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IoT applications in occupational health and safety in the construction industry: Bibliometric, visual, and methods analyses

İnşaat sektöründe iş sağlığı ve güvenliğinde IoT uygulamaları: Bibliyometrik, görsel ve yöntem analizleri

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Abstract

The Internet of Things (IoT) has become an indispensable methodology for integrating technology into the fabric of daily life. The construction industry is one of the emerging application areas of the IoT. In the construction industry context, occupational health and safety (OHS) represents a critical and developing IoT application area. Consequently, the objective of this study is to present a map of the applications of IoT technology in the OHS field, a rapidly developing research area within the construction industry. A total of 80 publications were included in the study, comprising 72 from the Web of Science (WoS) database and 8 from the Scopus database. The bibliometric analysis of the collected data, text mining, and the creation of visual maps were conducted using the Bibliometrix and VOSviewer tools. The reviewed publications were also analyzed by categorizing them according to the methods employed. The study revealed that the current agenda should be expanded by combining the keywords identified in niche themes with the keywords identified in motor themes. This study offers a comprehensive and up-to-date overview for researchers interested in research and innovations. The study will facilitate identifying essential changes and trends in the literature for researchers.

Anahtar kelimeler: Internet of Things, IoT, Occupational health and safety, Construction industry, Systematic literature review.

Öz

Nesnelerin interneti (IoT) teknolojinin günlük yaşama entegre edilmesinde kullanılan önemli yöntemlerden biri haline gelmiştir. IoT'un gelişen uygulama alanlarından biri de inşaat sektörüdür. İnşaat sektöründe halen güncel ve gelişime açık konulardan biri de iş sağlığı ve güvenliğidir (İSG). Dolayısıyla bu çalışma inşaat sektöründe giderek büyüyen bir araştırma alanı olan IoT teknolojisinin İSG alanındaki uygulamaların bir haritasını sunmayı amaçlamaktadır. Çalışmaya Web of Science (WoS) veri tabanından 72, Scopus veri tabanından 8 adet olmak üzere toplam 80 makale dâhil edilmiştir. Toplanan verilerin bibliyometrik analizinde, metin madenciliğinde ve görsel haritaların oluşturulmasında Bibliometrix ve Vosviewer araçları kullanılmıştır. Ayrıca incelenen yayınlar, kullanılan yöntemler bakımından kategorilere ayrılarak analiz edilmiştir. Çalışma, mevcut gündemin niş temalarda belirlenen anahtar kelimelerin motor temalarda belirlenen anahtar kelimeler ile birleştirilerek genişletilmesi gerektiği sonucunu ortaya çıkarmıştır. Bu çalışma, alandaki araştırmalarla ve yeniliklerle ilgilenen araştırmacılara güncel bir özet sunmaktadır. Araştırmacıların literatürdeki önemli değişiklikleri ve eğilimleri fark etmelerine katkı sağlayacaktır.

Keywords: Nesnelerin interneti, IoT, İş sağlığı ve güvenliği, İnşaat sektörü, Sistematik literatür taraması.

1 Introduction

Construction sites pose the risk of many occupational accidents due to their highly dynamic structure [1],[2]. It remains one of the most prominent figures in the industries where the highest number of fatal work accidents occur in numerous countries [3],[4].

Various and numerous materials and types of equipment are used in construction activities. Commonly, unskilled workers work in construction works. Since the activities must be completed within a specific period, work is done quickly and often carelessly. The growth trend in the construction industry over the years has led to an increase in the number of workers. All these reasons make the construction sector risky and prone to occupational accidents. In countries worldwide, many studies and local legal regulations are carried out to provide OHS in construction. In recent years, technological developments have begun to be rapidly adapted to prevent occupational accidents in the construction industry. One of these adaptations is the use of IoT technologies for OHS purposes. IoT is a network in which data on objects, machines, and environments are collected and exchanged through network connections and sensors [5]-[8]. Information is shared between users and many objects, including sensors, vehicles, houses, and devices connected to the internet [9],[10]. Applications such as wearable technologies and early warning systems are used to prevent occupational accidents through IoT. Therefore, adapting communication between "things" that do not involve human intervention to OHS applications is an essential field of study.

In the literature, there are studies on OHS applications of IoT technology. Kanan et al. (2018) developed an IoT-based alert tracking system that detects passage through dangerous areas [11]. Yang et al. (2020) introduced an IoT-integrated system that warns the user about the misuse of personal protective equipment [12]. Chung et al. (2020) accumulated near-miss-accident data through IoT [13]. Okpala et al. (2020) determined that integrating IoT into safety systems reduces costs related to occupational accidents [14]. Prabha et al. (2021)'s IoT-based model reduced the number of injuries [15]. Wang et al. (2022) proposed an IoT-related system to take appropriate safety measures for different accident zones [16]. Zhang et al. (2022) developed an IoT-based system that tracks construction site entries and exits [17]. Yuan et al. (2024) developed a personal

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safety monitoring system for construction sites that employ artificial intelligence and IoT technology [18]. Construction workers' perspectives on data collection via IoT for OHS were evaluated by Häikiö et al. (2020) [19]. Tabatabaee et al. (2022) identified factors that are fences to the use of IoT-based technologies [20]. According to Waqar et al. (2023), despite the numerous advantages of IoT technologies, technology adoption in small construction projects is a significant obstacle [21].

Studies in literature provide valuable contributions to the applications of IoT in the field of OHS. A paucity of studies has been conducted that provide comparative analyses of the application of IoT, an emerging technology, for OHS purposes in the construction industry. In addressing this dearth of research, this study aims to review and systematically analyze extant studies methodically. Systematic reviews provide essential contributions to issues such as identifying new research topics, problems that need to be corrected in future studies and evaluating how and why events occur [22]. Within the scope of this study, information on the studies carried out until February 2024 on the use of IoT for OHS purposes in the construction industry was obtained from WoS and Scopus databases, and bibliometric analyses were carried out. While WoS primarily covers studies in the field of natural sciences and engineering, studies in the field of social sciences are mainly covered by Scopus [23]. These two databases cover partially overlapping areas [23]. Therefore, combining publications from these two databases provided a broader literature.

The main aim of this study is to find answers to the following questions:

1) What are the general features and trends of the studies on the application of the IoT in the field of OHS in the construction industry? What are the most and least developed research areas? What are the potential future areas?
2) What are the methods in which IoT is integrated for OHS purposes in studies?

Following the objectives mentioned above, the subsequent sections of the study are structured as follows: Section 2 introduces the research methodology. Section 3 presents the results and discussions of the research. Section 4 includes limitations and potential future areas of investigation. Section 5 presents the results of the paper.

2 Methodology

In this study, Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) stages were applied to perform bibliometric analysis. PRISMA is a crucial protocol that can be applied in any field with a systematic literature review. It ensures that study results are reported accurately, transparently, and traceability [22],[24]-[26]. PRISMA stages were applied to decide which publications listed from the WoS and Scopus databases would be included in this study. The PRISMA flow chart adapted from Page et al. (2021) includes the phases of identification, screening, eligibility, and inclusion, as seen in Figure 1 [22].

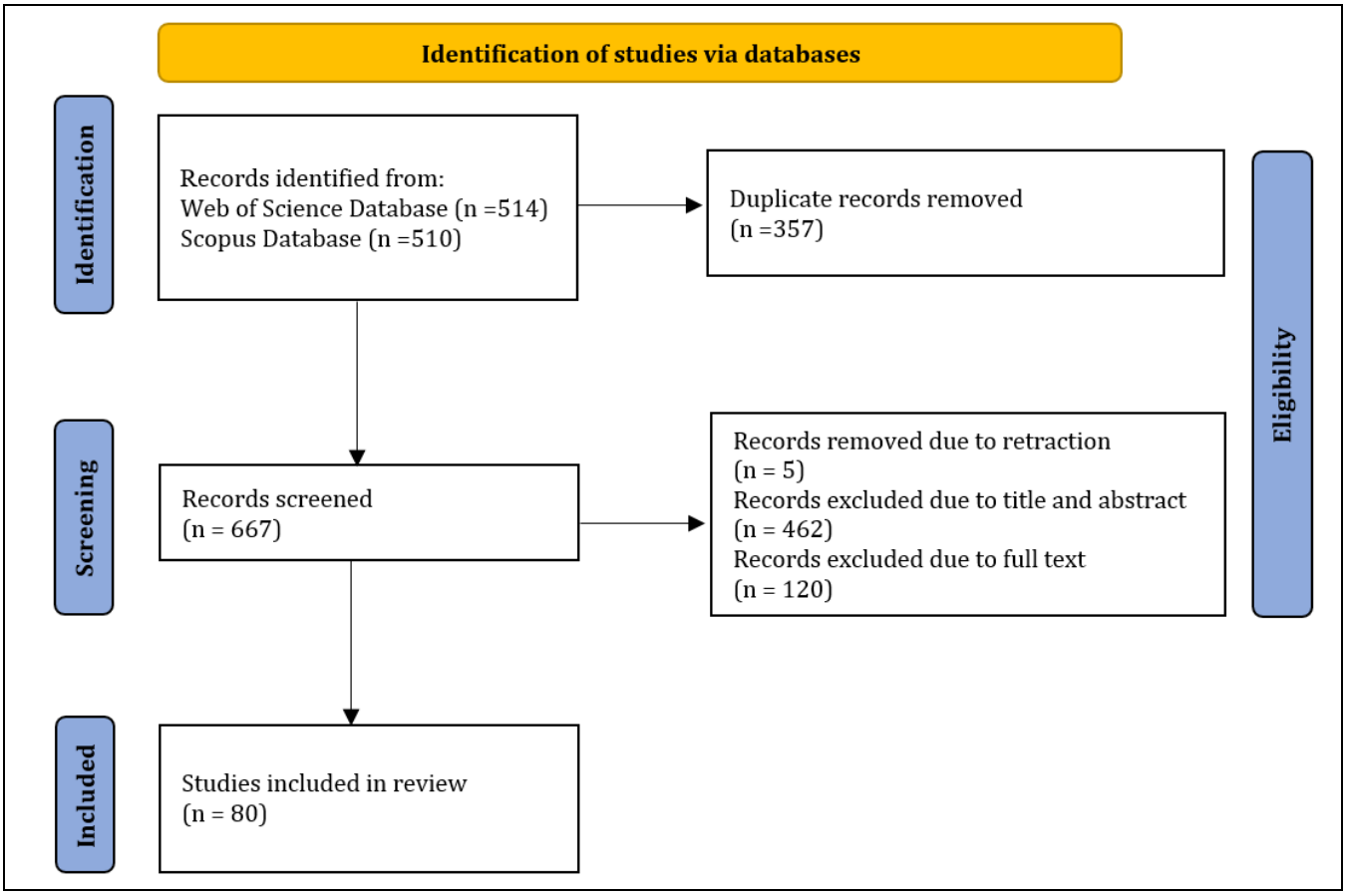


Figure 1. PRISMA flow chart used in a systematic literature review of IoT applications in the field of OHS in the construction industry.

Search strategy, inclusion and exclusion criteria, and keywords are shown in Table 1. The search query identifies three critical areas of interest: firstly, the IoT applications; secondly, the construction industry; and thirdly, OHS. A literature review was performed to categorize the most appropriate search keywords. The OR Boolean operator found any words, including synonyms, abbreviations, and alternative spellings. The AND Boolean operator combined the three parts that were searched. Wildcards were used to make the search shorter and more straightforward. The asterisk (*) wildcard used in searches replaces zero or more characters. For instance, a search for "construction work*" may yield results containing "construction work," "construction works," or "construction worker". A search for the keywords TS "*example keyword*" in WoS and (TITLE-ABS-KEY("*example keyword*")) in Scopus yields a list of publications that contain the search terms in their title, abstract, or keywords [27]. The search strategy was last executed on February 8, 2024.

Under the limitations delineated in Table 1, 514 articles from the WoS and 510 articles from the Scopus were identified. When duplications were removed, 667 publications were listed. Titles and abstracts were then analyzed, and 462 articles irrelevant to the research questions were eliminated. A further 5 publications were excluded due to retractions. A full-text review was performed according to the inclusion criteria, and 120 more publications were eliminated. Some of the publications in which full texts were reviewed were eliminated because they focused on structural health and structural safety (e.g., [28]-[30]) and did not address OHS. After the elimination phase, 80 publications were determined to be included in the study, 72 from WoS and 8 from Scopus.

The profiles of the selected publications were exported separately from WoS and Scopus databases in BibTeX Document (.bib) format. WoS and Scopus employ disparate citation versions, even when the cited publication is identical [23].

Table 1. Search strategy.

Search Criteria	Search string	Inclusion Criteria	Exclusion Criteria
Database	TS= ("internet of things" OR "internet of thing" OR "internet of thing* technolog*" OR "internet of thing* (IoT)" OR "internet of thing* (IOT)" OR "iot" OR "IoT" OR "IOT" OR "industry 4.0" OR "construction 4.0" OR "technolog* 4.0") AND TS= ("construction industry" OR "construction" OR "construction site*" OR "construction project*" OR "construction sector" OR "building industry" OR "building sector") AND TS= ("occupational health and safety" OR "occupational safety and health" OR "occupational risk*" OR "safety" OR "health" OR "health and safety" OR "safety and health" OR "health care" OR "healthcare" OR "safety management" OR "construction safety" OR "construction safety management" OR "safety engineering" OR "personal safety" OR "safety risk*" OR "construction work*" OR "accident*" OR "accident prevention" OR "construction hazard*")	Web of Science	Other databases
	(TITLE-ABS-KEY ("internet of things" OR "internet of thing" OR "internet of thing* technolog*" OR "internet of thing* (IoT)" OR "internet of thing* (IOT)" OR "iot" OR "IoT" OR "IOT" OR "industry 4.0" OR "construction 4.0" OR "technolog* 4.0") AND TITLE-ABS-KEY ("construction industry" OR "construction" OR "construction site*" OR "construction project*" OR "construction sector" OR "building industry" OR "building sector") AND TITLE-ABS-KEY ("occupational health and safety" OR "occupational safety and health" OR "occupational risk*" OR "safety" OR "health" OR "health and safety" OR "safety and health" OR "health care" OR "healthcare" OR "safety management" OR "construction safety" OR "construction safety management" OR "safety engineering" OR "personal safety" OR "safety risk*" OR "construction work*" OR "accident*" OR "accident prevention" OR "construction hazard*"))	Scopus	Other databases
Field	Topic	Web of Science	Words not included in the topic
	Title, abstract and keywords	Scopus	Words not included in the title, abstract and keywords
Document Type	Articles, Early Access	Articles	Review articles and other documents
Source	Journals	Journals	Publications other than the journals
Language	English	English	Other languages
Publication years	Till the end of January 2024	Till the end of January 2024	Early February 2024

For this reason, the files exported from WoS and Scopus databases had to be combined into the same version, even though they had the same extension. Combining was done in R Studio. After combining, Bibliometrix software was used for text mining. The files exported from both databases were also combined in RIS format and made suitable for creating visual maps in VOSviewer.

3 Results and discussions

The results obtained by performing bibliometric and visual analyses of 80 publications collected from WoS and Scopus databases according to the constraints in Table 1 and determined according to the process in Figure 1 are discussed below.

3.1 Analysis of publication trend by year

The publication trend offers a valuable vision of the evolution of scientific research [31]. The distribution of the publications included in the study by years is shown in Figure 2.

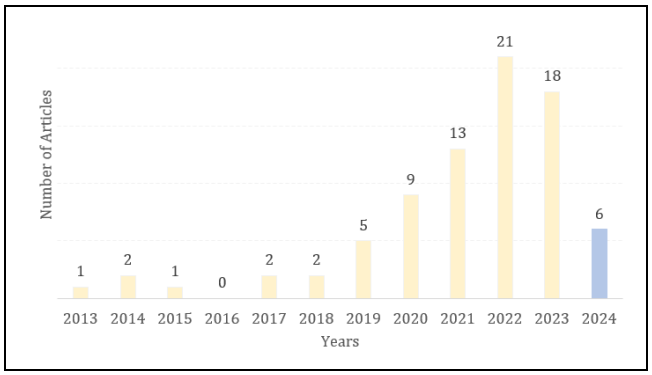


Figure 2. Annual distribution of research articles included in this study.

It can be observed that the field of IoT applications as part of OHS in the construction industry commenced in 2013. The reason for this situation is that Industry 4.0 was announced in 2013 [32]. Although the rate of increase between 2013 and 2018 was slow, it is seen that interest in the subject has increased since 2019 and peaked in 2022. 6 publications from 2024 were included in this study. These 6 publications were published in January 2024 and presented as early access. Although it looks like a sharp decline in the graph, it does not yet reflect the trend of 2024. On the contrary, it contributes 7,5% to this study in the year's first month. This rate shows that the subject has received broad interest and recognition.

Articles published in 2022, 2023, and 2024 correspond to 56% of this study. This rate is an essential indicator of a literature gap on the subject.

3.2 Analysis of sources of publications

The distribution of the publications subjected to bibliometric analysis according to their sources and years of publication is presented in Table 2.

Considering their distribution within the total, the most relevant source is *"Sensors"*, with 13%, followed by *"Automation in Construction"*, with 11%. The contribution rate of *"Applied Sciences-Basel"*, *"International Journal of Environmental Research, and Public Health"* and *"Sustainability"* journals is 5%. While the rate for the *"International Journal of Construction Management"* and *"Journal of Construction Engineering and Management"* is 4%, *"Buildings"*, *"Construction Innovation-England"*, *"Journal of Building Engineering"*, *"Journal of Engineering Design and Technology"*, *"Journal of Management in Engineering"*, and *"Safety Science"* have a rate of 3%. The rate of each remaining source is 1%.

The institutions and countries where IoT applications are addressed in the field of OHS in the construction industry are analyzed and given in Figure 3.

Table 2. Most relevant sources.

Journal	Distribution numbers of publications by years												Total
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	
"Sensors"		1				1		1	3	1	2	1	10
"Automation in Construction"	1				1	1	1	2	2	1			9
"Applied Sciences-Basel"										2	1	1	4
"International Journal of Environmental Research and Public Health"									1	3			4
"Sustainability"									2	2			4
"International Journal of Construction Management"										2	1		3
"Journal of Construction Engineering and Management"							1			1	1		3
"Buildings"											1	1	2
"Construction Innovation-England"										2			2
"Journal of Building Engineering"								1			1		2
"Journal of Engineering Design and Technology"											1	1	2
"Journal of Management in Engineering"								1		1			2
"Safety Science"											2		2
"Advances in Civil Engineering"									1				1
"Computer-Aided Design and Applications"												1	1
"Electronics"											1		1
"Engineering Construction and Architectural Management"								1					1
"Frontiers of Engineering Management"										1			1
"Heliyon"											1		1
"IEEE Access"											1		1
"IEEE Sensors Letters"											1		1
"IEEE Transactions on Industrial Informatics"								1					1
"Infrastructures"											1		1

Table 2. Continued.

Journal	Distribution numbers of publications by years												Total
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	
"Intelligent Automation and Soft Computing"											1		1
"International Journal of Advanced Operations Management"									1				1
"International Journal of Electrical and Electronics Research"										1			1
"International Journal of Grid and High-Performance Computing"								1					1
"Iranian Journal of Science and Technology-Transactions of Civil Engineering"										1			1
"Journal of Civil Engineering and Management"										1			1
"Journal of Cleaner Production"										1			1
"Journal of Construction in Developing Countries"									1				1
"Journal of Information Technology in Construction"		1											1
"Journal of Intelligent and Fuzzy Systems"												1	1
"Lecture Notes in Electrical Engineering"			1										1
"Measurement"							1						1
"Neural Computing & Applications"										1			1
"Practice Periodical on Structural Design and Construction"								1					1
"Safety"							1						1
"Safety and Health at Work"									1				1
"Sensors and Materials"							1						1
"SSRG International Journal of Electrical and Electronics Engineering"											1		1
"Structures"											1		1
"Technology in Society"									1				1
"Transactions of the İnstitute of Measurement and Control"					1								1

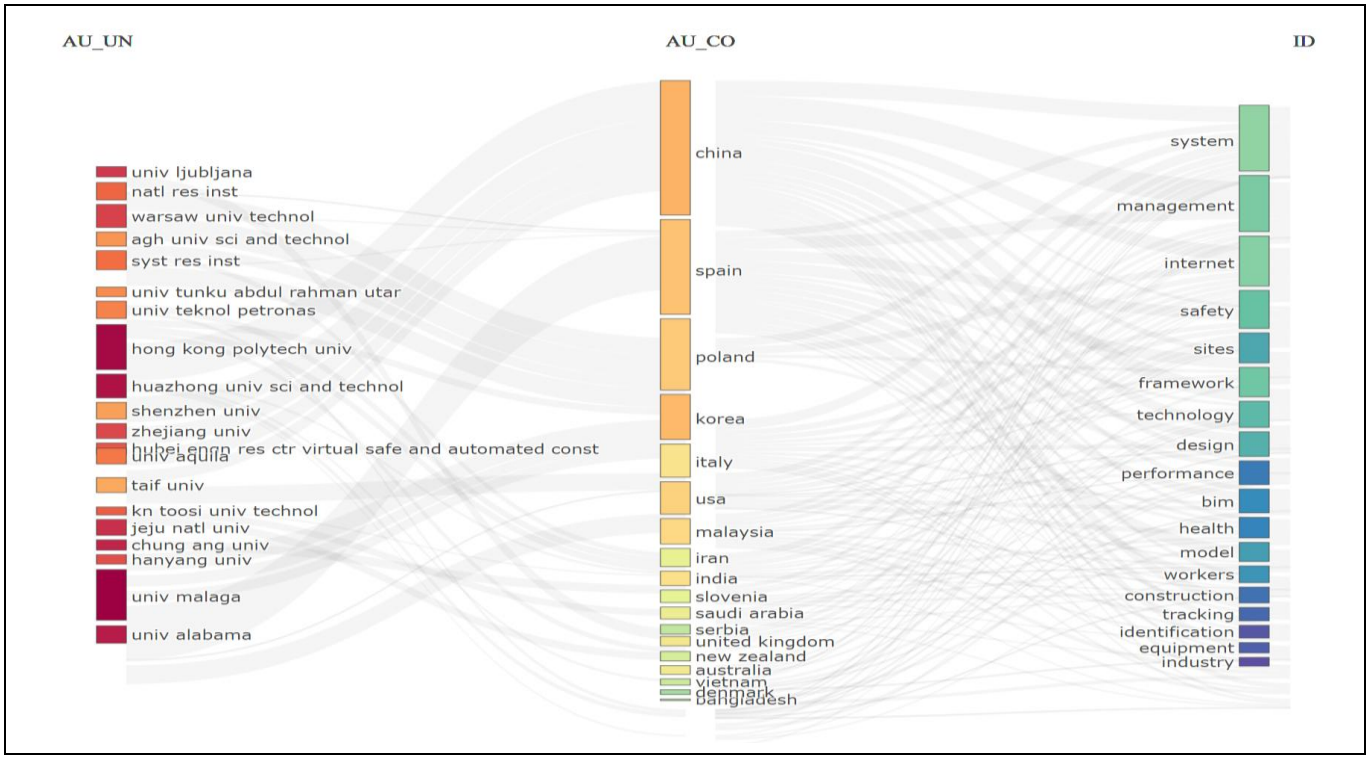


Figure 3. Three-field plot of publications.

The left part of Figure 3 represents affiliations, the middle represents countries, and the right part represents keyword pluses. Keyword Plus are words and word groups indexed from the titles of cited publications. The gray lines represent the connection between the parts. According to Figure 3, it is seen that the country that shows the most interest and contribution to the subject is China and contributes to all the topics highlighted in Keyword Plus. It seems that most of the research on the subject is done by Hong Kong Polytech University in China. In second place is the University of Malaga in Spain.

Other countries that significantly focus on the subject include Poland, South Korea, Italy, the USA, Malaysia, and others, as illustrated in Figure 3.

3.3 Analysis of keywords co-occurrence

According to the keyword co-occurrence approach, there is a contextual correlation between words that occur frequently together and gives an idea about the future of the research field [33]. 80 publications included in the bibliometric analysis were transferred to VOSviewer software for keywords co-occurrence analysis. VOSviewer allows tracking the link between author keywords. At this phase, some keywords had to be combined to obtain meaningful correlation. For instance, the author keywords "internet of things (iot)" or "iot" correspond to the keyword "internet of things".

Similarly, both author keywords expressed as "construction worker" and "construction workers" correspond to the "construction worker". Combining synonyms results in more meaningful correlations. Otherwise, VOSviewer analyzes synonymous keywords as different keywords. A thesaurus file was used to combine synonyms. Following the combination of the data sets, when the lower threshold limit for keyword co-occurrence analysis was set to 3, the number of keywords identified in the analyzed publications was 336. The visualization network map in Figure 4 was created using VOSviewer's clustering techniques. The visualization network map includes 30 nodes, 126 links, 211 total link strength, and 6 color sets. The number of times a keyword appears is called the occurrence metric [34]. The nodes in Figure 4 represent the occurrence metric. The size of a node is directly related to how often a keyword appears in different publications. The lines get thicker as the links get more frequent [35]. The length of the curved lines between keywords shows how connected they are [36]. The longer the curved line between two keywords, the less likely these two keywords appear in the same scientific study. The colors of the nodes represent keyword groups that are comparatively strongly correlated to each other.

Figure 4 illustrates the distribution of the six clusters, with the first cluster represented by red, the second by green, the third by blue, the fourth by yellow, the fifth by purple, and the sixth by turquoise. Occurrence metrics, total link strength, links, and average publication year of keywords are given in Table 3. Total link strength shows the connection strength between nodes; links show the number of other nodes connected to a node, and average publication year shows the year a particular keyword was used more on average [37]. In Table 3, the publication year's quartile is given to understand better the period in which the studies were concentrated. For instance, the occurrence of the keyword "accident prevention" is 5, and the total link strength value is 14. The total link strength value shows the strong relationship between the primary keyword "internet of things" and "accident prevention." The number of other keywords linked to "accident prevention" is 10, and studies on the subject are concentrated in the second half of 2022.

Figure 5 shows the overlay visualization map of keywords. As previously stated at the outset of Section 3, research into the utilization of the IoT in the context of OHS within the construction industry has witnessed a marked increase in pace since 2019.

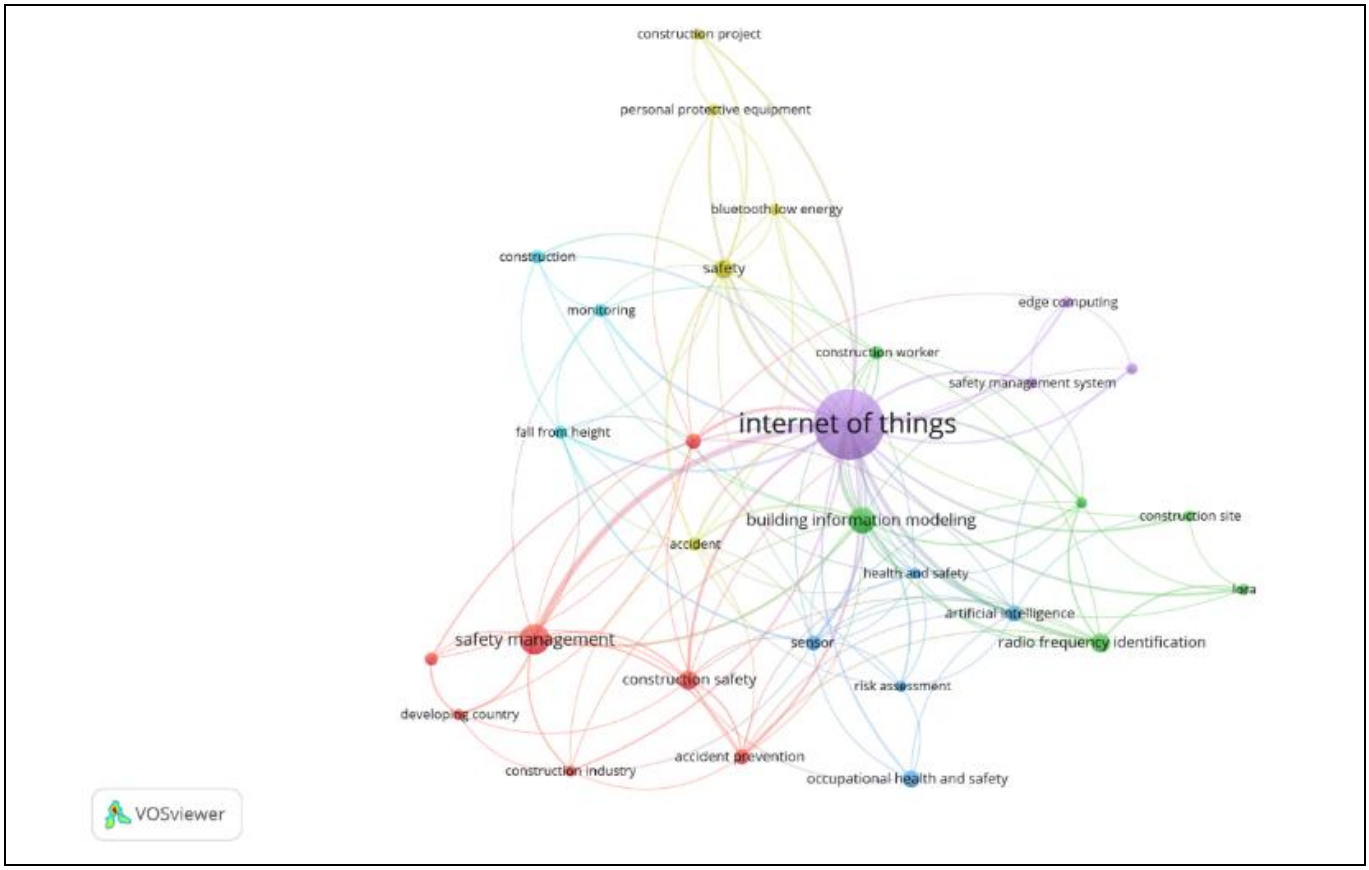


Figure 4. A visual representation generated through a keywords co-occurrence analysis.

Table 3. Pieces of information of network data of keywords.

Keyword	Occurrence metrics	Total link strength	Links	Average publication year	Quartile of publication year
internet of things	52	93	27	2020	4
safety management	14	26	11	2021	1
building information modeling	11	29	16	2021	2
construction safety	7	15	10	2021	3
radio frequency identification	7	18	9	2018	2
safety	7	19	12	2021	3
occupational health and safety	6	6	5	2021	3
accident prevention	5	14	10	2022	3
artificial intelligence	5	11	9	2022	1
sensor	5	16	13	2019	2
worker safety	5	14	11	2022	4
accident	4	15	11	2022	1
construction	4	7	5	2022	1
construction worker	4	9	8	2020	1
fall from height	4	12	9	2021	1
monitoring	4	9	7	2018	3
safety technology	4	7	5	2021	3
bluetooth low energy	3	8	6	2022	2
construction industry	3	9	7	2022	3
construction project	3	6	3	2021	2
construction site	3	6	4	2023	1
developing country	3	7	5	2022	2
edge computing	3	6	4	2021	2
health and safety	3	14	12	2019	3
lora	3	8	5	2021	2
personal protective equipment	3	7	5	2021	3
risk assessment	3	8	7	2021	1
safety management system	3	6	4	2020	1
smart construction	3	5	4	2020	3
wireless sensor network	3	12	8	2016	3

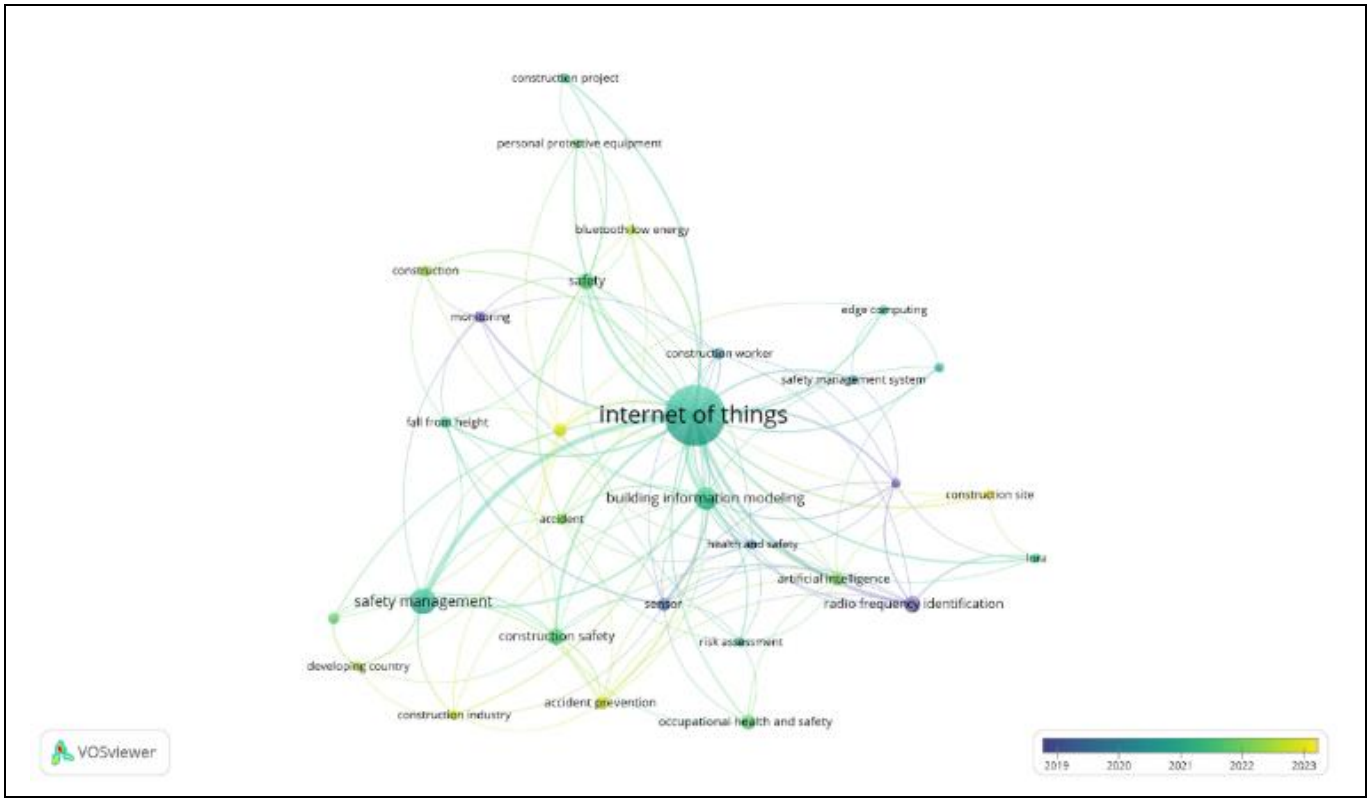


Figure 5. Overlay visualization network map of the keywords co-occurrence analysis.

In the color spectrum in Figure 5, topics related to the keywords represented by blue-purple color were researched between 2013 and 2019 and have not been carried forward to the present day. The color spectrum has turned to green and then yellow since 2021. Yellow clusters give an essential message to researchers. Because the yellow clusters here represent current research areas that need to be focused on [33]. The focus of the studies is shifting towards the yellow nodes. Studies on the "internet of things" were carried out intensively between 2021 and 2022. Studies soon will probably focus more on topics such as "developing country", "accident prevention" and "worker safety".

3.4 Analysis of authorship

The analysis results using Bibliometrix indicate that 280 authors were involved in the 80 publications examined in the study. One of the publications was a single-author study. There was 25% international co-authorship. Information about the ten authors most relevant to the subject is shown in Figure 6.

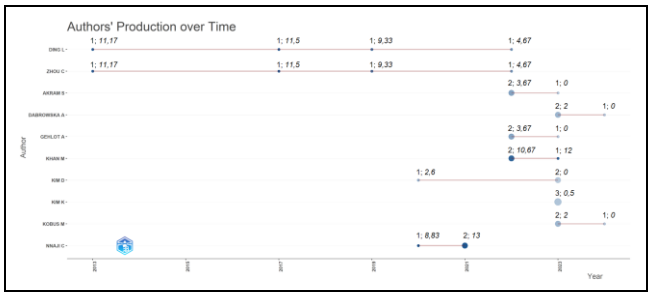


Figure 6. Most relevant ten authors according to the author names, publication year, number of documents, and total citations per year.

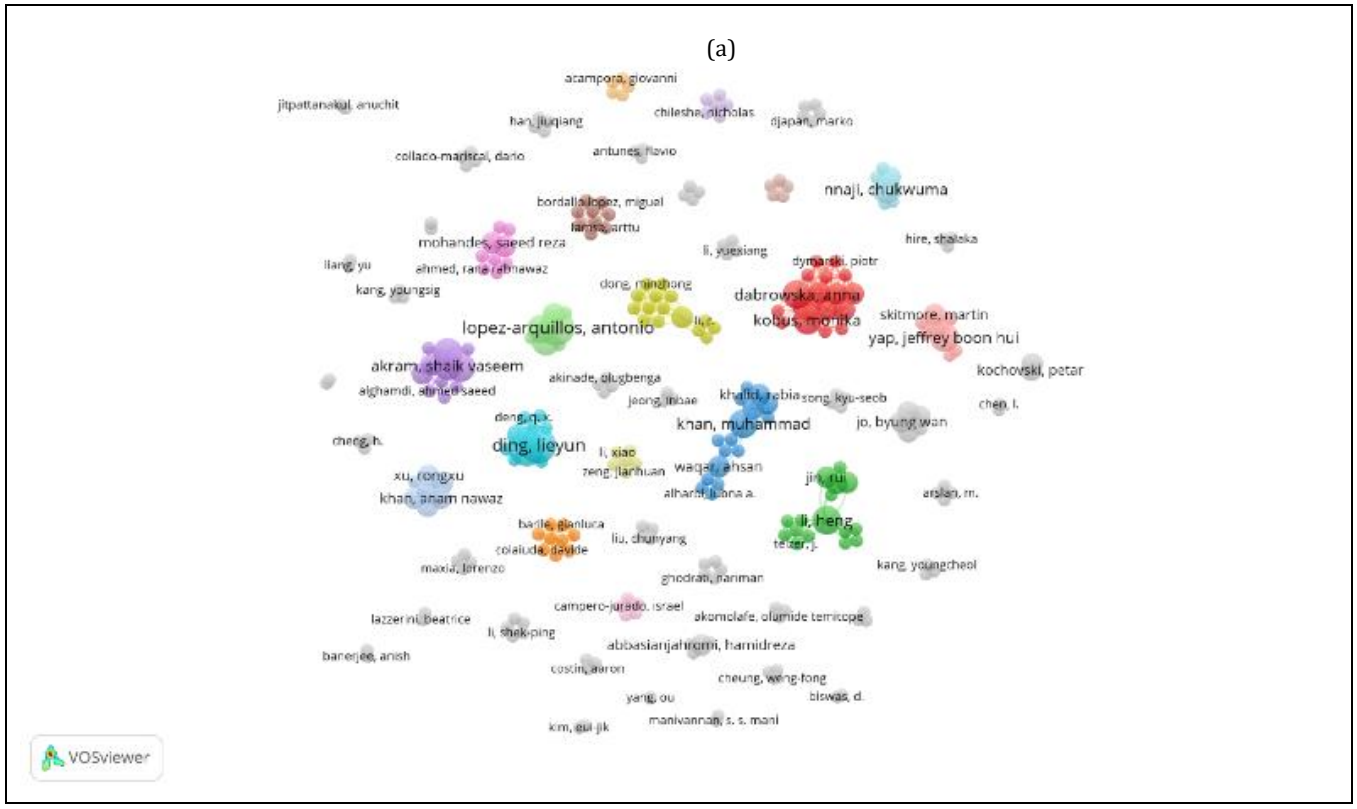
The node size symbolizes the count of publications attributed to the author, while the nodes' darkness indicates the total annual citations. The figures above the nodes indicate the number of publications in the relevant year and the total number of citations per year (in italics). The figure indicates that the subject has recently attracted the attention of numerous authors, particularly in recent years VOSviewer generated the co-authorship network. The co-authorship network, where each node represents an author, is seen in Figure 7(a). Setting the lower limit of documents required for an author to be included in the analysis to 1 resulted in the observation of co-authorships between all authors. The network, which included 280 authors, contained 54 clusters. The largest of the co-authorship clusters, the 1st cluster in Figure 7(b), contains 17 authors, while the smallest cluster contains 1 author.

The authors' names are inscribed on the nodes. The larger the node, the more comprehensive the author's collaboration network. For instance, for Dabroska Anna, Sowinski Piotr, and Kobus Monika, documents are 3, links are 16, and total link strength is 25. The authors' density visualization map is shown in Figure 8. As the authors' studies on IoT applications in the field of OHS in the construction industry increase, the intensity of yellow increases.

3.5 Thematic analysis of publications

Thematic analysis can be considered a simple form of the conceptual structure of the literature, depending on the metrics taken into account. Thematic maps are indicators of the development and popularity of keywords over the years. Thematic maps are helpful for researchers to identify potential areas for future research [38].

(a)



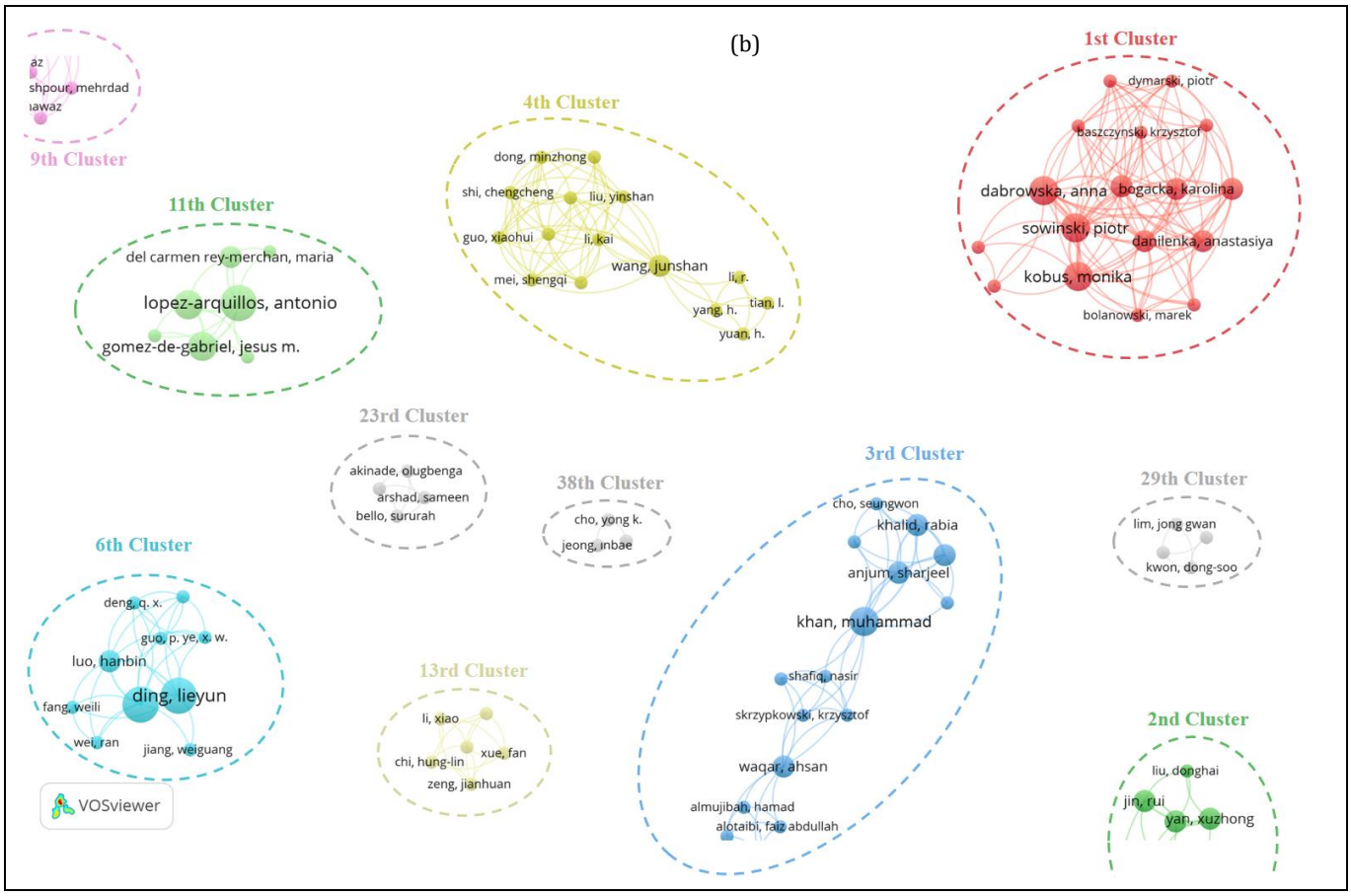


Figure 7. (a): A visual representation of the co-authorship analysis. (b): A part containing the largest and some other clusters of the visualization of the co-authorship analysis.

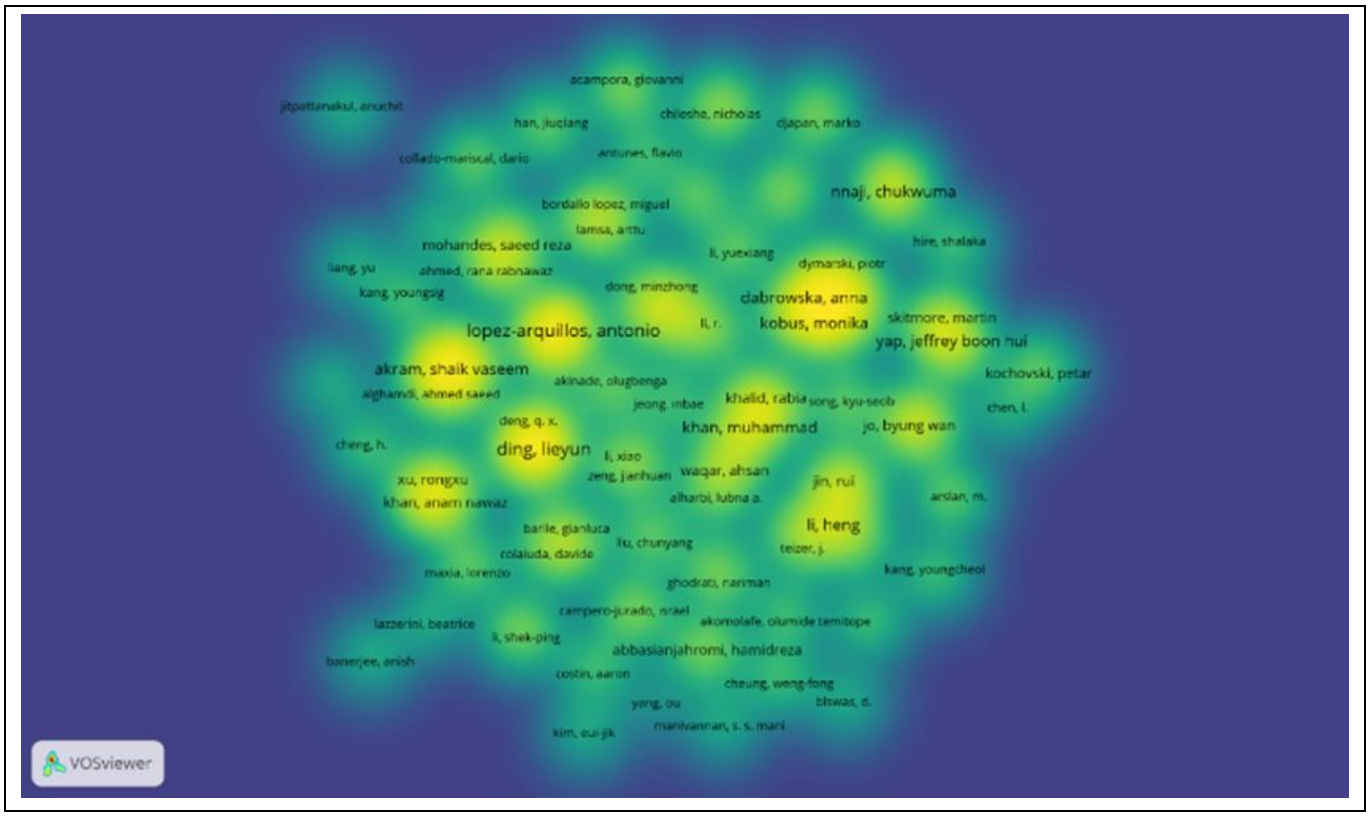


Figure 8. Density visualization map of the co-authorship analysis.

The thematic map generated with the keywords employed by the authors is presented in Figure 9. The horizontal axis, which represents centrality, highlights the significance of the theme in question. The vertical axis indicates intensity and measures the development process of the theme represented on this axis [39]. There are 4 different themes in the thematic map created by Bibliometrix and according to the Walktrap clustering algorithm. The four quarter-circles of the chart are defined as follows: the upper-right quarter-circle contains motor themes, the lower-right quarter-circle contains basic themes, the lower-left quarter-circle contains emerging or declining themes, and the upper-left quarter-circle contains niche themes [40]. According to Figure 9, motor themes represent the most important topics of both high-centered and high-density literature. It is seen that concepts such as the "internet of things", "artificial intelligence", "safety technology", and "early warning system" are at the center of the existing literature on the subject and are widespread research topics. The research topics represented by the basic themes indicate essential but not fully developed research topics within the field of research. Topics such as "construction safety", "accident prevention" and "monitoring system" are examples of lower-right quarter-circle themes. Lower-left quarter-circle themes are the regions that represent newly emerged or disappearing themes. "artificial intelligence", "cyber-physical system", "risk", "industry 4.1" and "construction worker" are represented by emerging or declining themes in this study. In contrast to the extensive internal linking in niche themes, there is a paucity of external links [41]. It shows that topics such as "safety management system", "smart construction" and "blockchain" are potential topics that should be linked more to the topics in motor themes. This result offers an idea for researchers interested in the subject.

Themes such as "radio frequency identification", "construction site" and "lora", which are at the intersection of niche themes and emerging or declining themes, can still be considered niche themes. This indicates that interest in this theme has declined in the research articles included in this study. A decline can be observed in these themes.

3.6 Citation analysis of publications

The 80 publications included in the study had a total of 1420 citations. The distribution of citations according to publications is seen in Figure 10. The figure is sorted from the most cited publication to the with at least one citation. The horizontal axis label includes the name of the first author, year of publication, and abbreviation of the journal name, respectively. The most cited publication has 134 citations. Figure 10 does not show publications that have not yet been cited. Already, 6 of these are new publications published in the first month of 2024.

The co-citation density map generated with Bibliometrix is presented in Figure 11. The normalized citation count of the publications determines the text sizes. Proximities of texts represent co-citation strength. The color intensities of the two articles are used to define the co-citation relationship between them. The density map shows the first author of the publication and the year.

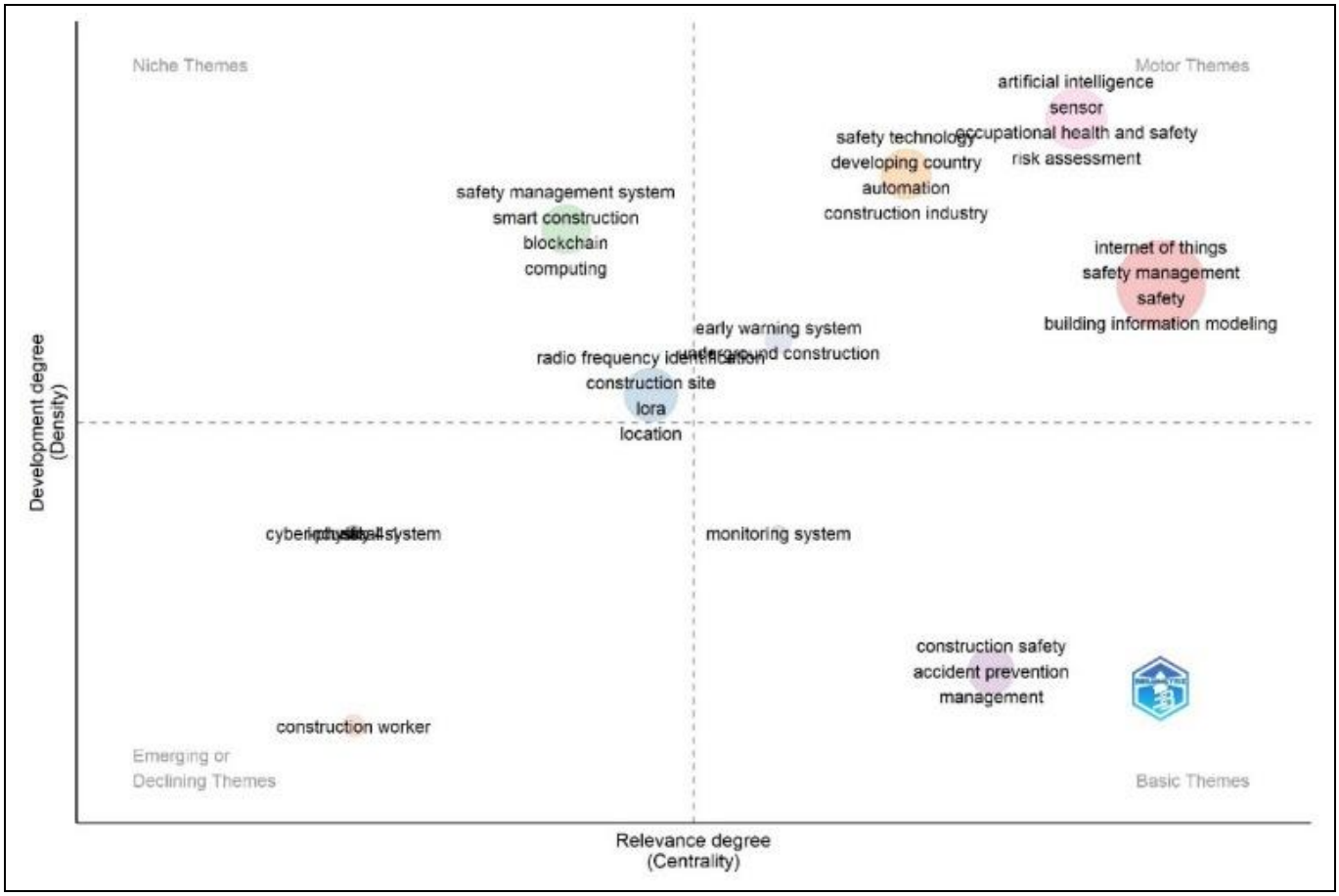


Figure 9. Thematic map of publications according to author keyword.

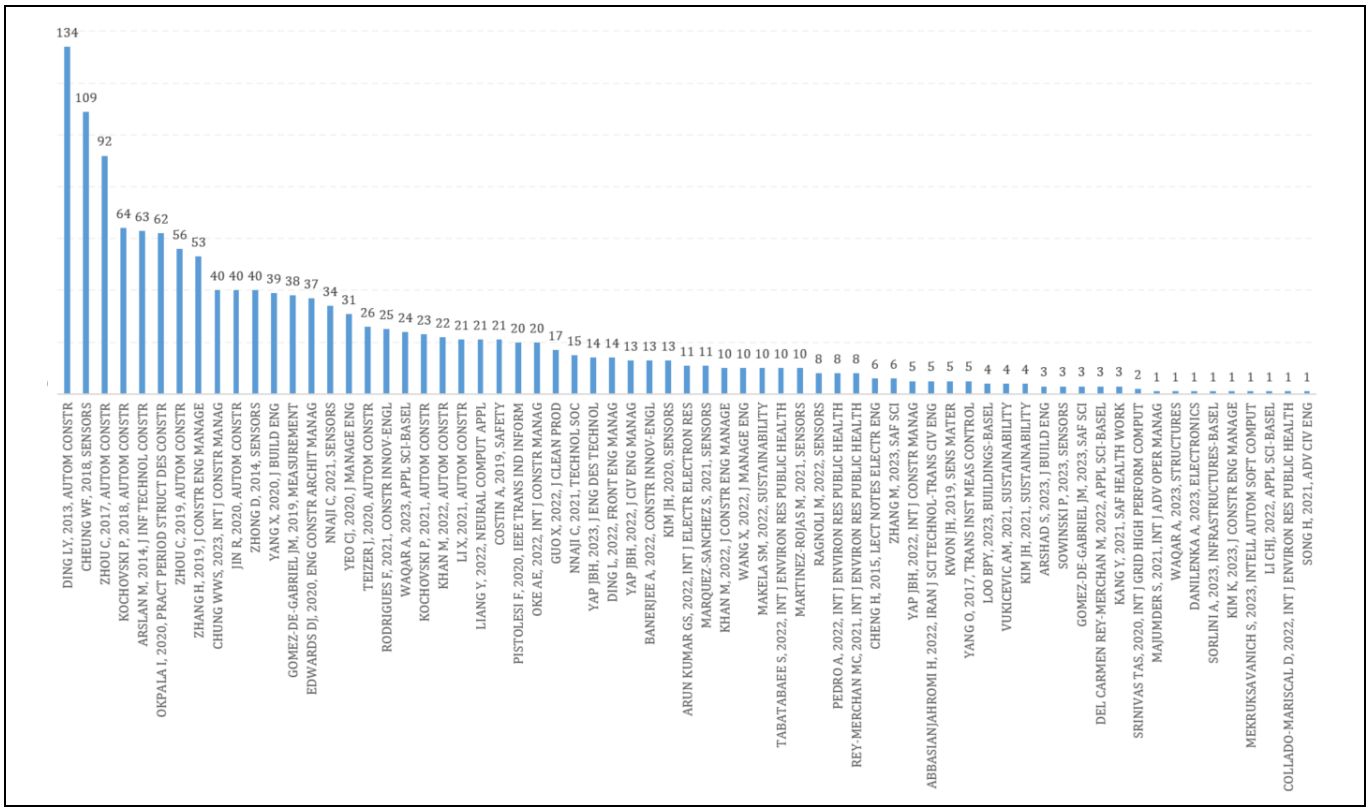


Figure 10. Distribution of total citations by publications.

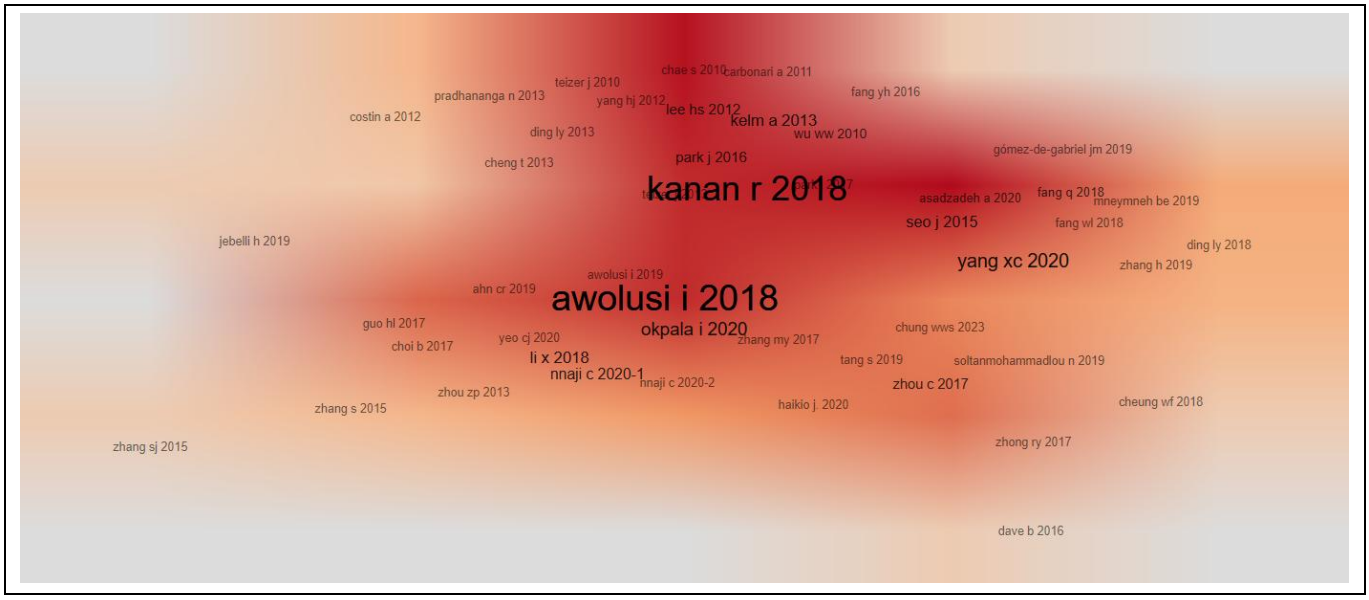


Figure 11. Co-citation density map of publications.

3.7 Method analysis of publications

In this study, a framework was created to classify the analyzed publications in terms of their methods. By examining the methodologies of 80 publications one by one, 9 research methodologies were identified that have been used in studies related to IoT adaptation in the field of occupational safety and health. The research methods employed in these studies were categorized as follows: framework development, model development, experimental, system development, method/approach development, mixed methods, literature review, case study, and other methods (multi-criteria decision-making, dataset introduction, simulation, field study).

Figure 12 presents the proportional distribution of the methods employed in the analyzed publications.

System development is the most frequently adopted method in studies. System development studies were performed using different techniques. To illustrate, although Song et al.'s (2023) study primarily focused on system development, the developed system is based on the deep Siamese neural network technique [42].

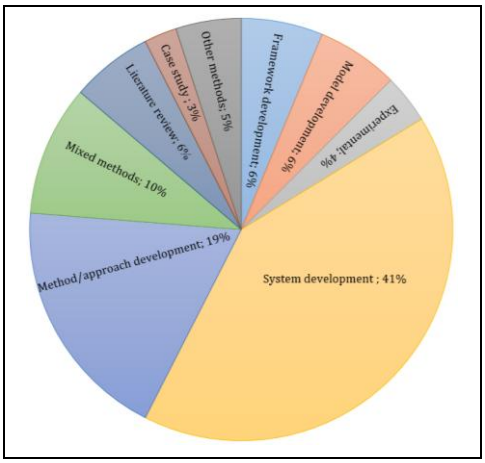


Figure 12. Method analysis distributions.

Additionally, the system developed by Wang et al. (2022) is dependent on literature review and questionnaire techniques [16]. The studies of Rodrigues et al. (2020) and Arslan et al. (2014), listed in the system development category, are presented as the prototype of the developed system [43]-[44]. Vukićević et al.'s (2021) system development study is based on a new technique used by the authors [45]. As a consequence, the majority of studies have adopted methods based on system development to advance OSH in the construction industry.

In 19% of the other studies, the method/approach development method based on different techniques was applied. Four studies on method/approach development were grounded in artificial intelligence or deep learning [46]-[49]. Conversely, five studies focused on accident prevention, leveraging Bluetooth low energy, SPARQL protocol, computer vision, and sensors [50]-[54]. Two studies focused on model development, utilizing survey data collection and statistical analysis [55],[56]. One study focused on real-time monitoring and estimating PM2.5 concentrations at construction sites, while the remaining study adopted an experimental approach [57],[58].

In 10% of the studies, mixed methods were used with a combination of different techniques. For instance, Waqar et al. (2023) employed a synthesis of literature review, expert opinion, interview, and structural equation techniques to enhance the usability of IoT technologies in small construction projects for OHS [21]. Some researchers adapted techniques such as questionnaires, overviews, identification of usage barriers, statistical analysis, and literature review were adapted to IoT applications in the field of OHS [5], [14], [20], [44], [55], [59]-[67]. The studies conducted by Rodrigues et al. (2020), Hire et al. (2024), and Khan et al. (2022) were mainly based on BIM [43], [68], [69]. The studies conducted by Kochovski and Stankovski (2021), Davila-Gonzalez and Martin (2024), and Pistolesi and Lazzerini (2020) were directly based on artificial intelligence [46], [70], [71]. Kim et al. (2021) and Zhou et al. (2019) discussed IoT within sensors [53], [54]. Indirectly, Shafei et al. (2024) included IoT in Construction 4.0 technologies, Kochovski and Stankovski (2018) in edge computing [72], [73].

In a series of studies, IoT was utilized as a component by directly incorporating it into the methodologies employed [12], [13], [16]-[18], [21], [42], [47]-[52], [57], [58], [69], [74]-[109]. Researchers concentrated on specific aspects of IoT utilization for OHS purposes. In this context, one group of researchers examined the application of IoT for safety control [48], [50], [68], [74], [77], [78]. Another group of researchers focused on utilizing IoT for real-time monitoring purposes, as indicated in studies [13], [18], [47], [70], [80], [81], [83], [86], [87], [90], [96], [99], [101], [105], [109]. Some researchers focused on utilizing IoT for the development and implementation of personal protective equipment [12], [42], [52], [64], [66], [69], [71], [75], [76], [85], [93], [94], [102], [103]. Additionally, IoT was employed for accident prevention purposes [16], [17], [43], [44], [49], [51], [53], [54], [56], [58], [60], [65], [79], [84], [88], [91], [92], [104], [106]-[108], [110].

It should be emphasized here that since researchers often use the words system, model, and method interchangeably, text mining results may be affected by this situation [111].

4 Limitations and future potential areas

This study conducted a bibliometric analysis of publications collected from WoS and Scopus databases to provide more extensive literature. According to the conclusion reached by reviewing the studies in the literature, researchers have difficulties combining files exported from different databases because the display formats are different. Since these two databases are widely preferred in literature reviews, there are studies on combining the outputs for systematic literature reviews. For instance Echchakoui (2020), Kumpulainen and Seppänen (2021), Caputo and Kargina (2021) are some of them. However, this is still a barrier for researchers. However, future studies may include other databases [23], [112], [113].

In this study, the search strategy in Table 1 was used. The search strategy had some limitations. Studies written in English, which is the common language, were included in the research. However, many publications have been written in different languages. Language was a significant limitation in this study, as in many bibliometric analyses. The study is limited to the search results performed on March 7, 2024. However, recent studies on the subject have been added to the literature since then. Studies that overcome the barriers mentioned here are one of the potential future study areas.

In this study, the analysis carried out through Bibliometrix determined that the annual growth rate of the subject was 17.69%. Document average age was determined as 2.8. The document average age indicates that the trend toward the subject has increased in recent years. Therefore, the subject is still a hot spot and has the potential for researchers to be interested.

Figure 9 shows the thematic map of the analyzed publications. Section 3.5 interprets the thematic map, and potential study areas are highlighted. The study suggests expanding the current agenda to include the following topics.

The topics related to the keywords "safety management system", "smart construction", "blockchain", "computing", "federated learning", "radio frequency identification", "construction site", "lora", "location" in the niche themes should be related to the topics related to the keywords "artificial intelligence", "sensor", "occupational health and safety", "risk assessment", "safety technology", "developing country", "automation, construction industry", "internet of things", "safety management", "safety", "building information modelling", "early warning system", "underground construction" in the motor themes. Future research can be expanded based on these keywords.

Figure 12 shows the distribution of the methods used in IoT applications in the field of OHS. Proportionally underutilized

methods still have potential. Additionally, the field is open for existing but unimplemented or new methods to be adapted.

5 Conclusions

This study analyzed research trends of IoT applications in the construction industry field of OHS. Shining topics have been highlighted to give researchers ideas for future studies. A detailed analysis of the institutions, countries, authors, and journals that stand out in research in the field is presented. The keywords used in the studies provide important clues. For this reason, the most frequently used keywords and their connections with each other were analyzed through keyword co-occurrence analysis. The thematic analysis determined hot spots and potential points in literature. In the previous section, keywords related to potential research areas were presented. In addition, while various problems in the research area were identified, determining the sources and solutions to these problems are areas of study that can be addressed in future research.

The construction industry continues to present one of the most hazardous environments in terms of OHS. For this reason, emerging technologies inevitably be adopted in the sector for OHS purposes. Although technology offers new opportunities daily, there is no equal opportunity to access technology in the construction industry. IoT technologies seem to be a reasonable technology for both large-scale and small-scale construction companies in terms of applicability and cost.

The analysis shows that the first study was conducted in 2013, with the largest share in the last three years. The novelty of the topic and research trends indicate that it may play an essential role in the future.

6 Author contribution statements

Şerife Ak contributed to generating the idea, analyzing and writing the article, evaluating the results, and checking the article.

7 Ethics committee approval and conflict of interest statement

"There is no need to obtain permission from the ethics committee for the article prepared". "There is no conflict of interest with any person / institution in the article prepared".

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