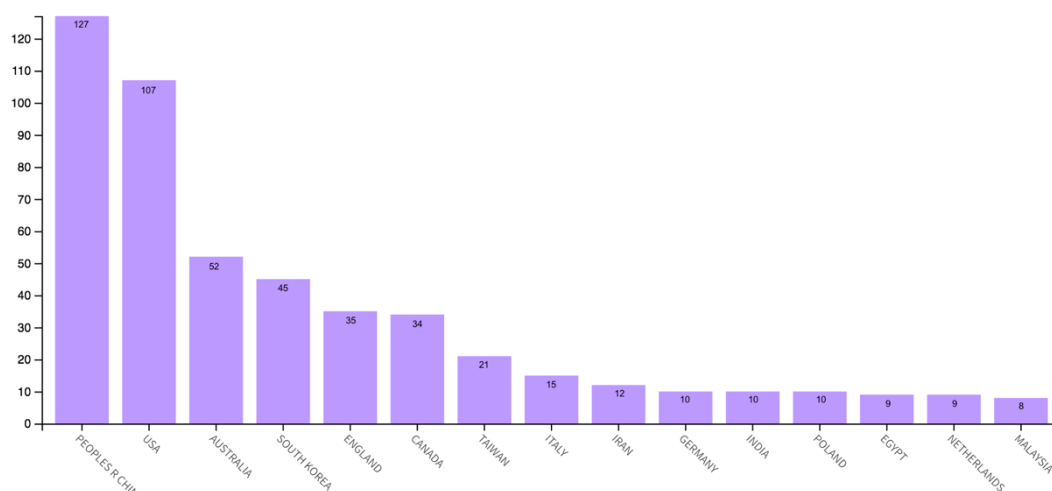


Figure 3. Number of publications by country (Developed by Author)

4.2 Bibliometric Analyses

Bibliometric analyses can build firm foundations for advancing a field in novel and meaningful ways by gaining a one-stop over-view by identifying knowledge gaps, deriving novel ideas for investigation, and positioning intended contributions to the field (Donthu et. al. ,2022). By utilizing VOS viewer which is a software tool for constructing and visualizing bibliometric networks, co-authorship of authors, co-occurrence of keywords, country based, and source analyses performed respectively below.

Country based analysis

In relation to retrieved publications, the countries and their collaborations were generated in Vos viewer as shown in Figure 6. China is the leading country in the research domain following by USA. USA and China have both linkages with each other and various countries. Next Canada, South Korea, Australia and England have dominance in the research area. Especially the bond between Canada and South Korea is strong while China and Australia have powerful link. Besides, some other countries like Taiwan, Malaysia, Germany, Iran and Italy were produced certain amount of publications in this domain. Japan, Turkey, Netherlands and Poland are among the countries producing limited number of publications. Additionally, the variety of countries from all over the world indicates the global interest

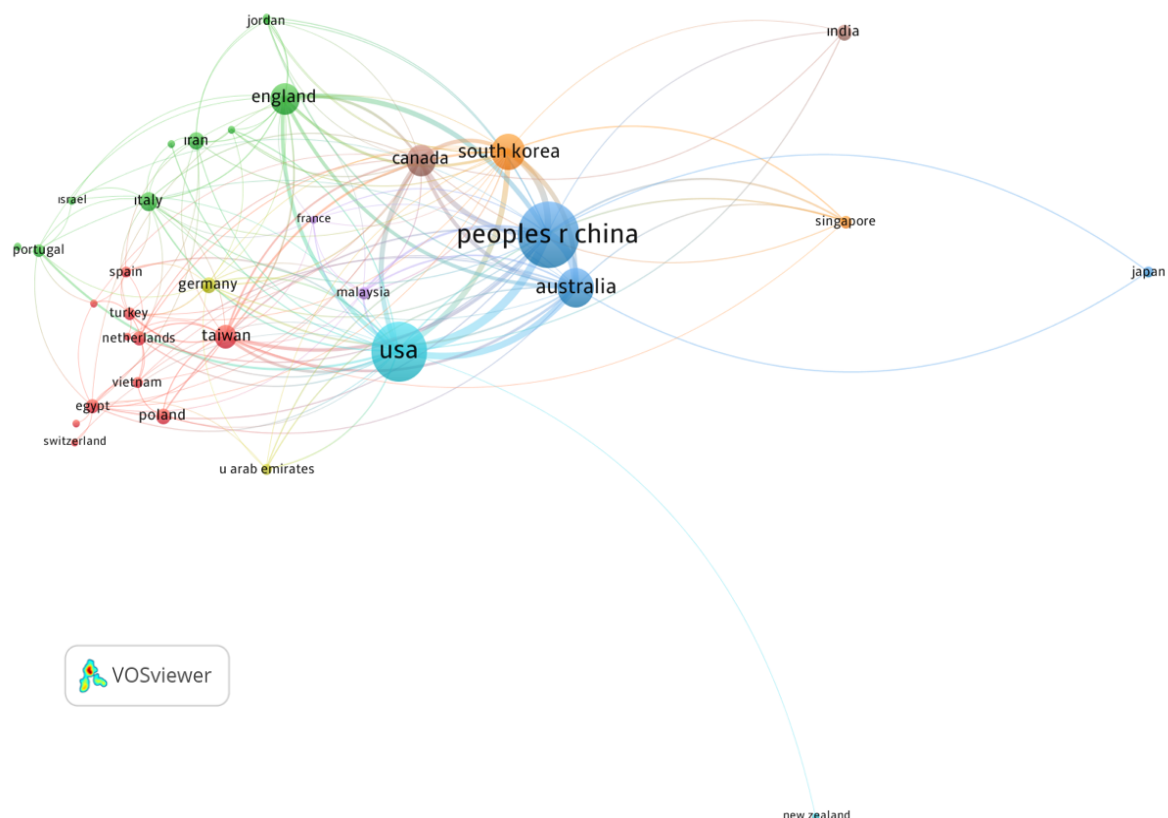


Figure 4. Country based analysis (Developed by Author)

Citation analysis and co-authorship of authors

The most cited article is on digital twin with 252 citations. Subsequently second, third and fifth most cited publications are all related to safety issues (Table 1). The fourth most cited article is a review study in construction engineering and management. The publisher of all articles in the top five cited list is “Automation in Construction”.

Table 1. Publication citation analysis.

Paper	Title	Citations
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Boje et.al. (2020)	Towards a semantic Construction Digital Twin: Directions for future research	252
Fang et.al. (2018)	Detecting non-hardhat-use by a deep learning method from far -field surveillance videos	229
Ding et.al. (2018)	A deep hybrid learning model to detect unsafe behavior: Integrating convolution neural networks and long short-term memory	224
Pan&Zhang (2021)	Roles of artificial intelligence in construction engineering and management: A critical review and future trends	189
Fang et.al. (2018)	Falls from heights: A computer vision-based approach for safety harness detection	187

As Figure 4 illustrates the co-authorship of authors, one of the most connected authors is Arashpour, M. Besides, Arashpour, M. Li,H., Ding,L., Fang,WL., Luo,H. and Chi,S. can be listed as most productive authors in the research area. Additionally, Fang, WL is the author of most second and fourth cited articles as seen in the Table 1.

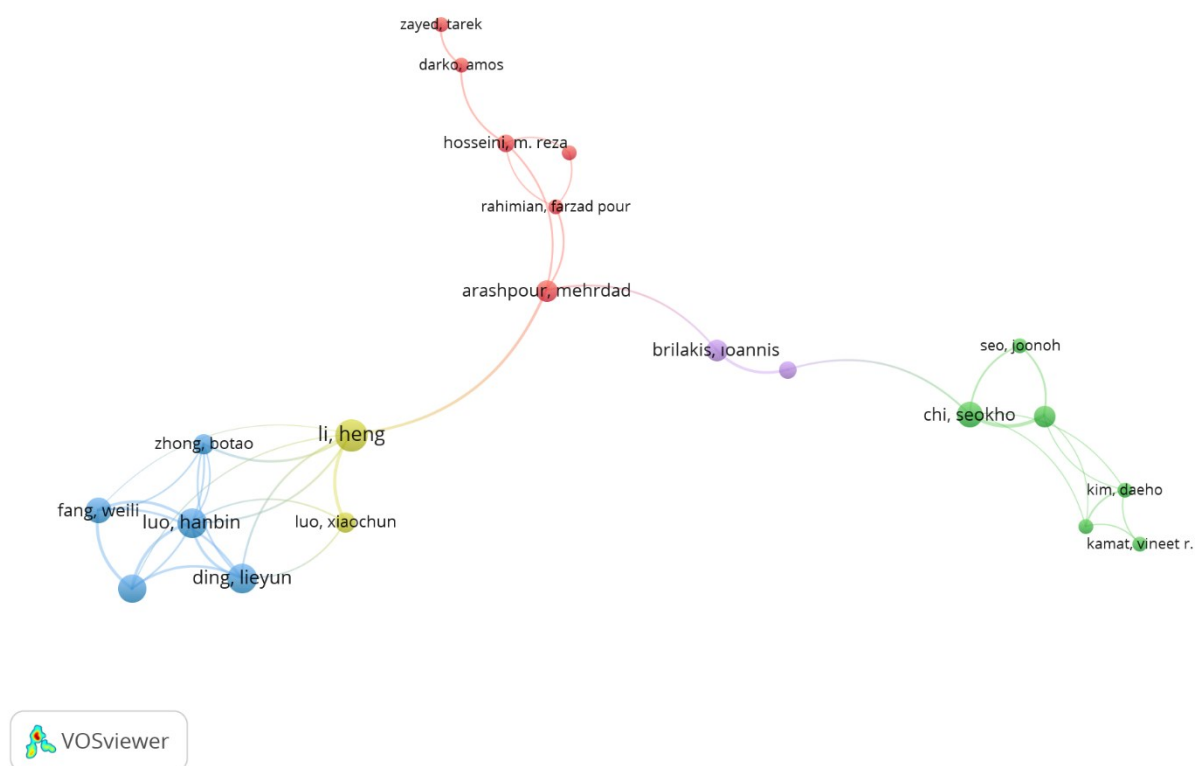
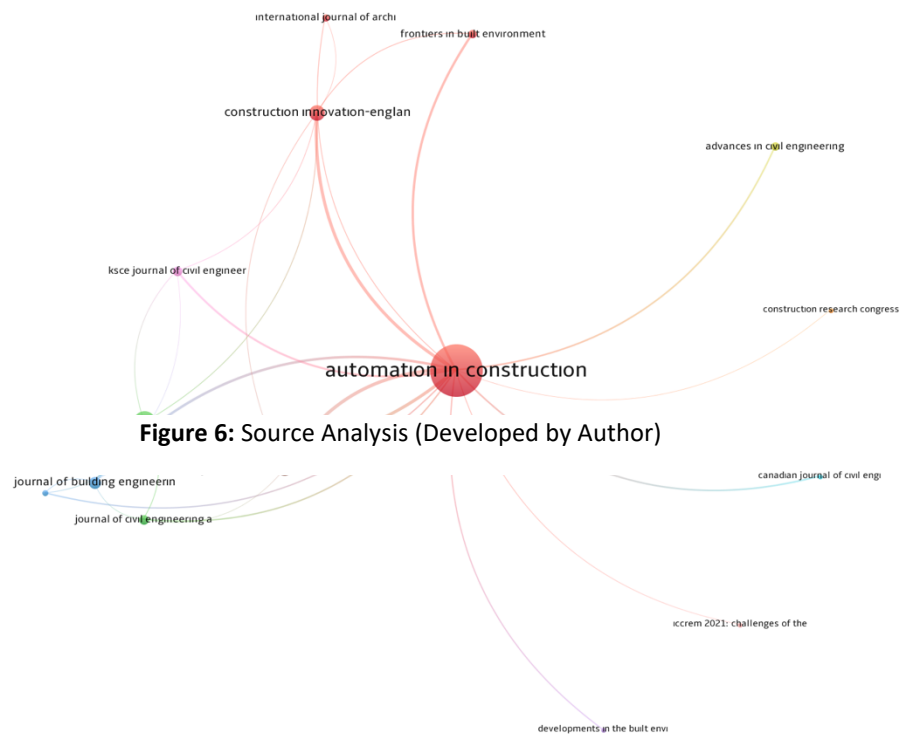


Figure 5. Co-authorship of authors (Developed by author)

Source Analysis

The source journals and conferences of the collected documents were illustrated by VOSviewer and presented in Figure7. For this analysis of published journals and conferences, the minimum number of documents and citations of a source was set in Vos viewer at 3 and 1, respectively. In total, 34 publications of 452 are products of conferences as proceedings. In the research field, “Automation in Construction” is the pioneering and the most interconnected international journal which is followed by “Buildings” and “Construction Innovation” respectively. On the other hand, “Construction research congress” and “ICCREM 2021” are the leading conferences in the domain.

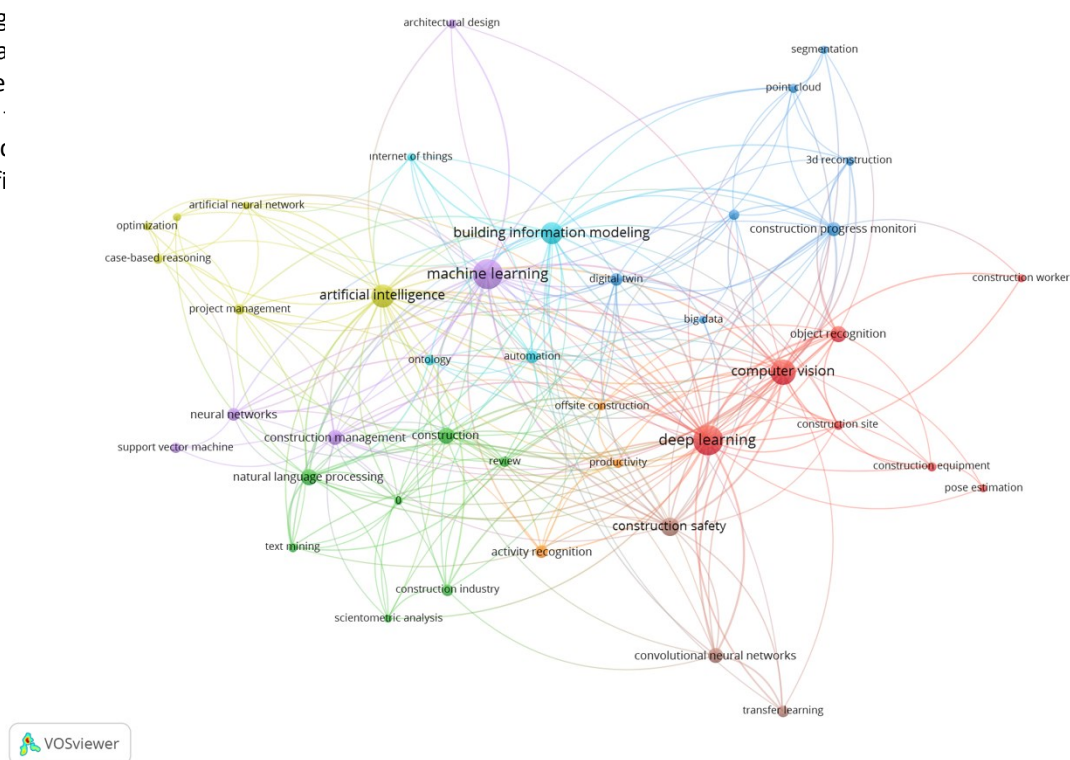


Co-occurrence Keywords Analysis

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As subfields of AI, machine learning, deep learning and computer vision have higher weights than other ones such as object recognition, activity

recognition, natural language processing and neural networks. Building Information Modeling (BIM) has considerable weight among other terms, additionally its connection with AI, ML, DL and computer vision is quite strong. Digital twin has powerful connection with ML, DL, AI and big data. Construction worker has quite strong relationship with object recognition and computer vision. The link between AI and project management is potent.

4. Discussion

This study addressed the question whether AI technologies respond sufficiently the construction industry problems to improve its productivity in the era of Industry 4.0. For this purpose, a systematic review performed for 452 publications to assess the density of them in various topics of AI technologies & subfields related implementations in the construction industry. The goal was to understand the state of researches in the domain to evaluate the potentials and future directions. The results showed that the research trend is growing exponentially globally. The construction industry has 4.1% and 6.8% of the total economic volume of the USA and China respectively (Egwim et.al; 2021). Thus, the results of this study showed that China and USA having the highest number of publications in research domain. Moreover, according to the findings there are studies from many different parts of the world, regardless of geography.

The event of AlphaGo beating the world chess champion in the beginning of 2016, caught the attention all over the world to AI (Xu, 2013), which can be seen in this study as an increase in publication numbers particularly since 2016 with 15 publications. In 2022 the number of publications increased to 121 which shows obviously a growing research interest. Previous studies mainly consist of ML based models and proposals such as the studies of Shoar et.al (2022). and Mahmoodzadeh et. al. (2022). However, in this study it is revealed that ML and DL had the highest ratios. Subsequently computer vision, NLP and neural networks are among the top AI technologies having usages in studies of construction industry in the literature. The findings of the keyword analysis revealed that the BIM and AI technologies has strong connections. Moreover, project management, construction management and construction progress monitoring are among the research areas most applying AI technologies. DL is one of the most implementing AI technology in the construction industry (Table 2). As Table 2 illustrates ML, computer vision and object recognition come after respectively.

Table 2. Interaction Matrix of construction industry research areas and AI technologies.

	Construction Management	Project Management	Construction Safety	Construction Progress Monitoring	Construction Site	Construction Equipment	Architectural Design	Construction Industry	Construction Scheduling	Modular Construction	Offsite Construction	Construction Technology	Construction Worker	Construction Equipment	Construction Project
Artificial Intelligence (AI)	X	X	X	X			X	X	X		X	X			X
Machine learning (ML)	X	X	X	X		X	X	X	X	X	X			X	
Deep Learning (DL)	X	X	X	X	X	X	X	X				X	X	X	X
Artificial Neural Network		X													
Convolutional Neural Network		X	X					X							
Neural Networks								X							X
Natural Language Processing (NLP)	X	X													
Object recognition	X		X	X	X	X					X			X	
Activity Recognition			X							X					
Computer Vision	X			X	X	X	X				X	X	X	X	
Image Processing	X			X									X		
Genetic Algorithm		X													
Text Mining	X	X	X												

Regona et. al., (2022) performed a review in construction research and showed that the major opportunity in implementing AI is to decrease the time spent on repetitive tasks by utilizing big data analytics and improving the work processes. In this manner, the results of this study indicated that construction management and project management activities are leading research subjects applying AI in the construction industry (Table 2).

5. Conclusions

This study mainly concentrated on investigating the latest research in relation to AI within the construction industry by a systematic review. The literature retrieved in May 2023 from WoS for between the years 2012-2023. VOS viewer software was utilized for the quantitative analysis to perform science mapping to comprehend and visualize the research trend of AI technologies in construction domain.

The findings of the research pointing out that there has been a dramatic increase in number of publications in the research area. China and USA are the leading countries having highest number of publications respectively. The findings showed that there is a strong linkage between BIM, digital twin, ML and DL as the most cited article is on semantic construction digital twin by Boje et.al (2020). Following next two highest cited articles are about safety issues that indicates an area of research interest in the domain. On the other hand, review papers are quite popular in the research area.

Construction industry traditional problems known to all such as delays, cost overruns, quality issues, uncertainty, high risk and safety have become hard to solve in the world of Industry 4.0 and upcoming Industry 5.0 as bringing smarter, higher technology, taller and bigger construction and buildings with sustainability point of view. Therefore, AI as a disruptive technology for many sectors, contain potentials for the construction industry to provide solutions to its unique problems.

As a future direction there is an urgent need of increase in research and development activities of the construction industry in practice. In other words, case studies on the application of specific AI technologies at construction companies or sites and feedbacks will be valuable. Buildings getting smarter day by day which arises the need of smarter construction industry. As this can be achieved by effective usage of AI technologies. This study provides an understanding of the state of current researches related to AI technologies in the construction industry.

While, AI has potentials to respond the problems of construction industry however there is a need of structured data which has not been gathered properly as a reason of fragmented nature of construction industry. Since data is the key for AI implementations, “knowledge systems” is an area to be focused by researchers as a future direction. Additionally, future research may extend this work by retrieving data from other databases such as Scopus.

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Conflict of Interests

The authors declare no conflict of interest.

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