INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 14 NO. 4 (2023) 171-193

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Digitalization of Building Site Management in the Construction Industry

Çağatay Takva[1*], Jan Cudzik[2], Zeynep Yeşim İlerisoy[3]

[1]Department of Architecture,
Atatürk University, Erzurum, 25100, TURKEY

[2]Department of Urban Architecture and Waterscapes,
Gdańsk University of Technology, Gdansk, 80-233, POLAND

[3]Department of Architecture,
Gazi University, Ankara, 06530, TURKEY

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2023.14.04.014
Received 24 January 2023; Accepted 16 October 2023; Available online 26 November 2023

Abstract: With Industry 4.0, a digital transformation has started in the construction industry. However, 4.0 technologies have difficulties in the integration of digital systems due to the diversity and complexity of the processes in the construction industry. Multidisciplinary work in architectural projects and the need for high productivity require digital renovation planning in the construction industry. The application of the technologies that emerged because of digital transformation on the building site has revealed the concept of the smart building site. Within the framework of many current issues such as the smart building site, the digital transformation on the building sites needs to be explored and defined. In this study, a bibliometric analysis was carried out on the publications in this field by evaluating the transformation potentials of the digitalized building sites of the future. Academic publications that will raise awareness in the improvement of building site management and the development of digital systems have been determined. Conceptual integrity was created by seeing the research gap for digitalization in building site management and it was aimed to guide researchers in future studies. As a result, based on the research area analysis and the diversity of academic publications, it was seen that the studies in the field of architecture were insufficient compared to the engineering fields.

Keywords: Bibliometric analysis, building site management, construction industry, digital transformation, industry 4.0, smart technologies

1. Introduction

The Industry 4.0 revolution includes sudden changes in innovative production processes where digitalization and the virtual world are at the forefront (de Almeida Barbosa Franco et al., 2022; Villalba-Díez et al., 2020; Piccarozzi et al., 2018; Maresova et al., 2018). Information transformation is important in the Industry 4.0 paradigm, where processes, systems, people, and computers interact (Alaloul et al., 2020; Sun et al., 2020; Da Costa et al., 2019; Sanghavi et al., 2019). Global value chains are transforming the industry and its structure (Qin et al., 2016). Technological innovations in information networks, sensors, devices, and machine learning are affecting manufacturing sectors by also improving robotics and automation systems (Rivera et al., 2021; Oztemel and Gursev, 2020; Fatorachian and Kazemi, 2018; Helo and Halo, 2017). The transformation environment is enriched by the repetitive

*Corresponding author: cagataytakva@atauni.edu.tr

activities of technological developments within organizations (Mosser et al., 2022; Richard et al., 2020). With the tools of the Industry 4.0 revolution, project and site managers can create sustainable and environmentally friendly designs with the information obtained in line with the possibilities of technology (Turner et al., 2021). In this context, a response to this revolution has been sought in the construction industry. For this reason, the term 'Construction 4.0' has emerged as the equivalent of Industry 4.0 in the construction industry (Kozlovska et al., 2021; Habibi Rad et al., 2021; Forcael et al., 2020). The Concept of Construction 4.0 covers the architecture, engineering, construction, and operation (AECO) industries (Chacón, 2021; Schönbeck et al., 2020; Craveiroa et al., 2019).

With Construction 4.0, real-time analyses and improvements can be made in the building site in addition to quality control, safe labour, time and cost optimization with the help of sensors (Rivera et al., 2021; Maskuriy et al., 2019). With the triple combination of building information modeling (BIM), unmanned aerial vehicles (UAV) and photogrammetry, monitoring and control can be performed at all stages of construction projects (Duarte-Vidal et al., 2021; Pellegrini et al., 2020; Saieg et al., 2018; Song et al., 2017; Merschbrock and Munkvold, 2015). The development of three-dimensional models for various applications such as intelligent monitoring of the construction process of large-scale projects, emergency aid and industrial operations, using sensors in unmanned aerial vehicles, allows multi-faceted planning in large-scale projects (Guan et al., 2022; Jacob-Loyola et al., 2021; Jeelani and Gheisari, 2021; Asadi et al., 2020; Howard et al., 2018). The adoption of advanced visualization technologies such as BIM-based virtual reality and augmented reality, together with simulation-based safety trainings and emergency management in building site activities, reduces risks and facilitates occupational health and safety management (Alizadehsalehi et al., 2020; Khan et al., 2020; Gao and Pishdad-Bozorgi, 2019; Malekitabar et al., 2016). Virtual reality (VR) and augmented reality (AR) in the AECO industry are other emerging digitalization methods (Schiavi et al., 2022; Delgado et al., 2020; Noghabaei et al., 2020; Wang et al., 2018; Chi et al., 2013). With the advancement of visualization and simulation systems, 3-dimensional printing (3DP) construction projects are also making progress (Pessoa et al., 2021; Hossain et al., 2020; Buchanan and Gardner, 2019; Tay et al., 2017). The use of digital data shows continuity and improvement with these techniques (De Soto et al., 2018). Construction 4.0 also triggers the formation of smart cities by equipping buildings with technological equipment (Chen et al., 2022).

In addition to the studies that show improvement in building site management and operation, there are also obstacles (Nagy et al., 2021; Lavikka et al., 2018). Factors such as the low ability of construction workers to apply and use technology at the building site, the high costs of special equipment, and the low willingness of industry stakeholders to accept digitalization create barriers to the full implementation of technology (García de Soto et al., 2022; Craveiroa et al., 2019; Schneider, 2018). The continuity of dynamic activities of building sites with different disciplines also complicates the digitalization process (Edirisinghe, 2019). Numerous interrelated processes, sub-processes and participating actors at different stages complicate the construction industry (Adepoju and Aigbavboa, 2021; Takva and İlerisoy, 2021; Liu et al., 2017). With this complexity, the uniqueness of projects, the time limit, the need for specialized production techniques, and the effects of weather conditions turn into an area where building sites and industry are constantly incapable of following, applying, and deriving value from digital technology (Takva et al., 2022; Begić and Galić, 2021; Lundberg et al., 2021). The challenges of digital transformation, the desire to overcome the increasing market competition even if it slows down the process, the need for cost-effective solutions, the digitized lifestyle of people, the need to improve working conditions and living environment, increasing security problems, the need for advanced and smart systems, new materials, methods, emergence of products and equipment, etc. have been the driving forces for the digital transformation (Forcael et al., 2020; İlerisoy and Takva, 2017; Lessing et al., 2015). With the driving forces of digitalization, technology has begun to enter the building site, and logistics processes characterized by the organization with digital twin technology (Opoku et al., 2021; Greif et al., 2020), information and communication technology (Monticolo et al., 2015) and construction safety inspection help ensure occupational safety in the field (Lin et al., 2014; Sev, 2009).

There are studies on digitalization in the construction industry in the literature. He et al. (2021) reviewed BIM applications for the prefabrication and design of industrial buildings and proposed a BIM approach for the digital fabrication and geometric design of modular homes. Chen et al. (2021) identified nine barriers to the digital transformation process in the service sector. The lack of knowledge in awareness, financial support, and digital transformation are some of them. Darko et al. (2020) evaluated the risk management of modular integrated constructions based on BIM in terms of surveys and future needs. Zhang et al. (2020) conducted a bibliometric analysis focusing on virtual reality applications in the built environment. Wolniak et al. (2020) conducted energy efficiency research on the Polish steel industry in the context of the development of Industry 4.0. The data of the Polish steel industry from 2000 to 2019 were analyzed with the help of softwares. Salhaoui et al. (2019) made applications in an industrial concrete factory using UAV and smart monitoring and control systems. Real-time photos from UAV analyzed and an efficient system has been created to improve product quality and reduce waste. Li et al. (2019) reviewed and analyzed the current state of blockchain technology. Blockchain-based solutions have been proposed to meet the challenges in the construction industry. Valente et al. (2019) investigated the production of concrete products in the construction industry by 3DP with extrusion-based additives. Wu et al. (2016) discussed worker-family conflict in the construction industry with a system dynamics model and simulation. Simulation results showed that family

conflict was reflected in job performance. Oesterreich and Teuteberg (2016) have linked art and digital transformation practice in the construction industry, revealing the benefits of digital transformation.

It has been observed that to frame the possibilities and challenges brought by various applications with the digitalization of smart building sites with the effect of technology, it is necessary to systematically analyze the existing studies on the digitalization of building site management and addressed in all aspects. It is aimed to reveal the general view of the studies in which the keywords are included within the scope of digitalization at the building site, to gather information about the current studies on building site management and the sub-studies studied under this concept, and to make predictions about the future of the research by revealing the digitalization study trend from the recent past to the present. The recent development of site management achieved with its digitalization can led to application of automation that could significantly increases the effectiveness of construction and limit its costs. All that can also become a an introduction to the application of claims in the field of artificial intelligence, which will allow for further increase of efficiency and reduction of mistakes related to the investment process.

2. Materials and Methods

The research was divided into five consecutive stages to ensure the integrity and relevance of the results. To search the literature and extract data, a flow chart was created depending on the methodology in the study (Fig. 1). In the first stage, Web of Science was chosen as the research database. The Web of Science database is one of the most comprehensive databases (Ali et al., 2022). Keywords related to the subject were determined in the database and necessary information was collected. In the second stage, the nature of academic publications was determined. The research was narrowed down by selecting articles, proceeding papers and reviews whose publication language is English. The analysis infrastructure of the research was completed with the selection of the subject headings. In the third stage, bibliometric analysis was performed. Keyword formation, citations by publications, article citations by country and citations by journal titles were analyzed. Evaluations were made by performing a performance analysis showing criteria such as publication year, publication by country, publication per author, publication per source, and scientific field map analysis showing the trends and approaches in the field. In the fourth stage, the effects of technological tools on building site management were discussed and innovations in the field were introduced. In the fifth stage, the results were presented on the basis of the findings.

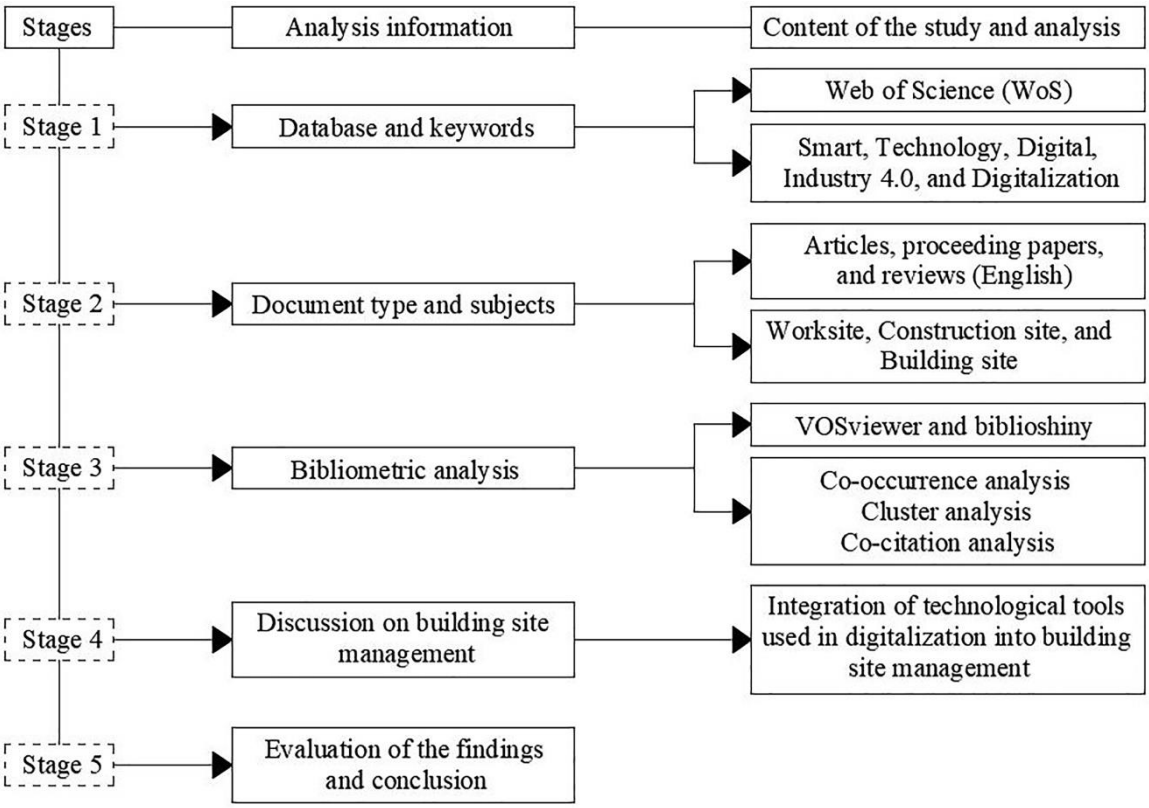

Fig. 1 - Research method and flow charts

2.1 Data Collection

The Web of Science Core Collection database is the most widely used database in bibliometric research, as it has an interdisciplinary scope and contains many scientific publications (Escamilla-Fajardo et al., 2020; Skute, 2019). The title for the search in the database consists of the keywords "smart" or "digital" or "digitalization" or "technology" or "industry 4.0", and the subject consists of the keywords "worksite" or "construction site" or "building site". There is no time limit for the publication year. Articles whose research areas did not include fields other than the construction industry (*public environmental occupational health, geology, telecommunications, geography, food science technology, electrochemistry, biotechnology applied microbiology, healthcare sciences services, linguistics, mathematical computational biology, mathematics, medical informatics, neurosciences neurology, oncology, mining mineral processing, physical geography, spectroscopy, sport sciences, water resources, government law, nuclear science technology, and rehabilitation*) were selected and manually filtered. Because of the determined criteria, 197 publications published between 1994 and 2022 were reached. It can be said that qualified academic studies on this subject have emerged since 1994.

2.2 Data Analysis

The data analysis are conducted with VOSviewer and Biblioshiny. VOSviewer program is used for visualization and Biblioshiny is widely adopted for descriptive analysis. VOSviewer is a scientific mapping analysis tool and visualization software (Zhang et al., 2022; Shah et al., 2019; Hosseini et al., 2018). Compared to other visualization software, it provides clear handling of big data and images (Donthu et al., 2020) and is used to create maps based on data (Cheng et al., 2021; Rajeswari et al., 2021). It presents the connection networks between the data and the elements by performing cluster analysis (Huang et al., 2022; Yang et al., 2019; Van Eck and Waltman, 2017). It can create networks for journals, researchers, and keywords on the basis of academic publications (Meng et al., 2020; Waltman et al., 2010). The VOSviewer program was chosen because it comprehensively includes scientometric methods such as common citation analysis and common word analysis. In the bibliometric analysis, the bibliometrix R-package was used as the second program. Biblioshiny data was obtained using this program. Biblioshiny is a version of Bibliometrix. Powered by Bibliometrix and web-based (Mougenot and Doussoulin, 2022; Fernandez-Rodriguez and Alvarez, 2021; Jiang et al., 2021; Wang et al., 2021; Aria and Cuccurullo, 2017). It works with Scopus, Web of Science, Dimensions, PubMed and Cochrane libraries. It has an organized and intuitive interface (Wang et al., 2022; Jalal et al., 2021; Nnolim and Nwodo, 2021; Li et al., 2021; Zupic and Čater, 2015). It reveals detailed map results that provide comprehensive comparisons between keywords plus and author keywords criteria (Martínez-Vázquez et al., 2021; Secinaro et al., 2020; Xie et al., 2020). In this study, the links between the most cited articles were evaluated by bibliometric analysis.

3. Findings

Bibliometrics covers the application of mathematical and statistical methods in evaluating scientific communication environments. Various findings related to scientific communication are reached by examining the characteristics of publications in bibliometric analyses. In bibliometric studies, which is one of a quantitative research methods, various determinations and inferences can be made by analyzing the publications in accordance with the determined characteristics (author, citation, keyword, publication year, language, etc.). With these determinations, the current situation of the literature is revealed, the development and problems can be determined, and the environment is prepared for the elimination of these problems in the future studies. Bibliometric analysis is an analysis method that has gained popularity recently (Donthu et al., 2021; Khan et al., 2021). It constitutes a research area where presented publications can be classified into articles, authors, and journals (Gaviria-Marin et al., 2019; Merigó and Yang, 2017). With bibliometric research, data turn into an academic structure (Ghaleb et al., 2022). WOSviewer is a pervasive bibliometric analysis tool for construction researchers (Jin et al., 2019). Analysis outputs are given under the subheadings of annual publications, publications per country, research areas, factorial terms, total number of publications on publishing platforms, authors and most cited publications, keywords and contents of selected publications. Most of the 197 articles obtained with the analysis of the determined keywords were published in journals.

3.1 Analysis of Annual Publications

The distribution of studies by years is an important parameter in deepening a subject. It can be said that this subject is a trend in the years when the publications are concentrated. In the review, which is not limited to the publication year, the first publication belongs to 1994. Between 1995 and 2008, it was seen that there were no publications in some years and the annual number of publications did not exceed one. The number of articles published after 2008 started to increase and the number of articles reached 24 in 2021 (Fig. 2). According to the publications made in June 2022, it was observed that 16 articles were published in a six-month period. The number of articles, which was 10 in 2016, increased to over 30 in 2022. The annual growth rate was 13.18%. The average number of citations per year increased

as it approached today. The average number of citations was 0.4 in 2000, 3.2 in 2010 and 7.1 in 2020. Based on the annual publications, the digitalization of the building site has started to gain importance since 2016 and is a current issue in the construction industry.

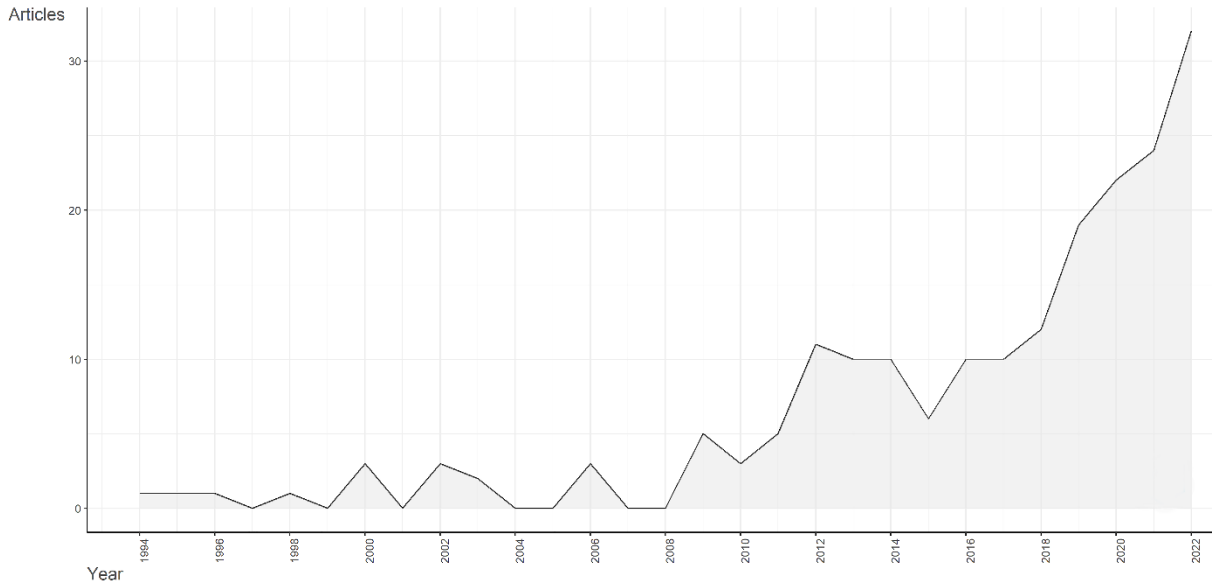

Fig. 2 - Annual scientific production

3.2 Analysis of Publications Per Country

It is important to analyze the publications by country and to understand the importance and potential of the research in the countries. In the analysis conducted according to the number of publications per country, there are studies on the subject in 36 countries. China is the country with the highest number of publications with 137 publications (Table 1). China is followed by the United States with 41 articles and Russia with 22 articles. A scientific research is built on previous studies on the subject, and each study is a part of the literature on that subject. For this reason, giving and receiving citations is a productive process in terms of ensuring the visibility of the research in the scientific environment and being a pioneer for future studies. Looking at the number of citations of countries, United States ranks first with 609 citations, China has 258 and Italy has 189 citations. The number of countries with a publication number is nine, and the countries with no citations are Denmark, Egypt, Ireland, and Spain. According to the analysis of the number of publications and the number of citations, it is seen that the digital development in the building site is given importance in technologically developed countries and scientific studies are concentrated in these areas. It has been determined that although the publications made in China are higher than the publications in the United States, they are behind in the number of citations. While Russia ranks third in the number of publications, with the decrease in the number of citations, it ranks fifteenth with the most significant decrease. While Italy ranks eighth in terms of the number of publications, it rises to the third place in the number of citations, indicating that quality publications are made.

Table 1 - Number of publications per country

Rank	Country	Number of articles	Country	Number of citations
1	China	137	United States	609
2	United States	41	China	258
3	Russia	22	Italy	189
4	Korea	20	Slovenia	176
5	Germany	14	Korea	151
6	United Kingdom	14	Luxembourg	151
7	Australia	12	Australia	118
8	Italy	12	Japan	114
9	Canada	10	United Kingdom	109
10	Malaysia	9	Canada	105
11	France	7	Germany	70
12	Singapore	7	Poland	64
13	Japan	6	Cyprus	50

14	Poland	6	Lithuania	31
15	Brazil	5	Russia	19
16	Switzerland	5	Iran	16
17	Iran	4	Singapore	9
18	Lithuania	4	India	7
19	Slovenia	4	Hungary	6
20	Spain	4	Switzerland	6

3.3 Research Area Analysis

Of the 197 research academic publications, 98 are articles, 90 are proceeding papers and 9 are review articles. As shown in Fig. 3, research areas covering publications related to the construction industry have been identified. These research areas are *engineering (multidisciplinary), architecture, construction-building technology, robotics, artificial intelligence, urban studies, computer science, materials science, science other topics, industrial engineering, electrical electronic engineering, business economics, environmental sciences, transportation, automation control systems, mechanics, chemistry, energy fuels, physics, educational research, operations research management science, instrumentation, social sciences other topics, optics, agriculture, arts humanities other topics, history, imaging science, photographic technology, metallurgical engineering and remote sensing*. Among the 197 articles, civil engineering with 20.4%, construction-building technology with 16%, industrial engineering with 6.6%, computer science with 5.6%, and artificial intelligence with 4% are the most widely published research areas in terms of record count. As a multidisciplinary field, the discipline of architecture is fed from other fields. However, the limited number of academic publications in this discipline, which has an important place under the title of the construction sector, creates a research gap and shows the need for more research in the field of architecture. The contribution of the architectural sector to the digitalization process will contribute to the effective use of building site management and optimum solutions. The role of digitalization should be considered in enabling architects, who are important actors in the management of the building site environment, to conduct the process more effectively.

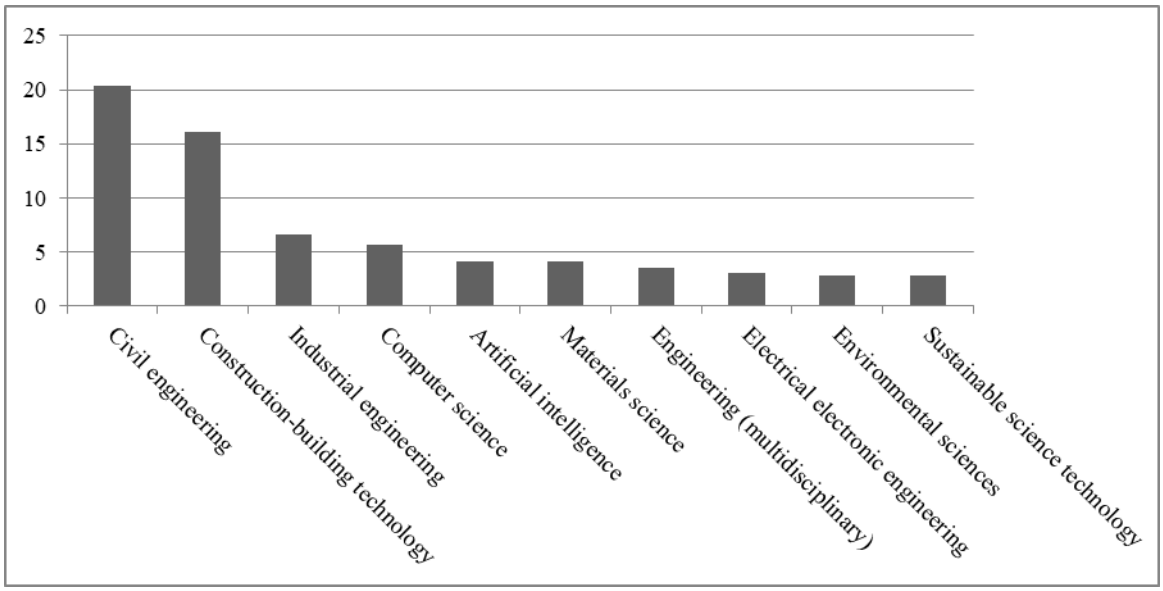

Fig. 3 - Representation of research areas considering data from the Web of Science database

3.4 Factorial Analysis

Dendrogram diagrams are designed to show the relationships between the research terms of the study and the position of these relationships among each other. This diagram shows the interaction between parts in groups because of software analysis in a grouping hierarchy. The height of the coordination line between subjects and clusters is also considered in this classification. Fig. 4 represents a dendrogram tree diagram based on the literature titles of the most frequently used research topics and their relationship to other topics. The links of the terms for the digitalization of building site management in the construction industry are given. The subjects were grouped as red and blue and indicated as two types. The research topics were divided into several clusters. Each cluster is divided into several subsets. While the terms in the red cluster constitute the main topics of the research at the upper scale, the terms in the blue cluster show the systematics of the detail keywords used in the construction industry under the main headings.

Analysis was performed using the multiple correspondence analysis method. With this analysis, it was found that versatile parameters and relationships play a role in building site management.

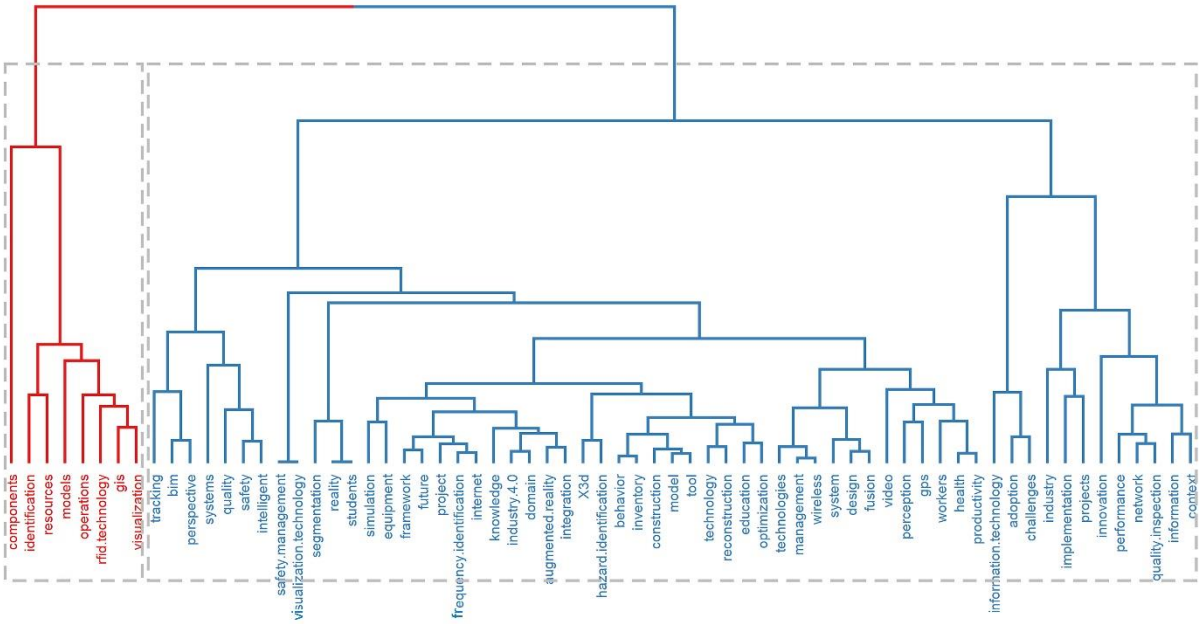

Fig. 4 - Dendrogram tree diagram of titles

3.5 Analysis of the Total Number of Publications on Publishing Platforms

Determining the publishing platforms with the largest number of publications in the literature studied is noteworthy in terms of understanding the journals and other publishing platforms where the research topic is most appropriate. The 197 articles researched were published in 79 different journals. The top of the list is the Automation in Construction journal with 20 publications and 1080 citations (Table 2). The journal publishes articles dealing with the use of information technology in design, engineering, construction technologies and maintenance and management of construction facilities (Zavadskas, 2010). This journal is followed by Computers in Industry (4 publications-253 citations) and Sustainability (4 publications-36 citations), which have the same number of publications. Although the number of publications is the same, the number of citations of the articles in Computers in Industry differs according to the articles in the Sustainability journal. It is observed that the citation rate in the proceeding papers is lower than in the journals. There are 60 journals with 1 publication number. There are 19 journals with at least 2 publication numbers. Articles in the Buildings and Construction Innovation journals have been published recently. Articles in Automation in Construction, Computer-aided Civil and Infrastructure Engineering, Computers in Industry and Journal of Construction Engineering and Management were mostly published in and around 2018. Articles in the Journal of Management in Engineering were mostly published in and around 2019, in the Journal of Cleaner Production in 2020 and around, and in Sustainability and Applied Sciences in 2021 and around, depending on the citation link. Considering the citation network of the journals with each other, Automation in Construction journal comes to the fore.

Table 2 - Journals and congresses where articles are published

Academic Journals	Number of citations	Number Of Articles
AUTOMATION IN CONSTRUCTION	1080	20
COMPUTERS IN INDUSTRY	253	4
SUSTAINABILITY	36	4
APPLIED SCIENCES	20	4
BUILDINGS	13	4
CONSTRUCTION RESEARCH CONGRESS 2022: COMPUTER APPLICATIONS, AUTOMATION, AND DATA ANALYTICS	---	4
JOURNAL OF MANAGEMENT IN ENGINEERING	85	3
ENGINEERING, CONSTRUCTION AND ARCHITECTURAL MANAGEMENT	73	3
COMPUTER-AIDED CIVIL AND INFRASTRUCTURE	67	3

ENGINEERING		
FRONTIERS OF ENGINEERING MANAGEMENT	45	3
ADVANCES IN CIVIL ENGINEERING	21	3
CONSTRUCTION RESEARCH CONGRESS 2020: COMPUTER APPLICATIONS	12	3
ADVANCED ENGINEERING INFORMATICS	95	2
CONSTRUCTION INNOVATION	9	2
CONSTRUCTION CONGRESS VI, PROCEEDING: BUILDING TOGETHER FOR A BETTER TOMORROW IN AN INCREASINGLY COMPLEX WORLD	2	2

3.6 Analysis of the Authors and the Most Cited Publications

In addition to the influence driven by citations by authors, it is also important to refer to top authors in terms of publications. Evaluated articles consist of 618 authors. Although the number of authors of academic publications with one author is 17, the number of authors of academic publications with more than one author is 601. There are 7 authors with a maximum of three academic publications. Jochen Teizer 351, Reza Maalek 84, David Arditi 55, Lieyun Ding 26, Weiguang Jiang 26, Cheng Zhou 26, and Qiang Zhang are 9 cited authors and have 3 academic publications. Table 3 presents the authors who published the most between 1994-2022. It is seen that article trends and consistency have intensified after 2012.

Table 3 - Top 20 authors with the highest number of citations in the Web of Science

Rank	Author	Total Citation	Total Document	H-index	Rank	Author	Total Citation	Total Document	H-index
1	Tao Cheng	351	2	2	11	Manu Venugopal	147	1	1
2	Jochen Teizer	351	3	2	12	Robert Klinc	141	1	1
3	Patrick Dallasega	159	1	1	13	Ziga Turk	141	1	1
4	Christian Linder	159	1	1	14	Soungho Chae	114	1	1
5	Erwin Rauch	159	1	1	15	Tomohiro Yoshida	114	1	1
6	Calin Boje	151	1	1	16	Reza Maalek	84	3	3
7	Annie Guerriero	151	1	1	17	Changyoon Kim	82	1	1
8	Sylvain Kubicki	151	1	1	18	Hyoungkwan Kim	82	2	1
9	Yacine Rezgui	151	1	1	19	Hyunsu Lim	82	1	1
10	Patricio Vela	147	1	1	20	Taeil Park	82	1	1

Seventy-seven publications, including articles published in 2022, have not yet been cited. There are 31 articles that have been cited at least 20 times. The number of articles cited at least 50 times is 11 (Table 4). There are 6 articles with more than 100 citations, 3 articles with more than 150 citations, and 1 article with more than 200 citations. Cheng and Teizer (2013) is the most cited article within the scope of this research. Dallasega et al. (2018) and Boje et al. (2020) are other publications with a high number of citations. When the first 20 most cited articles analyzed are evaluated in terms of document types, 17 of them are articles, 2 of them are reviews and 1 of them is a proceeding paper. From this viewpoint, it is seen that the citation rate of the review and proceeding paper publications is generally low.

Table 4 - Analysis of the 20 most cited academic publications

Reference	Title	Document type / method	Number of citations
Cheng and Teizer, 2013	Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications	Article / simulation and experiment	204
Dallasega et al., 2018	Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review	Article / systematic literature review	159
Boje et al., 2020	Towards a semantic Construction Digital Twin: Directions for future research	Review / literature review	151

Cheng et al., 2011	Performance evaluation of ultra wideband technology for construction resource location tracking in harsh environments	Article / experiment	147
Turk and Klinc, 2017	Potentials of Blockchain Technology for Construction Management	Proceeding Paper / experiment	141
Chae and Yoshida, 2010	Application of RFID technology to prevention of collision accident with heavy equipment	Article / experiment	114
Kim et al., 2013	On-site construction management using mobile computing technology	Article / mobile system and experiment	82
Riaz et al., 2006	SightSafety: A hybrid information and communication technology system for reducing vehicle/pedestrian collisions	Article / management system propose	65
Hasanzadeh et al., 2017	Measuring the Impacts of Safety Knowledge on Construction Workers' Attentional Allocation and Hazard Detection Using Remote Eye-Tracking Technology	Article / laboratory experiment	64
Wang and Cho, 2015	Smart scanning and near real-time 3D surface modeling of dynamic construction equipment from a point cloud	Article / a smart scanning method and surface model	55
Panteli et al., 2020	Building information modelling applications in smart buildings: From design to commissioning and beyond A critical review	Article / scientific literature review	50
Edirisinghe, 2019	Digital skin of the construction site: Smart sensor technologies towards the future smart construction site	Review / a systematic and hierarchical classification	49
Maalek and Sadeghpour, 2013	Accuracy assessment of Ultra-Wide Band technology in tracking static resources in indoor construction scenarios	Article / experiment	49
Malesa et al., 2013	Application of 3D digital image correlation in maintenance and process control in industry	Article / 3D digital image correlation method	49
Zhou et al., 2018	Smart construction site in mega construction projects: A case study on island tunneling project of Hong Kong-Zhuhai-Macao Bridge	Article / literature review	38
Lee et al., 2006	Improving Tower Crane Productivity Using Wireless Technology	Article / experiment	36
Turner et al., 2021	Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities	Article / literature review	31
Zavadskas et al., 2012	Multiple criteria selection of pile-column construction technology	Article / experiment and multiple criteria decision making model	31
Dong et al., 2009	Construction defect management using a telematic digital workbench	Article / laboratory experiment	30
Greif et al., 2020	Peeking into the void: Digital twins for construction site logistics	Article / a decision support system	30

With the network visualization map, the most cited publications are shown in Fig. 5. Five different clusters appear, and sub-studies referencing academic studies with high citations are also seen in the network. Networking between top citations and citations will shape potential citations for future work. The contents of academic publications that received more than 80 citations were examined, and the subjects they specialized in were deepened. In the highest citation category, Cheng and Teizer (2013), published in the Automation in Construction journal, determined that important construction information related to both safety and activities in construction site operations can be monitored in real time with automation systems and converted into digital environments. At this point, it is emphasized that by ensuring the planned execution of a construction project, the workforce of workers, equipment operators or decision makers will be reduced during the construction process. Second in the citation ranking and published in Computers in Industry, Dallasega et al. (2018) conducted a literature study investigating the effects of Industry 4.0 concepts on construction supply chains with their technological, organizational, geographical, and cognitive proximity dimensions. Third in the citation ranking and published in Automation in Construction, Boje et al. (2020) reviewed the current state

of BIM use at the construction site and analyzed the components and strategies of Digital Twins applied in various engineering fields.

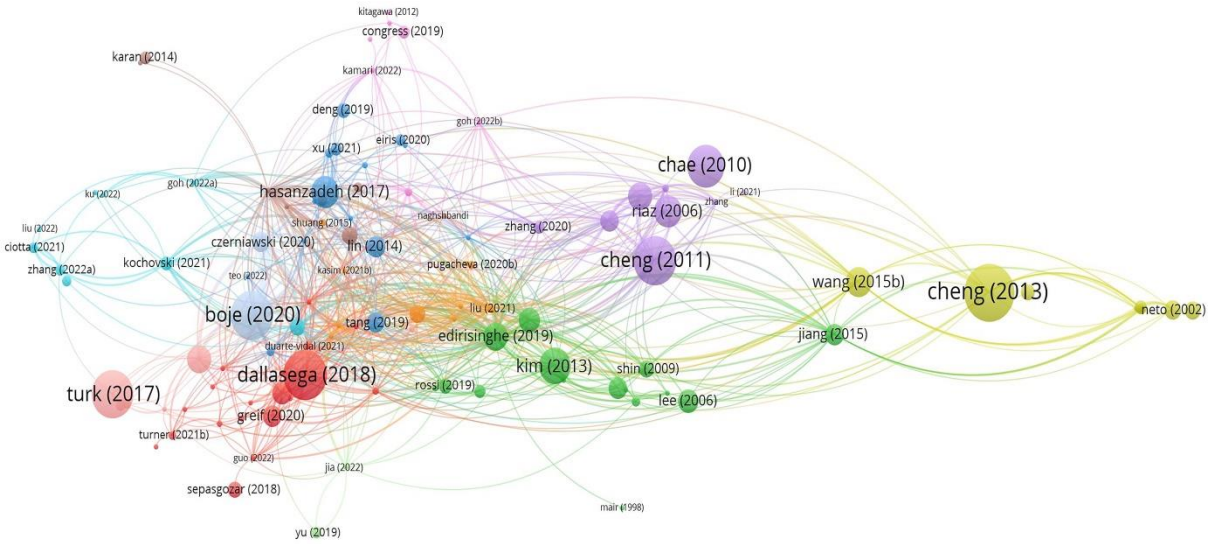

Fig. 5 - Link between top cited authors and publication years

Fourth in the citation ranking and published in the journal Automation in Construction, Cheng et al. (2011) demonstrated that building site management can be achieved with real-time location tracking technology based on radio frequency. Turk and Klinc (2017), which is fifth in the citation ranking, investigated how blockchain technology can be used in the construction industry. In the light of the information obtained from the literature review, it was concluded that solutions can be offered to existing problems with blockchain in construction information management by using BIM. Chae and Yoshida (2010), ranked sixth in the citation ranking, discussed the prevention of heavy equipment colliding with hydraulic excavators and cranes with radio frequency identification (RFID) technology. A prototype has been developed and the workspace has been designed, and crash simulation and testing have been carried out. It was emphasized that accidents can be prevented by using location status information, integration of communication applications and increasing worker-operator awareness. Seventh in the citation ranking and published in the journal Automation in Construction, Kim et al. (2013) revealed that three-dimensional sensing technologies such as total stations, global positioning system (GPS), ultra-wideband (UWB), laser scanning and digital photogrammetry and smart phones can be integrated with building site management. The proposed system, by converting location and building site information into digital data, states that it will be effective in increasing work efficiency and reducing cost and construction time with knowledge transfer, by enabling site engineers to easily understand job descriptions and duties.

3.7 Keyword Analysis

In the analysis created for the keywords summarizing the studies, a keyword analysis was conducted to investigate the scientific outputs and to identify the trends in the digitalization of building site management in the construction industry (Wang and Ho, 2016). On the basis of the results of the vocabulary analysis, word sets are further implemented (Fu et al., 2013; Mao et al., 2010). In the study, word cluster maps were taken as data to identify trending keywords and topics with potential applications related to synthesis (Fig. 6). Clusters arranged according to colors were evaluated. Cluster 1 is the red zone with 12 common keywords. Common words in the set are as-built, BIM, computer vision, construction safety, construction, site, digital tools, digital twin, digitalization, internet of things (IoT), object recognition, and review. A digital twin is a virtual representation of a real entity or physical system, using data through machine learning and simulation and outputs in the form of decisions and actions (Salem and Dragomir, 2022; Ozturk, 2021; Tao et al., 2018). It is gathered around the objectives such as ensuring sustainability, finding the right software solution, providing time and cost performance, and monitoring all processes (Qi et al., 2021; Errandonea et al., 2020).

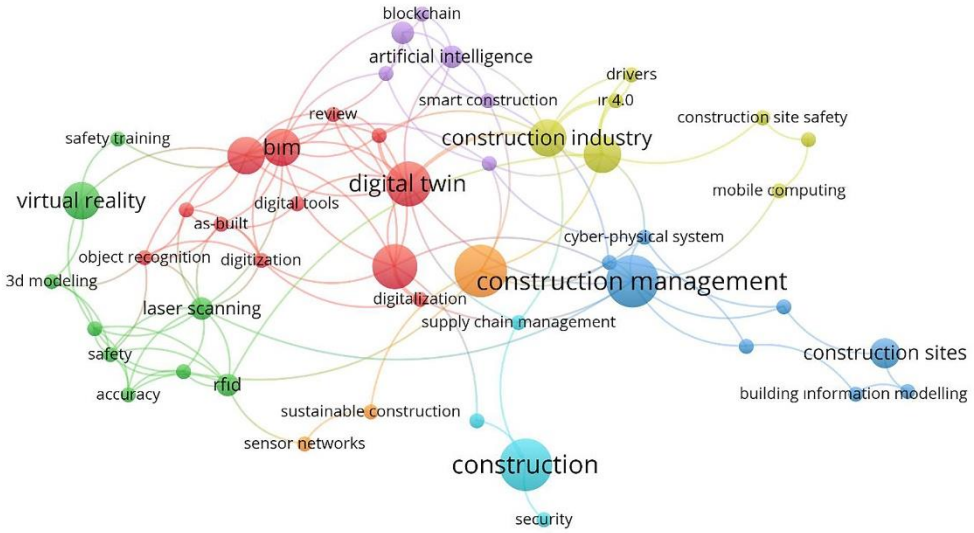

Fig. 6 - Network visualization map of trending keywords

Cluster 2 is the green zone with 9 common keywords. Common words in the set include virtual reality, 3-dimensional modeling, security accuracy, RFID, laser scanning, security training, and visualization. RFID is a wireless sensor technology based on the detection of electromagnetic signals and is an automatic identification system of computing and computing technologies (Domdouzis et al., 2007; Roberts, 2006). This technology brings safety to the forefront with its monitoring and control activities at the building site with virtual reality and laser scanning technologies (Xu and Zheng, 2021). Cluster 3 is the blue zone with 8 common keywords. Common words in the set are BIM, construction management, construction sites, cyber-physical system, digital twins, information technology, project management, and supply chain management. The word construction management is in the foreground. Decision-making and security risk management functions with digital systems stand out in this cluster. Cluster 4 is the yellow region with 7 common keywords. Common words in the cluster are construction industry, construction site safety, drivers, Industry 4.0, mobile computing, safety management and wireless communication device. Technological equipment and supporting systems for the construction industry concept show the function of this cluster. Cluster 5 is the purple region with 6 common keywords. Common words in the cluster are artificial intelligence, blockchain, IoT, petrochemical construction, smart construction, and artificial intelligence tools (data analytics, machine learning, deep learning, etc.). Based on this cluster, situations in the solution of functional areas such as environmental conditions, management of resources, waste and assets, security and surveillance for vehicles entering or leaving the building site can be used together within the scope of the smart building site (Kochovski and Stankovski, 2021).

Trend keywords are derived from current studies and will form reference keywords for future studies. There are 3-dimensional modeling, RFID, security, mobile computing keywords in early research topics between 2014-2016. In 2022 and recent studies, the keywords of *artificial intelligence, blockchain, IoT, petrochemical construction, smart construction, BIM, computer vision, construction safety, construction, site, digital tools, digital twin, security education, cyber-physical system* are the most current words and will be at the forefront of future research. The absence of keywords on topics such as the use of autonomous robots in the digitalized building site environment and the integration of wearable technologies on the building site reveals the need for research on these issues. Considering that the recently discussed keywords constitute current technologies, it is seen that these areas should be given importance in the coming of technological innovations in future studies. Comprehensive keywords that can be used in future studies are given in Fig. 7.

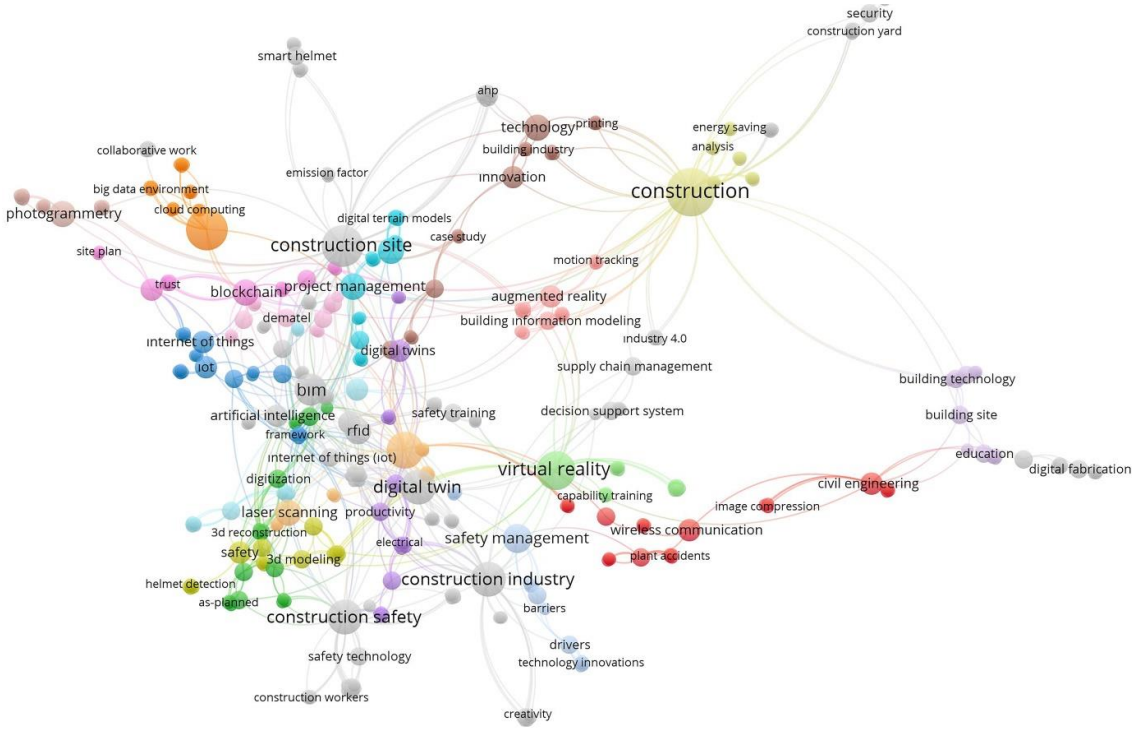

Fig. 7 - Comprehensive keyword map

When the words in the titles of academic publications are examined, the most used word is "construction" which was used 117 times. Also, in the titles, "technology" was included 104 times, "site" 54 times, "digital" 50 times, "smart" 42 times, "management" 28 times, "based" 27 times, "application" 21 times, "safety" 21 times, "system" 18 times, "building" 16 times and "information" 14 times. Another application used in keyword analysis is the three-field diagram method. The Three-Fields Diagram is used in research to show the connections between concepts by providing systematic review. The links between the diagram and the authors, countries, keywords, titles, abstract, sources, references and cited sources can be explained with the visualization method. In Fig. 8, the countries of the works of the 15 authors who discussed the leading publications in terms of research subject and the keywords of these articles are shown in connection. On the left are the countries of the authors, the names of the authors in the middle and the keywords of the articles on the right. By country, China and the USA are associated with the most studies. These countries are followed by Canada, Korea, Malaysia and Germany. Looking at the most popular keywords, construction management, construction site and virtual reality come to the fore. The number of studies on blockchain and laser scanning seems limited. This graphic contains reference information for future studies.

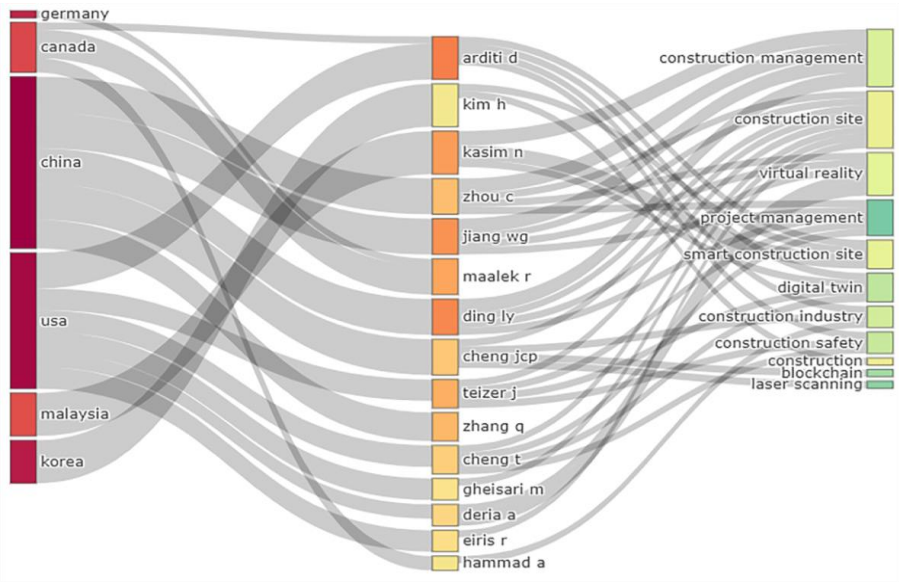

Fig. 8 - Country, studies of highly cited authors, and the relationship of keywords

3.8 Content Analysis of the Selected Publications

A content analysis of digitalization in the construction industry was conducted to identify prominent themes. It is important to deepen the studies on the subject and to identify the research gaps. Understanding the overall framework and reviewing the latest developments and progress will facilitate roadmap for future work. In this direction, the current situation analysis was made by in-depth examination of the documents and the terms, methods, and results discussed in the construction sector were presented by creating conceptual integrity (Table 5). Twenty academic publications in which digitalization is at the forefront were examined.

Table 5 - Content analysis of selected documents

Reference	Title	Keywords	Document type / method	Result
Ding et al., 2022	IoT sensor-based BIM system for smart safety barriers of hazardous energy in petrochemical construction	IoT; BIM; Smart safety barrier; Hazardous energy management; Petrochemical construction	Article / hazardous energy analysis and control using BIM	In the study, a new smart safety barrier model is proposed using the IoT sensor-based BIM system. The proposed system enabled the construction site virtualization, human information management, business information management, hazardous area control.
Salem and Dragomir, 2022	Options for and Challenges of Employing Digital Twins in Construction Management	Digital twins; Construction project management; Cyber-physical system; Construction management; Smart building; Engineering project management	Article / literature review on construction project management	In order to monitor and analyze the development of digital twins, 3 stages have been proposed: BIM, current monitoring and working system of digital twins, and artificial intelligence mechanisms on construction projects in the construction site.
Kochovski and Stankovski, 2021	Building applications for smart and safe construction with the DECENTER Fog Computing and Brokerage Platform	Smart construction; Internet of things; Cloud-to-edge computing; Fog computing; Blockchain; Artificial intelligence	Article / software development and experimental tests	A software has been developed on the smart building site. The test results revealed that the use of Fog computing gives consistent outputs in terms of privacy and security when monitoring employee and company data.
Xu and Zheng, 2021	Incorporating Virtual Reality Technology in Safety Training Solution for Construction Site of Urban Cities	Virtual reality; Safety training; Hazard perception; Construction accidents	Article / an evaluation survey and simulation	This study stated that the proposed virtual reality platform provides many benefits and that physical injuries can be prevented with the system, which is a product of human-machine interaction for the training of construction workers.
Ciotta et al., 2021	Integration of blockchains and smart contracts into construction information flows: Proof-of-concept	Blockchain; Smart contract; Documentation management; BIM; CDE; Structural systems	Article / a proof-of-concept, cost, and security analyses	The work is to increase the reliability and transparency of its management in structural security documentation. Inferences were made by making cost and security analyses and tests of smart contracts.
Han et al., 2021	Immersive technology-driven investigations on influence factors of cognitive load incurred in construction site hazard recognition, analysis and decision making	Construction safety; Cognitive load; Safety hazard; Virtual reality; Immersive technologies; Safety education	Article / immersive experiments, the self-evaluation method, and task performance-based data	In the study, a virtual reality-driven immersive system including real construction site hazard scenarios has been developed. Experimental results show that the cognitive load of individuals given double-task increases and their job performance decreases.
Khan et al., 2021	IMU based smart safety hook for fall prevention at construction sites	Support vector machines; Personal protective equipment; Protocols; Machine learning algorithms; Manuals; Real-time systems; Safety	Proceeding paper / a Smart Safety Hook (SSH) system and experiment	Machine learning algorithms analyzed 3 test scenarios with and without safety hook attached. The results revealed that the smart safety hook is effective in preventing falls from height in construction sites.

Maalek et al., 2021	Towards automatic digital documentation and progress reporting of mechanical construction pipes using smartphones	3D metric reconstruction; Smartphone photogrammetry; Point cloud pipe detection; Mechanical progress reporting; Mechanical pipes as-built digital documentation	Article / laboratory and field experiments	The research presented a new framework for mechanical piping and progress reporting and automated digital documentation in construction projects using smartphones. This system has been tested with different experiments.
Czerniawski and Leite, 2020	Automated digital modeling of existing buildings: A review of visual object recognition methods	BIM; Computer vision; Object recognition; Digitalization; Laser scanning; Digital building representation; 3D reconstruction; As-built	Review / object recognition methods and Comparative performance analysis	A comprehensive and quantitative comparative performance evaluation of 64 object recognition articles was conducted. Scope (semantic coverage) and recognition performances of building component classes are reported in detail and applied in the context of a building classification.
Zhang and Arditi, 2020	Advanced Progress Control of Infrastructure Construction Projects Using Terrestrial Laser Scanning Technology	Construction management; Construction scheduling; Progress control; Laser scanning	Article / automated method using laser scanning technology and laboratory experiments	The proposed method has been tested at the Wacker Drive reconstruction project in Chicago. It has been revealed that laser scanning technology accelerates the multi-scan processing process, identifies irregularly shaped objects, and can be applied economically.
Wang et al., 2020	Smart Helmet and Insole Sensors for Near Fall Incidence Recognition during Descent of Stairs	Stairs; Fall; Construction site; Smart helmet; Smart shoes	Article / three experimental conditions	It has been revealed that smart helmets and smart shoes equipped with sensors perform well against falls while descending stairs.
Tang et al., 2019	Personalized safety instruction system for construction site based on internet technology	Construction safety; Construction workers; Personalized safety instruction; Management information system; Real-time location	Article / a real-time personalized safety instruction method	A more efficient secure monitoring mechanism called Personalized Safety Instruction Management (PSIM) system has been developed on the construction site compared to traditional safety methods.
Zhao et al., 2019	Development of Intelligent Prefabs Using IoT Technology to Improve the Performance of Prefabricated Construction Projects	Prefabrication components; IoTs; RFID; LoRa; Sensor networks; Cloud-based BIM	Article / experimental test	A new method based on Cloud-based BIM and IoT technologies has been proposed in construction sites. Its applicability has been tested in prefabrication projects.
Rossi et al., 2019	Embedded smart sensor device in construction site machinery	Smart machines; Real-time monitoring; Power absorption profiles; Pattern matching; Information traceability; Wireless technologies	Article / a real-time power consumption analysis and experimental tests	This article showed how smart technologies can improve the monitoring and controlling process. Experimental tests on the current and power of electric motors and suggestions about the power consumption of building site machines are given.
Sepasgozar et al., 2018	Dissemination Practices of Construction Sites Technology Vendors in Technology Exhibitions	Construction technology; Dissemination; Diffusion; Exhibitions; Strategy; Technology vendors	Article / hard and fuzzy clustering analysis techniques	The results showed that construction technology vendors can be classified into five types according to the range of dissemination strategies they use. The combination of these strategies is directly related to the spread of technology.
Štefanič and Stankovski, 2018	A review of technologies and applications for smart construction	Building Information Modelling (BIM); Communications & control systems; Information technology	Article / a literature review of recently published scientific articles	The review of scientific articles revealed on the one hand the great application potential for the field of construction and, on the other hand, very low use of state-of-the-art technology.

Lin et al., 2014	A user-centered information and communication technology (ICT) tool to improve safety inspections	Construction safety; Safety inspection; Site inspection; Safety audit; Field data collection; User-centered design; Safety technology	Article / an original two-step user-centered design approach	The Information and communication technology (ICT) tool has been developed and is intended to help advance security and health data analysis techniques. It is aimed to increase safety in the building site environment.
Karan et al., 2014	Digital Modeling of Construction Site Terrain Using Remotely Sensed Data and Geographic Information Systems Analyses	Preconstruction planning; Remote sensing; Geographic information system; Information technologies; Construction sites; Digital terrain models	Article / Airborne light detection and ranging (LiDAR), satellite imagery, models, and comparative analysis	The results of the study showed that LiDAR-based site topography analysis gave the best vertical accuracy over satellite-image-based analysis. It is envisaged that this model will make up for the shortcomings of existing methods.
Shin and Jang, 2009	Utilization of ubiquitous computing for construction AR technology	Augmented reality; Ubiquitous computing; Construction; Motion tracking; Wireless sensor network	Article / preliminary experiment	Display technique, motion tracking method, and server implementation from ubiquitous augmented reality technology equipment for a building site are discussed.
Nienhuser et al., 2009	A Situation context aware Dempster-Shafer fusion of digital maps and a road sign recognition system	Context awareness; Roads; Digital cameras; Sensor fusion; Information systems; Vehicles; Navigation; Solids; Data mining; Face recognition	Proceeding paper / a fusion approach	A new approach is proposed for map and camera based speed sign recognition system. It is foreseen that the system applied for traffic rules in Germany can be used in construction areas.

4. Results and Discussions

Keeping up with the technology of building sites becomes possible with real-time protection and monitoring of resources, supply chain-logistics regulation, security management, and project management. Rapid developments in digitalization pave the way for revolutionary innovations and supply chain applications in the built environment (Yevu et al., 2021). As one of the dynamic change processes, digitalization brings potential benefits to the construction industry (Zheng et al., 2021). Potential benefits also create time and cost advantages (Yin et al., 2020). The use of digital tools in construction activities, in addition to improving the sustainability results of the building, also positively affects the performance of the construction (Nikmehr et al., 2021). Digitalization, which also improves the life cycle of the projects, provides the integration of the planning, delivery, construction, and maintenance features of the projects in the built environment in a certain order (Jacobsson et al., 2017). The unsolved problems, human factor, and complications in the architecture, engineering and construction (AEC) industry indicate that construction and planning programs need to be reconsidered. Considering that effective solutions can be developed in the fields of robotics, software and programming in the construction sector in the future with digital tools, the importance of digitalization in the decision-making process is seen. Increasing internet usage, development of wireless technologies, and construction 4.0 terminology also bring digitalization one step closer to advanced technological applications. The digitalization process at the building site is gathered under 4 different headings and the sub-branches of these headings are given in Fig. 9 as research trends.

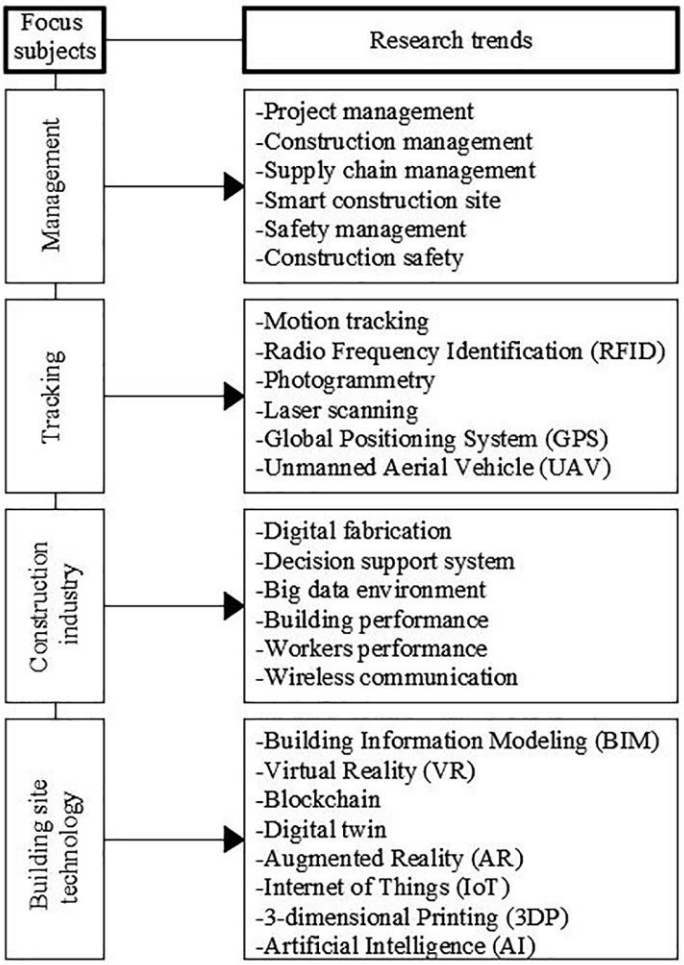

Fig. 9 - Research areas for the digitalization of the building site

Real-time protection and monitoring of resources is based on the planned and scheduled continuation of project management in intensive and complex operations of construction resources (personnel, equipment, materials) field operations. It should include the effective use of technologies that provide easy access to information and provide data collection, processing and visualization. Sensing technologies such as VR, GPS, or UWB along with RFID help protect and track resources in building site management (Cheng and Teizer, 2013). With VR visualization, it is possible to collect and track automatic data on the locations of workers, materials, equipment by mobile sources with GPS systems or UWB system.

Supply chain and logistics on site includes building materials and their transportation, with dynamic and real-time decision making. Various parameters such as quantity purchase, warehouse inventory and maintenance, determination of tools and consumables, time and cost calculation, purchasing and accounting form the ring of the supply chain, and they need to be digitized in a systematic framework (Sacks et al., 2020). In addition to strategic planning, threshold-based measures, data-driven reporting and automated invoicing processes, the digital twin technology used on site provides benefits in new logistics processes and adoption of product-to-service delivery (Greif et al., 2020). Making building site planning in BIM, one of the other technological innovations, provides an impression by preparing updates from material consumption to logistics. Every building element in the construction area can be tracked in the entire process from production to distribution and manufacturing with the tags placed on the sensor systems brought by RFID technology (Edirisinghe, 2019).

Building site safety management is one of the most affected areas in terms of production accidents worldwide. The application of information and communication technologies and the IoT is important in the creation of smart building sites. Technologies such as radar, sonar, GPS, UWB, and location detection systems are used for the building site personnel to work in a safe, efficient and quality construction environment away from dangers (Jiang et al., 2021). With wearable smart devices, body temperature, blood pressure, pulse rate, muscle tension, movement, electrocardiogram data or other biomedical criteria can be monitored. With the GPS and RFID tags placed on the helmets, physiological parameters such as health and safety hazard or fatigue can be determined. In addition, security management can be provided by visualizing data with BIM and AR systems integrated into smart glasses (Edirisinghe, 2019).

Building site management encompasses the whole of systematic practices to make the right decisions at multiple hierarchical levels, with stakeholders and organizations at a certain time scale. A deeper understanding of construction activity information is needed in the aggregate of real-time and visual-based studies (Xu et al., 2021). This deep understanding can be achieved with the innovations brought by digitalization. BIM, RFID, VR, laser scanning, cyber-physical systems, digital twins, artificial intelligence, blockchain, IoT, GPS, wireless network technologies, etc. configurations and all stages of construction projects can be managed remotely and under close control (Luo et al., 2022). Artificial intelligence can be applied to machine vision systems that allow the identification of specific elements on a building site and to detect the performance of construction workers in real time. When using VR technology in trainings related to the construction industry, it provides practical explanation of legislation and directives, reducing the risks that people may be exposed to. It plays an active role in optimizing the building site and identifying hazardous areas (Forcael et al., 2020).

All the processes, that became a part of industry 4.0 are generating a big amount of data. Besides creating simulations of a construction site and enabling off-site surveillance, this data could become a trigger to the development of automated processes and the application of artificial intelligence in site management (Top and Topraklı, 2022). The change is also strongly connected models of design and process management. The models show how the verification process can be developed and applied within the software and with additional hardware solutions like digital fabrication (Nyka et al., 2020). With accurate statistics and structured processes, decision-making could become more automated and reliable. The change could not only impact the duration of the entire construction time but also create the need for specific competencies of the managing team. Their role in the process would also change and involve skills connected to data management and systems supervision.

5. Conclusion

The process that started with Industry 4.0 has opened the doors of the digital world. The construction world has also started to benefit from these technologies. The wideness of the construction world and the complex applications in the business field also make the integration of digital technologies difficult. However, with the development of new technologies, the digitalization process in the construction industry has also accelerated. Building site management has an important place in the construction industry. Time, cost, building materials, logistics and planning parameters play a role in the efficient execution of applications in building site management. With big amount of data and automation new tools can strongly support the process and create new opportunities for application of artificial intelligence. Digitalization has an important place in matters such as monitoring, surveillance and control of these parameters. Optimum solutions are sought in building site management with digitalization technologies. In the study, the applications of digitalization systems in building site management were emphasized. It was aimed to reveal the digitalization potential of the building site in the construction sector with a bibliometric approach. The research methodology conducted in academic studies without year restrictions shows that the number of publications is low and there is a research gap in this field. In the subject of the research, which has been started to be researched recently, it has been seen that the building sites keep up with the technology, the real-time protection and monitoring of the resources, the supply chain-logistics arrangement, the security management at the building site and the studies on project management are insufficient, and the research area needs to be expanded. Considering the increasing topicality of the subject and the technological developments that will shape the sector in the coming years, it is foreseen that more studies will be needed in this field. The technological change in the construction industry is important for the discovery and development of digitalization in the building site. With the study, academic publications on the use of technology for the smart building sites of the future have been put forward and contributed to the research topic.

Acknowledgement

The authors would like to thank and acknowledge the universities for all kinds of support given.

References

Adepoju, O. O., & Aigbavboa, C. O. (2021). Assessing knowledge and skills gap for construction 4.0 in a developing economy. *Journal of Public Affairs*, *21*(3), e2264, pp. 1-10.

Alaloul, W. S., Liew, M. S., Zawawi, N. A. W. A., & Kennedy, I. B. (2020). Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders. *Ain shams engineering journal*, *11*(1), pp. 225-230.

Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022). Collaboration and Risk in Building Information Modelling (BIM): A Systematic Literature Review. *Buildings*, *12*(5), 571, pp. 1-24.

Alizadehsalehi, S., Hadavi, A., & Huang, J. C. (2020). From BIM to extended reality in AEC industry. *Automation in Construction*, *116*, 103254, pp. 1-13.

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of informetrics*, *11*(4), pp. 959-975.

Asadi, K., Suresh, A. K., Ender, A., Gotad, S., Maniyar, S., Anand, S., ... & Wu, T. (2020). An integrated UGV-UAV system for construction site data collection. *Automation in Construction*, *112*, 103068, pp. 1-23.

Begić, H., & Galić, M. (2021). A Systematic Review of Construction 4.0 in the Context of the BIM 4.0 Premise. *Buildings*, *11*(8), 337.

Boje, C., Guerriero, A., Kubicki, S., & Rezgui, Y. (2020). Towards a semantic Construction Digital Twin: Directions for future research. *Automation in Construction*, *114*, 103179.

Buchanan, C., & Gardner, L. (2019). Metal 3D printing in construction: A review of methods, research, applications, opportunities and challenges. *Engineering Structures*, *180*, pp. 332-348.

Chacón, R. (2021). Designing construction 4.0 activities for AEC classrooms. *Buildings*, *11*(11), 511.

Chae, S., & Yoshida, T. (2010). Application of RFID technology to prevention of collision accident with heavy equipment. *Automation in construction*, *19*(3), pp. 368-374.

Chen, C. L., Lin, Y. C., Chen, W. H., Chao, C. F., & Pandia, H. (2021). Role of government to enhance digital transformation in small service business. *Sustainability*, *13*(3), 1028.

Chen, Y., Huang, D., Liu, Z., Osmani, M., & Demian, P. (2022). Construction 4.0, Industry 4.0, and Building Information Modeling (BIM) for Sustainable Building Development within the Smart City. *Sustainability*, *14*(16), 10028.

Cheng, P., Tang, H., Dong, Y., Liu, K., Jiang, P., & Liu, Y. (2021). Knowledge Mapping of Research on Land Use Change and Food Security: A Visual Analysis Using CiteSpace and VOSviewer. *International Journal of Environmental Research and Public Health*, *18*(24), 13065.

Cheng, T., & Teizer, J. (2013). Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications. *Automation in construction*, *34*, pp. 3-15.

Cheng, T., Venugopal, M., Teizer, J., & Vela, P. A. (2011). Performance evaluation of ultra wideband technology for construction resource location tracking in harsh environments. *Automation in Construction*, *20*(8), pp. 1173-1184.

Chi, H. L., Kang, S. C., & Wang, X. (2013). Research trends and opportunities of augmented reality applications in architecture, engineering, and construction. *Automation in construction*, *33*, pp. 116-122.

Ciotta, V., Mariniello, G., Asprone, D., Botta, A., & Manfredi, G. (2021). Integration of blockchains and smart contracts into construction information flows: Proof-of-concept. *Automation in Construction*, *132*, 103925.

Craveiroa, F., Duartec, J. P., Bartoloa, H., & Bartolod, P. J. (2019). Additive manufacturing as an enabling technology for digital construction: A perspective on Construction 4.0. *Automation in construction*, *103*, pp. 251-267.

Czerniawski, T., & Leite, F. (2020). Automated digital modeling of existing buildings: A review of visual object recognition methods. *Automation in Construction*, *113*, 103131.

Da Costa, M. B., Dos Santos, L. M. A. L., Schaefer, J. L., Baierle, I. C., & Nara, E. O. B. (2019). Industry 4.0 technologies basic network identification. *Scientometrics*, *121*(2), pp. 977-994.

Dallasega, P., Rauch, E., & Linder, C. (2018). Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. *Computers in industry*, *99*, pp. 205-225.

Darko, A., Chan, A. P., Yang, Y., & Tetteh, M. O. (2020). Building information modeling (BIM)-based modular integrated construction risk management–Critical survey and future needs. *Computers in Industry*, *123*, 103327.

de Almeida Barbosa Franco, J., Domingues, A. M., de Almeida Africano, N., Deus, R. M., & Battistelle, R. A. G. (2022). Sustainability in the Civil Construction Sector Supported by Industry 4.0 Technologies: Challenges and Opportunities. *Infrastructures*, *7*(3), 43.

de Soto, B. G., Agustí-Juan, I., Hunhevicz, J., Joss, S., Graser, K., Habert, G., & Adey, B. T. (2018). Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall. *Automation in construction*, *92*, pp. 297-311.

Delgado, J. M. D., Oyedele, L., Demian, P., & Beach, T. (2020). A research agenda for augmented and virtual reality in architecture, engineering and construction. *Advanced Engineering Informatics*, *45*, 101122.

Ding, L., Jiang, W., & Zhou, C. (2022). IoT sensor-based BIM system for smart safety barriers of hazardous energy in petrochemical construction. *Frontiers of Engineering Management*, *9*(1), pp. 1-15.

Domdouzis, K., Kumar, B., & Anumba, C. (2007). Radio-Frequency Identification (RFID) applications: A brief introduction. *Advanced Engineering Informatics*, *21*(4), pp. 350-355.

Dong, A., Maher, M. L., Kim, M. J., Gu, N., & Wang, X. (2009). Construction defect management using a telematic digital workbench. *Automation in Construction*, *18*(6), pp. 814-824.

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, pp. 285-296.

Donthu, N., Kumar, S., & Pattnaik, D. (2020). Forty-five years of Journal of Business Research: A bibliometric analysis. *Journal of business research*, *109*, pp. 1-14.

Duarte-Vidal, L., Herrera, R. F., Atencio, E., & Rivera, M. L. (2021). Interoperability of digital tools for the monitoring and control of construction projects. *Applied Sciences*, *11*(21), 10370.

Edirisinghe, R. (2019). Digital skin of the construction site: Smart sensor technologies towards the future smart construction site. *Engineering, Construction and Architectural Management*, *26*(2), pp. 184-223.

Errandonea, I., Beltrán, S., & Arrizabalaga, S. (2020). Digital Twin for maintenance: A literature review. *Computers in*

Industry, *123*, 103316.
Escamilla-Fajardo, P., Núñez-Pomar, J. M., Ratten, V., & Crespo, J. (2020). Entrepreneurship and innovation in soccer: Web of science bibliometric analysis. *Sustainability*, *12*(11), 4499.
Fatorachian, H., & Kazemi, H. (2018). A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework. *Production Planning & Control*, *29*(8), pp. 633-644.
Fernandez-Rodriguez, M. A., & Alvarez, L. (2021). Microgels and Nanogels at Interfaces and Emulsions: Identifying Opportunities From a Bibliometric Analysis. *Frontiers in Physics*, *9*, 754684.
Forcael, E., Ferrari, I., Opazo-Vega, A., & Pulido-Arcas, J. A. (2020). Construction 4.0: A literature review. *Sustainability*, *12*(22), 9755.
Fu, H. Z., Wang, M. H., & Ho, Y. S. (2013). Mapping of drinking water research: A bibliometric analysis of research output during 1992–2011. *Science of the Total Environment*, *443*, pp. 757-765.
Gao, X., & Pishdad-Bozorgi, P. (2019). BIM-enabled facilities operation and maintenance: A review. *Advanced engineering informatics*, *39*, pp. 227-247.
García de Soto, B., Agustí-Juan, I., Joss, S., & Hunhevicz, J. (2022). Implications of Construction 4.0 to the workforce and organizational structures. *International Journal of Construction Management*, *22*(2), pp. 205-217.
Gaviria-Marin, M., Merigó, J. M., & Baier-Fuentes, H. (2019). Knowledge management: A global examination based on bibliometric analysis. *Technological Forecasting and Social Change*, *140*, pp. 194-220.
Ghaleb, H., Alhajlah, H. H., Bin Abdullah, A. A., Kassem, M. A., & Al-Sharafi, M. A. (2022). A Scientometric Analysis and Systematic Literature Review for Construction Project Complexity. *Buildings*, *12*(4), 482.
Greif, T., Stein, N., & Flath, C. M. (2020). Peeking into the void: Digital twins for construction site logistics. *Computers in Industry*, *121*, 103264.
Guan, S., Zhu, Z., & Wang, G. (2022). A Review on UAV-Based Remote Sensing Technologies for Construction and Civil Applications. *Drones*, *6*(5), 117.
Habibi Rad, M., Mojtahedi, M., & Ostwald, M. J. (2021). Industry 4.0, disaster risk management and infrastructure resilience: a systematic review and bibliometric analysis. *Buildings*, *11*(9), 411.
Han, Y., Diao, Y., Yin, Z., Jin, R., Kangwa, J., & Ebohon, O. J. (2021). Immersive technology-driven investigations on influence factors of cognitive load incurred in construction site hazard recognition, analysis and decision making. *Advanced Engineering Informatics*, *48*, 101298.
Hasanzadeh, S., Esmaeili, B., & Dodd, M. D. (2017). Measuring the impacts of safety knowledge on construction workers' attentional allocation and hazard detection using remote eye-tracking technology. *Journal of management in engineering*, *33*(5), 04017024.
He, R., Li, M., Gan, V. J., & Ma, J. (2021). BIM-enabled computerized design and digital fabrication of industrialized buildings: A case study. *Journal of Cleaner Production*, *278*, 123505.
Helo, P., & Hao, Y. (2017). Cloud manufacturing system for sheet metal processing. *Production Planning & Control*, *28*(6-8), pp. 524-537.
Hossain, M. A., Zhumabekova, A., Paul, S. C., & Kim, J. R. (2020). A Review of 3D Printing in Construction and its Impact on the Labor Market. *Sustainability*, *12*(20), 8492.
Hosseini, M. R., Martek, I., Zavadskas, E. K., Aibinu, A. A., Arashpour, M., & Chileshe, N. (2018). Critical evaluation of off-site construction research: A Scientometric analysis. *Automation in Construction*, *87*, pp. 235-247.
Howard, J., Murashov, V., & Branche, C. M. (2018). Unmanned aerial vehicles in construction and worker safety. *American journal of industrial medicine*, *61*(1), pp. 3-10.
Huang, Y. J., Cheng, S., Yang, F. Q., & Chen, C. (2022). Analysis and Visualization of Research on Resilient Cities and Communities Based on VOSviewer. *International Journal of Environmental Research and Public Health*, *19*(12), 7068.
İlerisoy, Z. Y., & Takva, Y. (2017). Nanotechnological developments in structural design: Load-bearing materials. *Engineering, Technology & Applied Science Research*, *7*(5), pp. 1900-1903.
Jacob-Loyola, N., Muñoz-La Rivera, F., Herrera, R. F., & Atencio, E. (2021). Unmanned aerial vehicles (UAVs) for physical progress monitoring of construction. *Sensors*, *21*(12), 4227.
Jacobsson, M., Linderoth, H. C., & Rowlinson, S. (2017). The role of industry: an analytical framework to understand ICT transformation within the AEC industry. *Construction management and economics*, *35*(10), pp. 611-626.
Jalal, R., Alon, I., & Paltrinieri, A. (2021). A bibliometric review of cryptocurrencies as a financial asset. *Technology Analysis & Strategic Management*, pp. 1-16.
Jeelani, I., & Gheisari, M. (2021). Safety challenges of UAV integration in construction: Conceptual analysis and future research roadmap. *Safety science*, *144*, 105473.
Jiang, C. M., Duangthip, D., Chan, A. K. Y., Tamrakar, M., Lo, E. C. M., & Chu, C. H. (2021). Global research interest regarding silver diamine fluoride in dentistry: a bibliometric analysis. *Journal of Dentistry*, *113*, 103778.
Jiang, W., Ding, L., & Zhou, C. (2021). Cyber physical system for safety management in smart construction site. *Engineering Construction and Architectural Management*, *28*(3), pp. 788-808.
Jin, R., Zou, P. X., Piroozfar, P., Wood, H., Yang, Y., Yan, L., & Han, Y. (2019). A science mapping approach based review of construction safety research. *Safety science*, *113*, pp. 285-297.

Karan, E. P., Sivakumar, R., Irizarry, J., & Guhathakurta, S. (2014). Digital modeling of construction site terrain using remotely sensed data and geographic information systems analyses. *Journal of Construction Engineering and Management*, *140*(3), 04013067.

Khan, M., Khalid, R., Anjum, S., Khan, N., & Park, C. (2021). IMU based smart safety hook for fall prevention at construction sites. *2021 IEEE Region 10 Symposium (TENSYMP)*. Jeju, Korea. August 23-25, 2021. pp. 1-6.

Khan, M. A., Pattnaik, D., Ashraf, R., Ali, I., Kumar, S., & Donthu, N. (2021). Value of special issues in the journal of business research: A bibliometric analysis. *Journal of business research*, *125*, pp. 295-313.

Khan, N., Ali, A. K., Van-Tien Tran, S., Lee, D., & Park, C. (2020). Visual language-aided construction fire safety planning approach in building information modeling. *Applied Sciences*, *10*(5), 1704.

Kim, C., Park, T., Lim, H., & Kim, H. (2013). On-site construction management using mobile computing technology. *Automation in construction*, *35*, pp. 415-423.

Kochovski, P., & Stankovski, V. (2021). Building applications for smart and safe construction with the DECENTER Fog Computing and Brokerage Platform. *Automation in construction*, *124*, 103562.

Kozlovska, M., Klosova, D., & Strukova, Z. (2021). Impact of industry 4.0 platform on the formation of construction 4.0 concept: a literature review. *Sustainability*, *13*(5), 2683.

Lavikka, R., Kallio, J., Casey, T., & Airaksinen, M. (2018). Digital disruption of the AEC industry: Technology-oriented scenarios for possible future development paths. *Construction management and economics*, *36*(11), pp. 635-650.

Lee, U. K., Kang, K. I., Kim, G. H., & Cho, H. H. (2006). Improving tower crane productivity using wireless technology. *Computer‐Aided Civil and Infrastructure Engineering*, *21*(8), pp. 594-604.

Lessing, J., Stehn, L., & Ekholm, A. (2015). Industrialised house-building–development and conceptual orientation of the field. *Construction innovation*, *15*(3), pp. 378-399.

Li, J., Greenwood, D., & Kassem, M. (2019). Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Automation in construction*, *102*, pp. 288-307.

Li, T., Cui, L., Xu, Z., Hu, R., Joshi, P. K., Song, X., ... & Cui, X. (2021). Quantitative analysis of the research trends and areas in grassland remote sensing: a scientometrics analysis of Web of Science from 1980 to 2020. *Remote Sensing*, *13*(7), 1279.

Lin, K. Y., Tsai, M. H., Gatti, U. C., Lin, J. J. C., Lee, C. H., & Kang, S. C. (2014). A user-centered information and communication technology (ICT) tool to improve safety inspections. *Automation in construction*, *48*, pp. 53-63.

Liu, Y., Van Nederveen, S., & Hertogh, M. (2017). Understanding effects of BIM on collaborative design and construction: An empirical study in China. *International journal of project management*, *35*(4), pp. 686-698.

Lundberg, O., Nylén, D., & Sandberg, J. (2022). Unpacking construction site digitalization: the role of incongruence and inconsistency in technological frames. *Construction management and economics*, *40*(11-12), pp. 987-1002.

Luo, H., Ling, L., Chen, K., Fordjour, A. A. M., & Chen, L. (2022). Digital technology for quality management in construction: A review and future research directions. *Developments in the Built Environment*, 100087.

Maalek, R., Lichti, D. D., & Maalek, S. (2021). Towards automatic digital documentation and progress reporting of mechanical construction pipes using smartphones. *Automation in Construction*, *127*, 103735.

Maalek, R., & Sadeghpour, F. (2013). Accuracy assessment of Ultra-Wide Band technology in tracking static resources in indoor construction scenarios. *Automation in Construction*, *30*, pp. 170-183.

Malekitabar, H., Ardeshir, A., Sebt, M. H., & Stouffs, R. (2016). Construction safety risk drivers: A BIM approach. *Safety science*, *82*, pp. 445-455.

Malesa, M., Malowany, K., Tomczak, U., Siwek, B., Kujawińska, M., & Siemińska-Lewandowska, A. (2013). Application of 3D digital image correlation in maintenance and process control in industry. *Computers in Industry*, *64*(9), pp. 1301-1315.

Mao, N., Wang, M. H., & Ho, Y. S. (2010). A bibliometric study of the trend in articles related to risk assessment published in Science Citation Index. *Human and Ecological Risk Assessment*, *16*(4), pp. 801-824.

Maresova, P., Soukal, I., Svobodova, L., Hedvicakova, M., Javanmardi, E., Selamat, A., & Krejcar, O. (2018). Consequences of industry 4.0 in business and economics. *Economies*, *6*(3), 46.

Martínez-Vázquez, R. M., de Pablo Valenciano, J., & Martínez, J. L. C. (2021). Marinas and sustainability: Directions for future research. *Marine Pollution Bulletin*, *164*, 112035.

Maskuriy, R., Selamat, A., Ali, K. N., Maresova, P., & Krejcar, O. (2019). Industry 4.0 for the construction industry—how ready is the industry?. *Applied Sciences*, *9*(14), 2819.

Meng, L., Wen, K. H., Brewin, R., & Wu, Q. (2020). Knowledge atlas on the relationship between urban street space and residents' health—a bibliometric analysis based on VOSviewer and CiteSpace. *Sustainability*, *12*(6), 2384.

Merigó, J. M., & Yang, J. B. (2017). A bibliometric analysis of operations research and management science. *Omega*, *73*, pp. 37-48.

Merschbrock, C., & Munkvold, B. E. (2015). Effective digital collaboration in the construction industry–A case study of BIM deployment in a hospital construction project. *Computers in Industry*, *73*, pp. 1-7.

Monticolo, D., Badin, J., Gomes, S., Bonjour, E., & Chamoret, D. (2015). A meta-model for knowledge configuration management to support collaborative engineering. *Computers in Industry*, *66*, pp. 11-20.

Mosser, J., Pellerin, R., Bourgault, M., Danjou, C., & Perrier, N. (2022). GRMI4. 0: a guide for representing and modeling Industry 4.0 business processes. *Business Process Management Journal*, *28*(4), pp. 1047-1070.

Mougenot, B., & Doussoulin, J. P. (2022). Conceptual evolution of the bioeconomy: a bibliometric analysis. *Environment, Development and Sustainability*, *24*(1), pp. 1031-1047.

Nagy, O., Papp, I., & Szabó, R. Z. (2021). Construction 4.0 Organisational Level Challenges and Solutions. *Sustainability*, *13*(21), 12321.

Nienhuser, D., Gumpp, T., & Zollner, J. M. (2009). A situation context aware dempster-shafer fusion of digital maps and a road sign recognition system. *2009 IEEE Intelligent Vehicles Symposium*. Xi'an, China. June 03-05, 2009. pp. 1401-1406.

Nikmehr, B., Hosseini, M. R., Martek, I., Zavadskas, E. K., & Antucheviciene, J. (2021). Digitalization as a strategic means of achieving sustainable efficiencies in construction management: A critical review. *Sustainability*, *13*(9), 5040.

Nnolim, N. E., & Nwodo, U. U. (2021). Microbial keratinase and the bio-economy: a three-decade meta-analysis of research exploit. *AMB Express*, *11*(1), pp. 1-16.

Noghabaei, M., Heydarian, A., Balali, V., & Han, K. (2020). Trend analysis on adoption of virtual and augmented reality in the architecture, engineering, and construction industry. *Data*, *5*(1), 26.

Nyka, L., Cudzik, J., & Szakajło, K. (2020). The CDIO model in architectural education and research by design. *World Transactions on Engineering and Technology Education*, *18*, pp. 85-90.

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in industry*, *83*, pp. 121-139.

Opoku, D. G. J., Perera, S., Osei-Kyei, R., & Rashidi, M. (2021). Digital twin application in the construction industry: A literature review. *Journal of Building Engineering*, *40*, 102726.

Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing*, *31*(1), pp. 127-182.

Ozturk, G. B. (2021). Digital twin research in the AECO-FM industry. *Journal of Building Engineering*, *40*, 102730.

Panteli, C., Kylili, A., & Fokaides, P. A. (2020). Building information modelling applications in smart buildings: From design to commissioning and beyond A critical review. *Journal of Cleaner Production*, *265*, 121766.

Pellegrini, L., Campi, S., Locatelli, M., Pattini, G., Di Giuda, G. M., & Tagliabue, L. C. (2020). Digital transition and waste management in architecture, engineering, construction, and operations industry. *Frontiers in Energy Research*, *8*, 576462.

Pessoa, S., Guimarães, A. S., Lucas, S. S., & Simões, N. (2021). 3D printing in the construction industry-A systematic review of the thermal performance in buildings. *Renewable and Sustainable Energy Reviews*, *141*, 110794.

Piccarozzi, M., Aquilani, B., & Gatti, C. (2018). Industry 4.0 in management studies: A systematic literature review. *Sustainability*, *10*(10), 3821.

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., ... & Nee, A. Y. C. (2021). Enabling technologies and tools for digital twin. *Journal of Manufacturing Systems*, *58*, pp. 3-21.

Qin, J., Liu, Y., & Grosvenor, R. (2016). A categorical framework of manufacturing for industry 4.0 and beyond. *Procedia cirp*, *52*, pp. 173-178.

Rajeswari, S., Saravanan, P., Kumaraguru, K., Jaya, N., Rajeshkannan, R., & Rajasimman, M. J. B. C. (2021). The scientometric evaluation on the research of biodiesel based on HistCite and VOSviewer (1993–2019). *Biomass Conversion and Biorefinery*, pp. 1-11.

Richard, S., Pellerin, R., Bellemare, J., & Perrier, N. (2020). A business process and portfolio management approach for Industry 4.0 transformation. *Business Process Management Journal*, *27*(2), pp. 505-528.

Riaz, Z., Edwards, D. J., & Thorpe, A. (2006). SightSafety: A hybrid information and communication technology system for reducing vehicle/pedestrian collisions. *Automation in construction*, *15*(6), pp. 719-728.

Rivera, M. L., Mora-Serrano, J., Valero, I., & Oñate, E. (2021). Methodological-technological framework for Construction 4.0. *Archives of computational methods in engineering*, *28*(2), pp. 689-711.

Roberts, C. M. (2006). Radio frequency identification (RFID). *Computers & security*, *25*(1), pp. 18-26.

Rossi, A., Vila, Y., Lusiani, F., Barsotti, L., Sani, L., Ceccarelli, P., & Lanzetta, M. (2019). Embedded smart sensor device in construction site machinery. *Computers in Industry*, *108*, pp. 12-20.

Sacks, R., Girolami, M., & Brilakis, I. (2020). Building information modelling, artificial intelligence and construction tech. *Developments in the Built Environment*, *4*, 100011.

Saieg, P., Sotelino, E. D., Nascimento, D., & Caiado, R. G. G. (2018). Interactions of building information modeling, lean and sustainability on the architectural, engineering and construction industry: a systematic review. *Journal of cleaner production*, *174*, pp. 788-806.

Salem, T., & Dragomir, M. (2022). Options for and Challenges of Employing Digital Twins in Construction Management. *Applied Sciences*, *12*(6), 2928.

Salhaoui, M., Guerrero-González, A., Arioua, M., Ortiz, F. J., El Oualkadi, A., & Torregrosa, C. L. (2019). Smart industrial iot monitoring and control system based on UAV and cloud computing applied to a concrete

plant. *Sensors*, *19*(15), 3316.
Sanghavi, D., Parikh, S., & Raj, S. A. (2019). Industry 4.0: Tools and implementation. *Management and Production Engineering Review*, *10*(3), pp. 3-13.
Schiavi, B., Havard, V., Beddiar, K., & Baudry, D. (2022). BIM data flow architecture with AR/VR technologies: Use cases in architecture, engineering and construction. *Automation in Construction*, *134*, 104054.
Schneider, P. (2018). Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field. *Review of Managerial Science*, *12*(3), pp. 803-848.
Schönbeck, P., Löfsjögård, M., & Ansell, A. (2020). Quantitative review of construction 4.0 Technology presence in construction project research. *Buildings*, *10*(10), 173.
Secinaro, S., Brescia, V., Calandra, D., & Biancone, P. (2020). Employing bibliometric analysis to identify suitable business models for electric cars. *Journal of cleaner production*, *264*, 121503.
Sepasgozar, S. M., Davis, S. R., & Loosemore, M. (2018). Dissemination practices of construction sites' technology vendors in technology exhibitions. *Journal of Management in Engineering*, *34*(6), 04018038.
Sev, A. (2009). How can the construction industry contribute to sustainable development? A conceptual framework. *Sustainable Development*, *17*(3), pp. 161-173.
Shah, S. H. H., Lei, S., Ali, M., Doronin, D., & Hussain, S. T. (2019). Prosumption: bibliometric analysis using HistCite and VOSviewer. *Kybernetes*, *49*(3), pp. 1020-1045.
Shin D. H. & Jang, W. S. (2009). Utilization of ubiquitous computing for construction AR technology. *Automation in Construction*, *18*(8), pp. 1063-1069.
Skute, I. (2019). Opening the black box of academic entrepreneurship: a bibliometric analysis. *Scientometrics*, *120*(1), pp. 237-265.
Song, Y., Wang, X., Tan, Y., Wu, P., Sutrisna, M., Cheng, J. C., & Hampson, K. (2017). Trends and opportunities of BIM-GIS integration in the architecture, engineering and construction industry: a review from a spatio-temporal statistical perspective. *ISPRS International Journal of Geo-Information*, *6*(12), 397.
Štefanič, M., & Stankovski, V. (2018). A review of technologies and applications for smart construction. *Proceedings of the Institution of Civil Engineers-Civil Engineering*, *172*(2), pp. 83-87.
Sun, S., Zheng, X., Villalba-Díez, J., & Ordieres-Meré, J. (2020). Data handling in industry 4.0: Interoperability based on distributed ledger technology. *Sensors*, *20*(11), 3046.
Takva, Ç. & İlerisoy, Z. Y. (2021). Investigation of Tessellation Patterns in Long-Span Structures. *Gazi University Journal of Science Part B: Art Humanities Design and Planning*, *9*(3), pp. 235-249.
Takva Ç., İlerisoy Z. Y., & Takva Y. (2022). Investigation of the Shard Tower within the Scope of Advanced Construction Techniques. *Mediterranean International Conference on Research in Applied Sciences*. Antalya, Turkey. April 22-24, 2022. pp. 385-398.
Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. *The International Journal of Advanced Manufacturing Technology*, *94*(9), pp. 3563-3576.
Tay, Y. W. D., Panda, B., Paul, S. C., Noor Mohamed, N. A., Tan, M. J., & Leong, K. F. (2017). 3D printing trends in building and construction industry: a review. *Virtual and Physical Prototyping*, *12*(3), pp. 261-276.
Top, S. M., & Topraklı, A. (2022). Analysis of the open or closed conditions of drum windows effect on visibility and temperature propagation with fire dynamics simulation in domed mosque design. *Journal of the Faculty of Engineering and Architecture of Gazi University*, *37*(4), pp. 1839-1853.
Turk, Ž., & Klinc, R. (2017). Potentials of blockchain technology for construction management. *Procedia engineering*, *196*, pp. 638-645.
Turner, C. J., Oyekan, J., Stergioulas, L., & Griffin, D. (2021). Utilizing industry 4.0 on the construction site: Challenges and opportunities. *IEEE Transactions on Industrial Informatics*, *17*(2), pp. 746-756.
Valente, M., Sibai, A., & Sambucci, M. (2019). Extrusion-based additive manufacturing of concrete products: revolutionizing and remodeling the construction industry. *Journal of composites science*, *3*(3), 88.
Van Eck, N. J., & Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics*, *111*(2), pp. 1053-1070.
Villalba-Díez, J., Molina, M., Ordieres-Meré, J., Sun, S., Schmidt, D., & Wellbrock, W. (2020). Geometric deep lean learning: Deep learning in industry 4.0 cyber–physical complex networks. *Sensors*, *20*(3), 763.
Waltman, L., Van Eck, N. J., & Noyons, E. C. (2010). A unified approach to mapping and clustering of bibliometric networks. *Journal of informetrics*, *4*(4), pp. 629-635.
Wang, C., & Cho, Y. K. (2015). Smart scanning and near real-time 3D surface modeling of dynamic construction equipment from a point cloud. *Automation in Construction*, *49*, pp. 239-249.
Wang, C. C., & Ho, Y. S. (2016). Research trend of metal–organic frameworks: a bibliometric analysis. *Scientometrics*, *109*(1), pp. 481-513.
Wang, C., Kim, Y., Kim, D. G., Lee, S. H., & Min, S. D. (2020). Smart helmet and insole sensors for near fall incidence recognition during descent of stairs. *Applied Sciences*, *10*(7), 2262.
Wang, J., Li, X., Wang, P., & Liu, Q. (2022). Bibliometric analysis of digital twin literature: A review of influencing

factors and conceptual structure. *Technology Analysis & Strategic Management*, pp. 1-15.
Wang, J., Lim, M. K., Wang, C., & Tseng, M. L. (2021). The evolution of the Internet of Things (IoT) over the past 20 years. *Computers & Industrial Engineering*, *155*, 107174.
Wang, P., Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *International journal of environmental research and public health*, *15*(6), 1204.
Wolniak, R., Saniuk, S., Grabowska, S., & Gajdzik, B. (2020). Identification of energy efficiency trends in the context of the development of industry 4.0 using the Polish steel sector as an example. *Energies*, *13*(11), 2867.
Wu, G., Duan, K., Zuo, J., Yang, J., & Wen, S. (2016). System dynamics model and simulation of employee work-family conflict in the construction industry. *International journal of environmental research and public health*, *13*(11), 1059.
Xie, H., Zhang, Y., Wu, Z., & Lv, T. (2020). A bibliometric analysis on land degradation: Current status, development, and future directions. *Land*, *9*(1), 28.
Xu, Y., Zhou, Y., Sekula, P., & Ding, L. (2021). Machine learning in construction: From shallow to deep learning. *Developments in the built environment*, *6*, 100045.
Xu, Z., & Zheng, N. (2021). Incorporating virtual reality technology in safety training solution for construction site of urban cities. *Sustainability*, *13*(1), 243.
Yang, Y., Reniers, G., Chen, G., & Goerlandt, F. (2019). A bibliometric review of laboratory safety in universities. *Safety Science*, *120*, pp. 14-24.
Yevu, S. K., Ann, T. W., & Darko, A. (2021). Digitalization of construction supply chain and procurement in the built environment: Emerging technologies and opportunities for sustainable processes. *Journal of Cleaner Production*, *322*, 129093.
Yin, M., Tang, L., Zhou, T., Wen, Y., Xu, R., & Deng, W. (2020). Automatic layer classification method-based elevation recognition in architectural drawings for reconstruction of 3D BIM models. *Automation in Construction*, *113*, 103082.
Zavadskas, E. K. (2010). Automation and robotics in construction: International research and achievements. *Automation in construction*, *19*(3), pp. 286-290.
Zavadskas, E. K., Sušinskas, S., Daniūnas, A., Turskis, Z., & Sivilevičius, H. (2012). Multiple criteria selection of pile-column construction technology. *Journal of civil engineering and management*, *18*(6), pp. 834-842.
Zhang, C., & Arditi, D. (2020). Advanced progress control of infrastructure construction projects using terrestrial laser scanning technology. *Infrastructures*, *5*(10), 83.
Zhang, P., Du, Y., Han, S., & Qiu, Q. (2022). Global Progress in Oil and Gas Well Research Using Bibliometric Analysis Based on VOSviewer and CiteSpace. *Energies*, *15*(15), 5447.
Zhang, Y., Liu, H., Kang, S. C., & Al-Hussein, M. (2020). Virtual reality applications for the built environment: Research trends and opportunities. *Automation in Construction*, *118*, 103311.
Zhao, L., Liu, Z., & Mbachu, J. (2019). Development of intelligent prefabs using IoT technology to improve the performance of prefabricated construction projects. *Sensors*, *19*(19), 4131.
Zheng, Y., Tang, L. C., & Chau, K. W. (2021). Analysis of Improvement of BIM-Based Digitalization in Engineering, Procurement, and Construction (EPC) Projects in China. *Applied Sciences*, *11*(24), 11895.
Zhou, H., Wang, H., & Zeng, W. (2018). Smart construction site in mega construction projects: A case study on island tunneling project of Hong Kong-Zhuhai-Macao Bridge. *Frontiers of Engineering Management*, *5*(1), pp. 78-87.
Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. *Organizational research methods*, *18*(3), pp. 429-472.