

Visualization Analysis of Emergency Exit Signs Literature Based on CiteSpace

Hongtao Chen ¹, Jinyi Zhi ^{1,2,*}, Ze-Rui Xiang ^{1,2,*} , Rui Zou ¹ and Tiecheng Ding ¹

¹ Department of Industrial Design, School of Design, Southwest Jiaotong University, Chengdu 611756, China; chenhongtao@my.swjtu.edu.cn (H.C.); zhijinyi@swjtu.edu.cn (J.Z.); sisuisme@my.swjtu.edu.cn (R.Z.); dingtc@my.swjtu.edu.cn (T.D.)

² Institute of Design and Research for Man-Machine-Environment Engineering System, Southwest Jiaotong University, Chengdu 610031, China

* Correspondence: xiangzerui@163.com

Abstract: Emergency exit signs are a mandatory and essential element for the prevention and planning of evacuation in all types of buildings. In recent decades, some achievements have been made in emergency exit signs research, but there is a lack of literature reviews on the subject. This study focused on exploring the research status and development trends in emergency exit signs using a visualization analysis of bibliometrics. The findings of this paper are as follows: First, through co-authorship analysis, we identified countries, institutions, and authors that have made outstanding contributions in the research area. Second, through co-citation analysis, we revealed important journals, documents, and authors in the research field. Third, through keyword co-occurrence analysis, we found research focuses include sign effectiveness, research methods, and research content. And the research frontiers include virtual reality, visibility, and emergency evacuation. The study can serve as a reference for relevant researchers studying emergency exit signs.

Keywords: emergency exit signs; visualization; co-authorship analysis; co-citation analysis; keyword co-occurrence analysis



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1. Introduction

Emergency exit signs are widely used in hotels [1], exhibition halls [2], tunnels [3], transit stations [4], passenger ships [5], and other locations with corresponding regulations [6–9]. They are the primary source of information that people evacuating a structure use to recognize the exit routes [10]. Emergency exit signs can be classified as one of two types [11] based on their installation location: type one is installed above an exit door, with a positioning function, and type two is installed along the path to an exit, with a directional function. According to the display method, a sign can also be either static or dynamic [12]. In emergency situations, these signs not only provide evacuation directions [13] but can also reduce the evacuation time [14] and increase the confidence of escape [5].

As early as the 1960s, Bono and Breed [15] studied the visibility of emergency exit signs. From the 1970s to the 1990s, Jin [16–18], Quellette [19], and Collins et al. [20] researched sign visibility more deeply. In the 21st century, published research regarding emergency exit signs has become more abundant and includes the interactivity [21], intelligibility [22,23], layout design [24], and color selection [25,26] of signs, among other aspects. In addition, tools such as questionnaires [27], eye tracking [28], and virtual reality [29,30] have been applied in the research. After more than 50 years of development, some achievements have been made in emergency exit signs research; however, it currently lacks comprehensive and objective literature reviews. To address this situation, papers related to emergency exit signs were collected for this work from the Web of Science Core Collection (WoSCC) through a topic search. The CiteSpace software was used for co-authorship, co-citation, and keyword co-occurrence analyses. The goal of this study was to understand the main

contributors among countries, institutions, and authors to determine important journals, documents, and authors and to discover the research focuses in the emergency exit signs research field.

The rest of this paper is organized into three primary sections: Section 2 introduces the data sources and research methods. Section 3 presents and thoroughly discusses the results of the visualization analysis. Section 4 indicates the conclusions, prospects, and limitations of the research.

2. Data Collection and Research Methods

2.1. Data Collection

The Web of Science contains articles from many influential academic journals and detailed document information. Many CiteSpace visualization analyses use it as the database source [31,32]. The current work selected data in the Web of Science Core Collection, which includes the Science Citation Index Expanded (SCI-E), Social Science Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index—Science (CPCI-S), Conference Proceedings Citation Index—Social Science & Humanities (CPCI-SSH), and Emerging Sources Citation Index (ESCI) [33]. The retrieval strategy was as follows: Topic = (“exit sign*” or “emergency sign*” or “evacuation sign*”) or ((“escape sign*” or “guidance sign*” or “wayfinding sign*” or “route sign*” or “safety sign*” or “egress sign*” or “sign* system*”) and (“emergency” or “evacuation”)). The search terms were derived from different names of emergency exit signs, and the search strategy was derived from multiple pre-searches. A general retrieval strategy was designed to avoid separate retrieval that would collect duplicate articles. The asterisk (*) represents any group of characters; for example, “sign*” matches “sign”, “signs”, or “signage”. Document types were limited to “article”, “review”, and “proceeding paper”, and the language of the literature was exclusively “English” [34]. Publication years had no set time restrictions to ensure that all relevant papers would be included in the analysis.

A total of 648 articles were obtained using the strategy described above, with a retrieval date of 11 March 2023. However, not all of the retrieved articles were related to the research topic. We performed manual filtering of search results by analyzing titles, keywords, and abstracts to eliminate articles in other fields such as medicine, biology, and economics that are not relevant to the research content and theme [34,35]. This was carried out to ensure that the data and findings were reliable [36]. Finally, the remaining 219 articles (see Supplementary Materials for details) were exported to a plain text file with full records and cited references for further analysis using the CiteSpace software. The data collection process is shown in Figure 1.

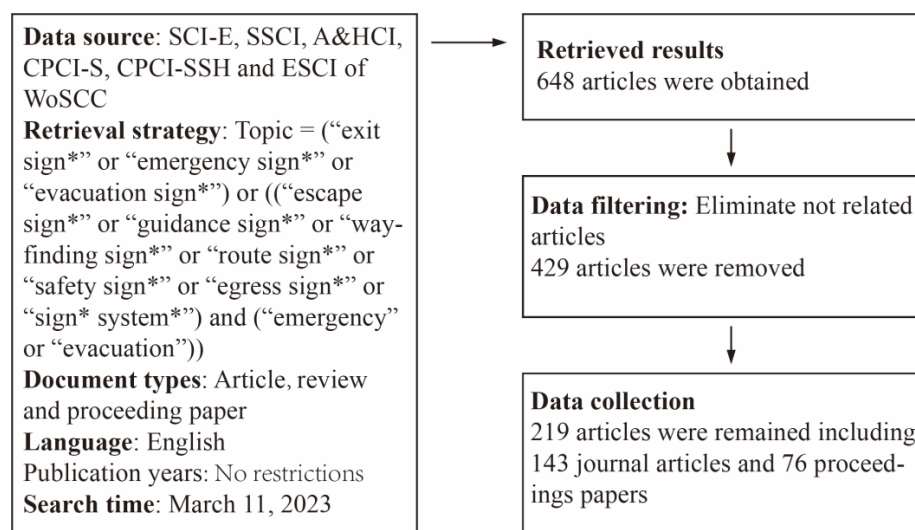


Figure 1. The data collection process of this paper.

2.2. Research Method

The visualization analysis of a knowledge map based on bibliometrics is a new type of literature review method [37]. This method is more objective for literature evaluations than a general literature review [38]. Analysis software commonly used for this type of literature review includes CiteSpace, VOSviewer, BibExcel, and Sci2 Tool [39,40], CiteSpace, which is a bibliometrics visualization software package developed by Dr. Chaomei Chen [41], has been widely used globally because of its advanced and powerful features [42]. It can perform co-authorship, co-citation, and keyword co-occurrence analyses for documents, and it has been used to explore the research focuses, as well as the research frontiers of specified areas [37]. Some scholars have applied it to the emergency evacuation field and have obtained good research results [34,43,44].

In this study, CiteSpace 6.1.R6 was used to perform visualization analysis of articles related to emergency exit signs. First, a new project, called “Exit Sign (WoS)”, was created in the CiteSpace software, and the data collected using the retrieval strategy described above were input. Second, in the software interface, the overall time slicing range was set to 1991–2023; the years per slice was set to 1; the node type was selected separately as “author”, “institution”, “country”, “keyword”, “reference”, “cited author”, or “cited journal”; and the remaining parameters were set to default values. Third, as CiteSpace was used to conduct the analysis, the software presented different networks and data according to the different nodes selected. The results obtained are discussed in greater detail in the next section.

3. Results and Discussion

3.1. Co-Authorship Analysis of Emergency Exit Signs Literature

When different countries, institutions, and authors appear in an article, they form a collaborative co-authorship network [45]. A co-authorship network analysis is vital to identify the knowledge exporters of the outstanding contributions and to understand the academic development of the research field [46]. In this study, co-authorship analyses for country, institution, and author were conducted sequentially to understand the primary contributors to emergency exit signs research from macroscopic, mesoscopic, and microscopic levels, respectively.

3.1.1. Country Co-Authorship Analysis

A country/region co-authorship analysis reveals which countries/regions have made outstanding contributions in certain research fields at a macroscopic level. Figure 2 shows a map of the country/region co-authorship network of emergency exit signs research, which is used to understand the research status of each country/region [32]. The nodes represent the countries/regions in the network, and the size of a node indicates the number of articles published by that country/region. The links between the nodes represent collaborative relationships, and the color of a link indicates whether the first collaborative year was early or late in the research development [42]. A node has a purple ring if its centrality is greater than 0.1, indicating that the role of that node is critical [47].

Figure 2 shows 36 nodes and 50 links. The 36 countries/regions with published articles are primarily located in Asia and Europe. The two largest nodes are the Chinese mainland and the United States, meaning that they had the most articles published. Meanwhile, these two countries also have purple rings, which further signifies the outstanding contributions of the two countries in emergency exit signs research. The Chinese mainland has collaborated with 12 countries/regions, including England, Japan, and Singapore, while the United States has collaborated with 11 countries/regions, including Taiwan, South Korea, and Germany. In addition, the Chinese mainland and the United States also have a collaborative relationship, but it is not close enough. Further analysis found that the United States began research related to emergency exit signs in 1993 [48] and has since been publishing articles at a stable rate. In contrast, article publication from the Chinese mainland began relatively late, as the research did not begin until 2002 [49]. However, the

Chinese mainland has published a rapidly increasing number of articles over the past five years and has become dominant in the emergency exit signs research domain. Overall, the collaborations among the various countries/regions are relatively close (density = 0.0794).

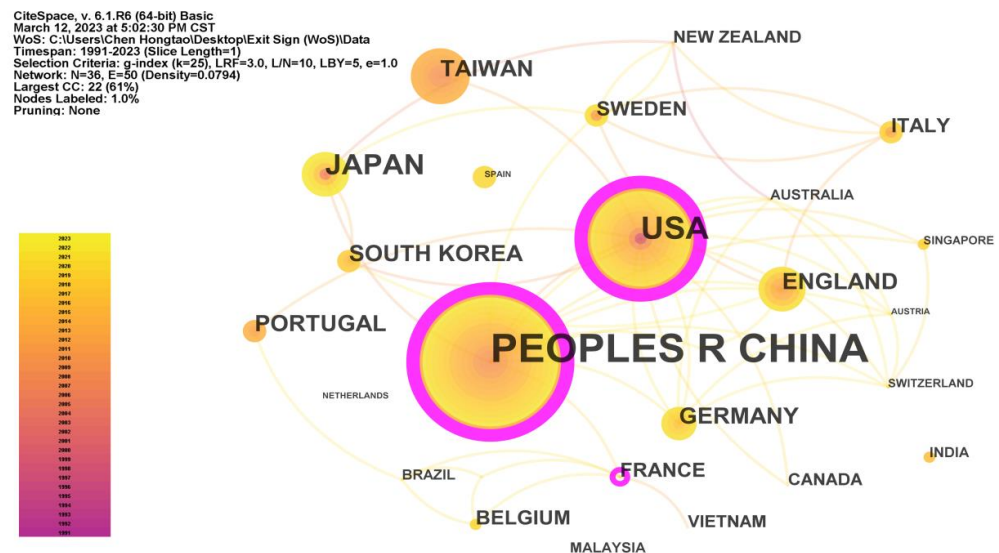


Figure 2. Map of the country/region co-authorship network of emergency exit signs research.

Table 1 lists the top 10 most productive countries/regions of emergency exit signs research. As shown in Table 1, the Chinese mainland ranks first with 68 published articles, followed by the United States (33 articles), Japan (19 articles), Taiwan (12 articles), Germany (12 articles), England (12 articles), Portugal (12 articles), South Korea (11 articles), Sweden (eight articles), and Italy (eight articles). According to the statistics, the total number of articles published in China was 80 (68 articles from the Chinese mainland and 12 articles from Taiwan), accounting for 36.53% of the total number of articles, indicating China's leading position in the emergency exit signs research field. However, the overall scale of the research is rather small, and the research power is relatively weak.

Table 1. Top 10 most productive countries/regions of emergency exit signs research.

Rank	Country/Region	Number	Year	Centrality
1	People's Republic of China	68	2002	0.35
2	United States of America	33	1993	0.21
3	Japan	19	2004	0.02
4	Taiwan	12	2000	0.00
5	Germany	12	2014	0.00
6	England	12	2006	0.04
7	Portugal	12	2012	0.03
8	South Korea	11	2009	0.02
9	Sweden	8	2012	0.03
10	Italy	8	2012	0.00

China and the United States' significant contributions in this research area may have something to do with their economic development and educational investment. At the national level, they have developed a series of standards such as ANSI Z535, GB 13495.1, etc., which provide relevant requirements for the use of emergency exit signs [50,51]. In addition, both countries have established corresponding national science foundations to incentivize scholars, which likewise promotes the development of emergency exit signs. It is worth noting that the International Organization for Standardization (ISO) has regulations for emergency exit signs [52], but we may see different styles of signs in our lives.

3.1.2. Institution Co-Authorship Analysis

An institution co-authorship analysis reveals which institutions have made outstanding contributions in certain research areas at a mesoscopic level. Figure 3 shows a map of the institution co-authorship network of emergency exit signs research, which is used to understand the research status of each institution. Similar to the country co-authorship analysis, the nodes in Figure 3 represent the institutions in the network, and the size of a node indicates the number of articles published by that institution.

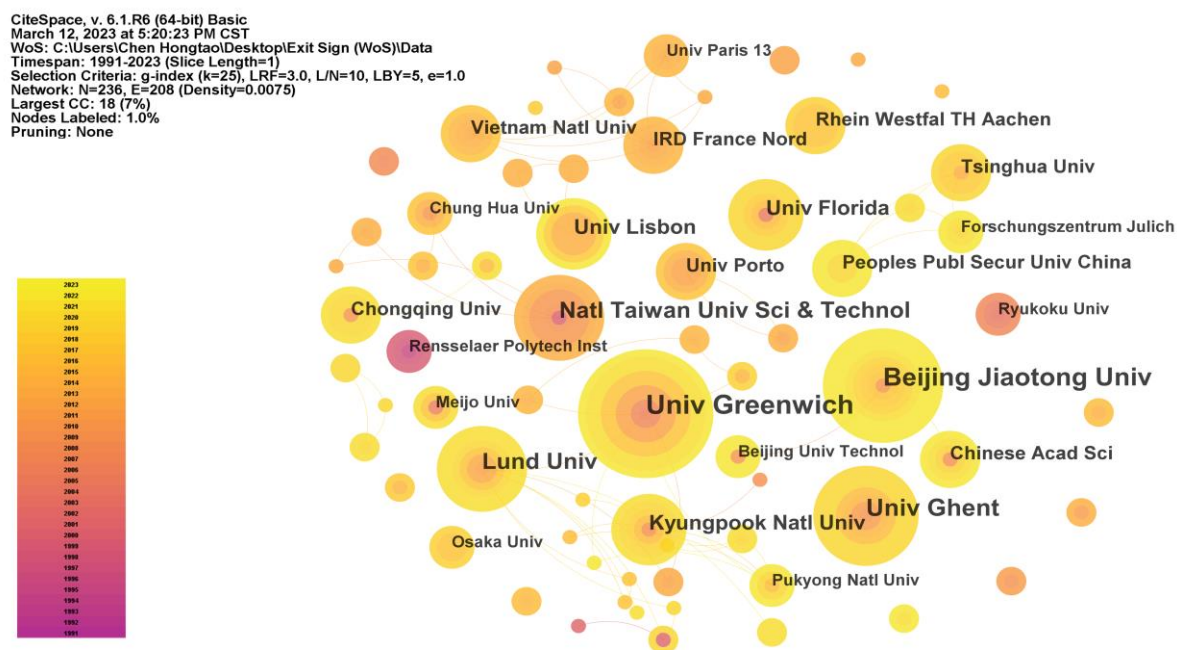


Figure 3. Map of the institution co-authorship network of emergency exit signs research.

Figure 3 shows 236 nodes and 208 links. The University of Greenwich and Beijing Jiaotong University are the two largest nodes in the figure, indicating that they have published the most articles. They are the two largest groups in the collaborative network, but there has been no collaboration between the two. The largest group in the collaborative network consists of 18 institutions, including the University of Greenwich, Lund University, and Pukyong National University, accounting for 7% of the total. The second largest group of collaborative networks consists of 11 institutions, including Beijing Jiaotong University, Beijing University of Technology, and the Chinese Academy of Sciences, accounting for 5% of the total. Further analysis revealed that no node has a centrality greater than 0.1, indicating that the collaborations between the institutions are not close enough (density = 0.0075).

Table 2 lists the top 10 most productive institutions of emergency exit signs research. As shown in Table 2, the University of Greenwich has published the most articles, ranking first with nine articles, followed by Beijing Jiaotong University (eight articles), Ghent University (seven articles), the National Taiwan University of Science and Technology (six articles), Lund University (six articles), Kyungpook National University (five articles), University of Lisbon (five articles), University of Florida (five articles), RWTH Aachen University (four articles) and People's Public Security University of China (four articles). The top 10 institutions are universities, mainly from Europe and Asia. They have contributed 59 articles together (accounting for 26.94% of the total). Considering the number of articles and the citation frequency, The University of Greenwich performed best in the emergency exit signs research area. Unlike other institutions, Ghent University has primarily focused on luminescent materials for emergency exit signs [53,54]. Beijing Jiaotong University, the National Taiwan University of Science and Technology, and the People's Public Security University of China are three institutions that have made outstanding contributions in China.

Table 2. Top 10 most productive institutions of emergency exit signs research.

Rank	Institution	Number	Year	Citation
1	University of Greenwich	9	2006	245
2	Beijing Jiaotong University	8	2010	129
3	Ghent University	7	2010	293
4	National Taiwan University of Science and Technology	6	2000	135
5	Lund University	6	2012	207
6	Kyungpook National University	5	2009	62
7	University of Lisbon	5	2014	129
8	University of Florida	5	2005	21
9	RWTH Aachen University	4	2017	36
10	People's Public Security University of China	4	2020	17

3.1.3. Author Co-Authorship Analysis

An author co-authorship analysis reveals the authors who have made outstanding contributions in certain research fields at a microscopic level. Figure 4 shows a map of the author co-authorship network of emergency exit signs research, which is used to understand the research status of each author. Similar to the institution co-authorship analysis, the nodes in Figure 4 represent authors in the network, and the size of a node indicates the number of articles published by that author.

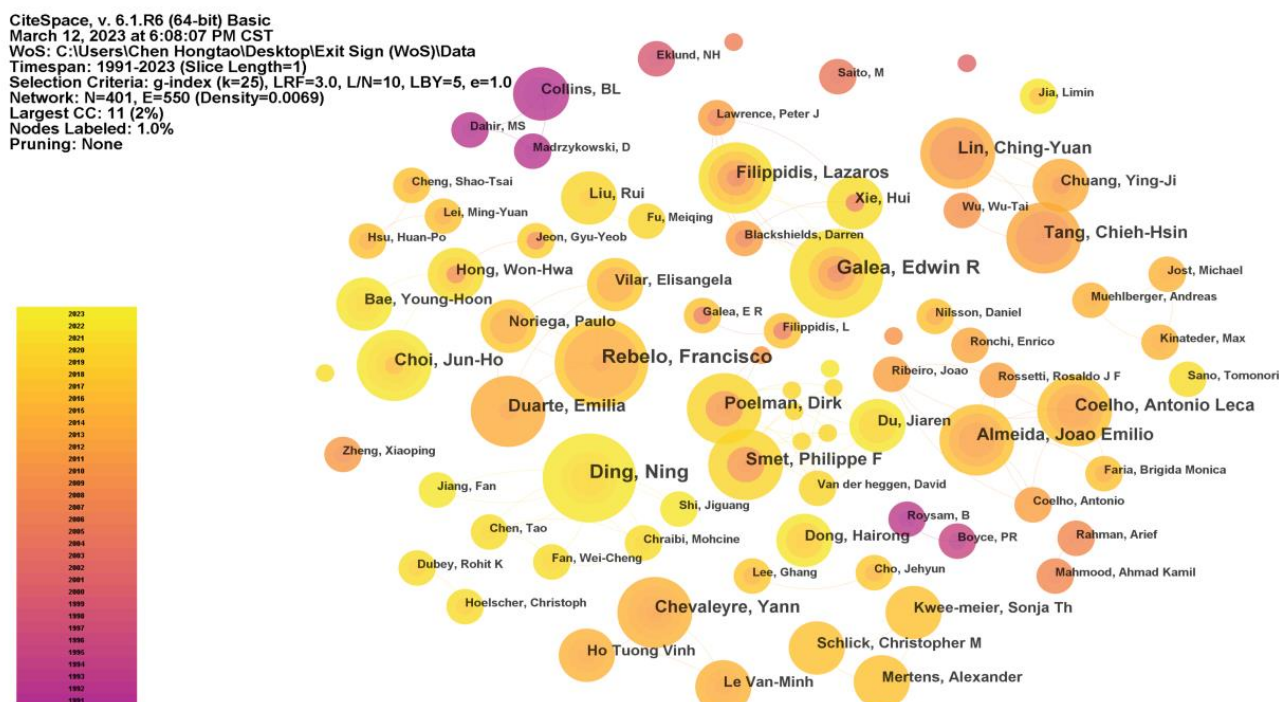
**Figure 4.** Map of the author co-authorship network of emergency exit signs research.

Figure 4 shows 401 nodes and 550 links. The largest collaborative network group consists of 11 authors, all of whom are from Belgium. The second largest group consists of nine authors, including Young-Hoon Bae, Ryun-Seok Oh, Won-Hwa Hong, and Jun-Ho Choi et al., primarily from South Korea. The team, led by Professor Jun-Ho Choi of the Pukyong National University, focuses on the study of the location and color of emergency exit signs [55,56]. The third largest group consists of nine authors, including Chieh-Hsin Tang, Wu-Tai Wu, and Ching-Yun Lin et al., primarily from Taiwan. The team, led by Prof. Ching-Yuan Lin of the National Taiwan University of Science and Technology, focused on the cognitive effects of emergency exit signs on wayfinding [57,58]. The fourth largest group consists of nine authors, including Max Kinateder and Paul Paulia et al., primarily from Germany. The fifth largest group consists of eight authors, including Peter R. Boyce

and Badrinath Roysam et al., primarily from the United States. The sixth largest group consists of eight authors, including Edwin R. Galea and Hui Xie, primarily from England. The link between the nodes in the network indicates that these team authors tended to cooperate with their own countries or institutions. Overall, the collaborations between authors are not strong (density = 0.0069).

Table 3 lists the top 10 most productive authors of emergency exit signs research. As shown in Table 3, the British scholar Edwin R. Galea has published seven articles, ranking first in terms of the number of articles published. Lazaros Filippidis, Francisco Rebelo, and António Leça Coelho have each published five articles, together ranking second. Ning Ding, Ching-Yuan Lin, and Emília Duarte have each published four articles, together ranking third. Jun-Ho Choi, Chieh-Hsin Tang, and Philippe F. Smet have each published four articles, together ranking fourth. In terms of the publishing time and the citation frequency, Edwin R. Galea and Lazaros Filippidis et al. entered the research field earlier than the others, and they are the pioneers and founders of the emergency exit signs research in the 21st century. Hui Xie conducted an interactive study between humans and signs in his doctoral dissertation [59] under the supervision of Professor Edwin R. Galea. The primary research interests of Ning Ding, a professor at the People's Public Security University of China, are crowd evacuation and emergency response [60]; this scholar is a new dominant researcher who has emerged in the past two years.

Table 3. Top 10 most productive authors of emergency exit signs research.

Rank	Author	Number	Year	Institution
1	Edwin R. Galea	7	2006	University of Greenwich
2	Lazaros Filippidis	6	2006	University of Greenwich
3	Francisco Rebelo	6	2012	University of Lisbon
4	António Leça Coelho	6	2012	Laboratório Nacional de Engenharia Civil (Portugal)
5	Ning Ding	5	2020	People's Public Security University of China
6	Ching-Yuan Lin	5	2009	National Taiwan University of Science and Technology
7	Emília Duarte	5	2012	IADE Creative University
8	Jun-Ho Choi	4	2016	Pukyong National University
9	Chieh-Hsin Tang	4	2009	National Taiwan University of Science and Technology
10	Philippe F. Smet	4	2010	Ghent University

3.2. Co-Citation Analysis of Emergency Exit Signs Literature

When two or more journals, documents, or authors appear in the references of a third document simultaneously, they have formed a co-citation relationship [61]. A co-citation analysis can reveal the knowledge structure between journals, documents, and authors in a research area and can also identify important journals, documents, and authors [32]. Co-citation analyses of journals, documents, and authors related to emergency exit signs research were conducted during this study.

3.2.1. Journal Co-Citation Analysis

A journal co-citation analysis is helpful for revealing the knowledge structure of a certain academic area on a macroscopic level, and it can objectively specify the status of the journal in the discipline [39]. Figure 5 shows a map of a journal co-citation network of emergency exit signs research, which was constructed to determine the important journals in this research field. Similar to the co-authorship analysis, the nodes represent the journals in the network, and the size of a node indicates the number of journal co-citations. A node with a purple ring has a high centrality and plays a key role [47].

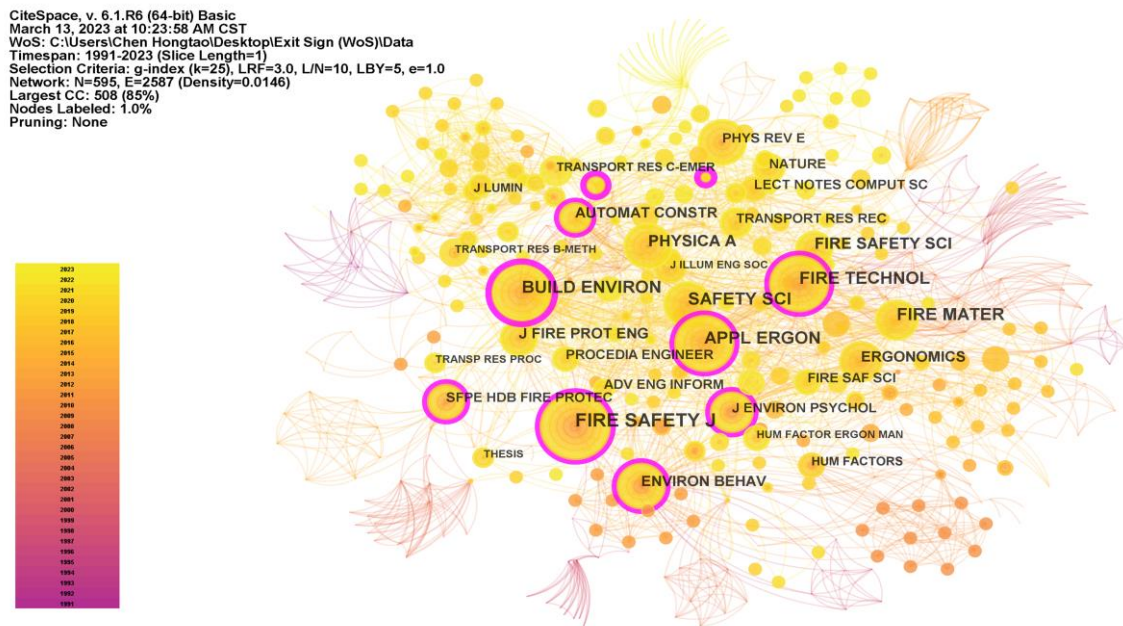


Figure 5. Map of the journal co-citation network of emergency exit signs research.

Figure 5 contains 595 nodes and 2587 links. These nodes are connected to form a large network, indicating a wide range of journal co-citations (density = 0.0146). The largest subnetwork includes 508 nodes, accounting for 85% of the total nodes. The Fire Safety Journal is the largest node and has a purple ring, indicating that it is the most important journal in emergency exit signs research. This journal was founded in 1976 and is devoted to research regarding fire safety science and engineering. In addition, the Applied Ergonomics, Fire Technology, Building and Environment, and Environment and Behavior journals also have purple rings, indicating that they are also key journals in the research. From the types of journals, we can see that the study of emergency exit signs is interdisciplinary.

Table 4 lists the top 10 most co-cited journals of emergency exit signs research. As shown in Table 4, articles published in the Fire Safety Journal have the highest co-citation number (87). This journal has a relatively early first publishing year (2001), a high centrality (0.12), and a large impact factor (3.187). Overall, it is an important journal in the emergency exit signs research field. The Automation in Construction journal has the highest impact factor without self-citations (8.512), and the Environment and Behavior journal has the second highest impact factor without self-citations (6.433). Six of these journals are from Elsevier, demonstrating the publishing group's dominant position in the research field. Fire Safety Science is a journal based in China, while the rest are from other countries. Further analysis reveals that the majority of these journals are SCIE. Emergency exit signs involve aesthetics, ergonomics, and safety science, and researchers of the social sciences, arts, and humanities can focus on research in this area.

Table 4. Top 10 most co-cited journals of emergency exit signs research.

Rank	Journal	Number	Year	Centrality	Impact Factor
1	Fire Safety Journal	87	2001	0.12	3.187
2	Applied Ergonomics	62	2009	0.19	3.241
3	Fire Technology	55	1999	0.15	3.129
4	Building and Environment	52	2007	0.25	5.741
5	Fire and Materials	52	2007	0.06	1.810
6	Safety Science	49	2008	0.09	5.552
7	Physica A: Statistical Mechanics and its Applications	41	2009	0.04	3.465
8	Fire Safety Science	41	2000	0.03	0.839
9	Environment and Behavior	32	1999	0.12	6.433
10	Automation in Construction	31	2007	0.13	8.512

3.2.2. Document Co-Citation Analysis

A document co-citation analysis is conducive to revealing the knowledge structure of a certain academic field on a mesoscopic level, and it can objectively determine the status of a document in the discipline [32]. Figure 6 shows a map of the document co-citation network of emergency exit signs research created to determine which documents are important in this field. Similar to the journal co-citation analysis, the nodes represent the documents in the network, and the size of a node indicates the number of document co-citations.

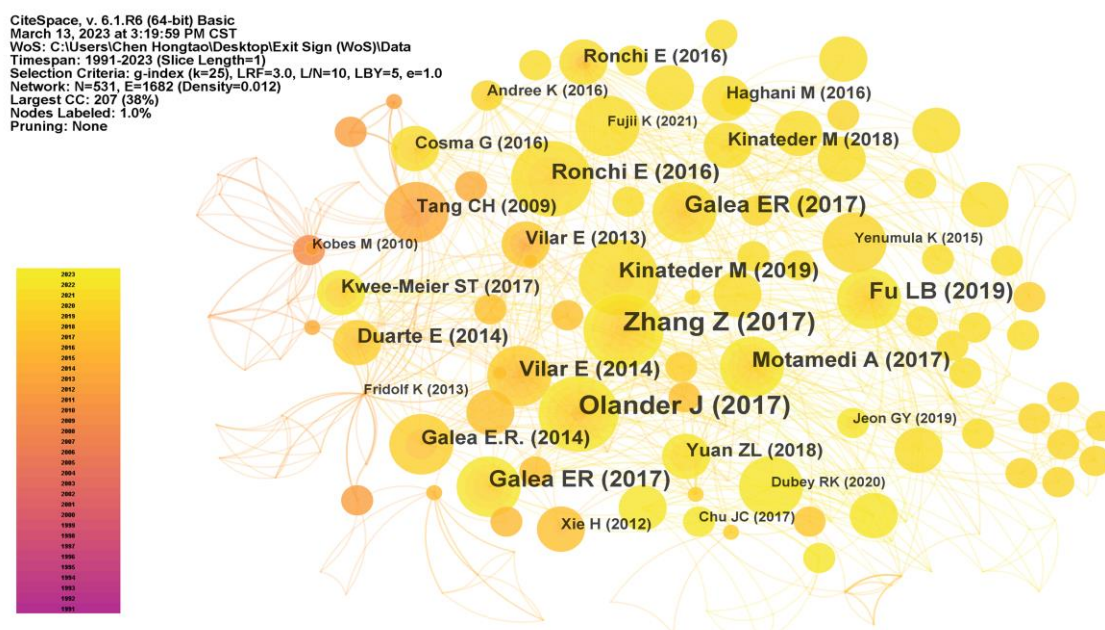


Figure 6. Map of the document co-citation network of emergency exit signs research.

Figure 6 contains 531 nodes and 1682 links. These nodes are connected to form a large network, indicating a large document co-citation network (density = 0.012). The largest subnetwork includes 207 nodes, accounting for 38% of the total nodes. “Dissuasive exit signage for building fire evacuation” ((Olander J (2017))) is the largest node. This document [62] presented analyses and tests for a set of key features of dissuasive emergency signs. “Optimal number and location planning of evacuation signage in public space” ((Zhang Z (2017))) is the second largest node; this paper primarily presented the results of an investigation of the positioning methods of evacuation signs [24]. In addition, “Behavioral compliance for dynamic versus static signs in an immersive virtual environment” ((Duarte E (2014))) has a high centrality (0.08), indicating that it is important to the knowledge structure of the research. This document found that dynamic exit signs attract more attention than static exit signs, which in turn are better than no exit signs [63].

Table 5 lists the top 10 most co-cited documents of emergency exit signs research. As shown in Table 5, “Dissuasive exit signage for building fire evacuation” is the most frequently co-cited document, having been co-cited 22 times. “An international survey and full-scale evacuation trial demonstrating the effectiveness of the active dynamic signage system concept” and “Evaluating the effectiveness of an improved active dynamic signage system using full scale evacuation trials” were written by the same author, Galea. Publication of documents with many co-citations was concentrated in 2017, which shows that emergency exit signs research has attracted significant attention in recent years. As mentioned above, the co-citation analysis not only helps us to identify important documents but also helps to visualize the relationships between documents.

Table 5. Top 10 most co-cited documents of emergency exit signs research.

Rank	Document	Node	Number
1	Dissuasive exit signage for building fire evacuation	Olander J (2017) [62]	22
2	Optimal number and location planning of evacuation signage in public space	Zhang Z (2017) [24]	20
3	An international survey and full-scale evacuation trial demonstrating the effectiveness of the active dynamic signage system concept	Galea ER (2017) [64]	14
4	The influence of emergency signage on building evacuation behavior: An experimental study	Fu LB (2019) [65]	14
5	Evaluating the effectiveness of an improved active dynamic signage system using full scale evacuation trials	Galea ER (2017) [64]	13
6	What color are emergency exit signs? Egress behavior differs from verbal report	Kinateder M (2019) [66]	12
7	Effects of competing environmental variables and signage on route-choices in simulated everyday and emergency wayfinding situations	Vilar E (2014) [29]	11
8	A virtual reality experiment on flashing lights at emergency exit portals for road tunnel evacuation	Ronchi E (2016) [30]	10
9	Signage visibility analysis and optimization system using BIM-enabled virtual reality (VR) environments	Motamedi A (2017) [67]	10
10	Behavioral compliance for dynamic versus static signs in an immersive virtual environment	Duarte E (2014) [63]	9

3.2.3. Author Co-Citation Analysis

An author co-citation analysis is useful for revealing the knowledge structure of a certain field on a microscopic level, and it can objectively determine the position of authors in the discipline [37]. Figure 7 shows a map of the author co-citation network of emergency exit signs research to specify the important authors in this research field. Similar to the document co-citation analysis, the nodes represent the authors in the network, and the size of a node indicates the number of author co-citations.

Figure 7 contains 619 nodes and 2511 links. These nodes are connected to form a large network, indicating a substantial author co-citation network (density = 0.0131). The largest subnetwork includes 359 nodes, accounting for 57% of the total. Edwin R. Galea is the author corresponding to the largest node and has had co-citation relationships with 51 authors, including Chieh-Hsin Tang, Max Kinateder, and Lazaros Filippidis et al. Hui Xie is the author corresponding to the second largest node. This node is connected to 39 other authors, including Edwin R. Galea, Joakim Olander, and Enrico Ronchi. Further analysis revealed that Edwin R. Galea and Hui Xie are from the Fire Safety Engineering Group of the University of Greenwich. They have been primarily concerned with the effectiveness of dynamic signs [64,68]. Additionally, the nodes associated with Dirk Helbing have purple rings, indicating that the author is a key scholar and plays important intermediate roles in the research.

Table 6 lists the top 10 most co-cited authors of emergency exit signs research. As shown in Table 6, the author with the most co-citations is Edwin R. Galea (51 co-citations), followed by Hui Xie (39 co-citations), Margrethe Kobes (35 co-citations), Chieh-Hsin Tang (34 co-citations), Dirk Helbing (33 co-citations), Enrico Ronchi (30 co-citations), Elisângela Vilar (26 co-citations), Max Kinateder (26 co-citations), L.T. Wong (24 co-citations), and Joakim Olander (22 co-citations). The articles written by these authors have many co-citations and have contributed positively to the development of emergency exit signs research. In both the co-authorship and co-citation analysis, Edwin R. Galea ranked first, which shows that this author plays a crucial role in the field. Margrethe Kobes investigated the possible effects of smoke and low exit signs on human fire response performance [1]. Enrico Ronchi studied the effectiveness of emergency exit signs in tunnels [69]. Elisângela Vilar examined the effects of competing environmental variables and exit signs on route choices [29].

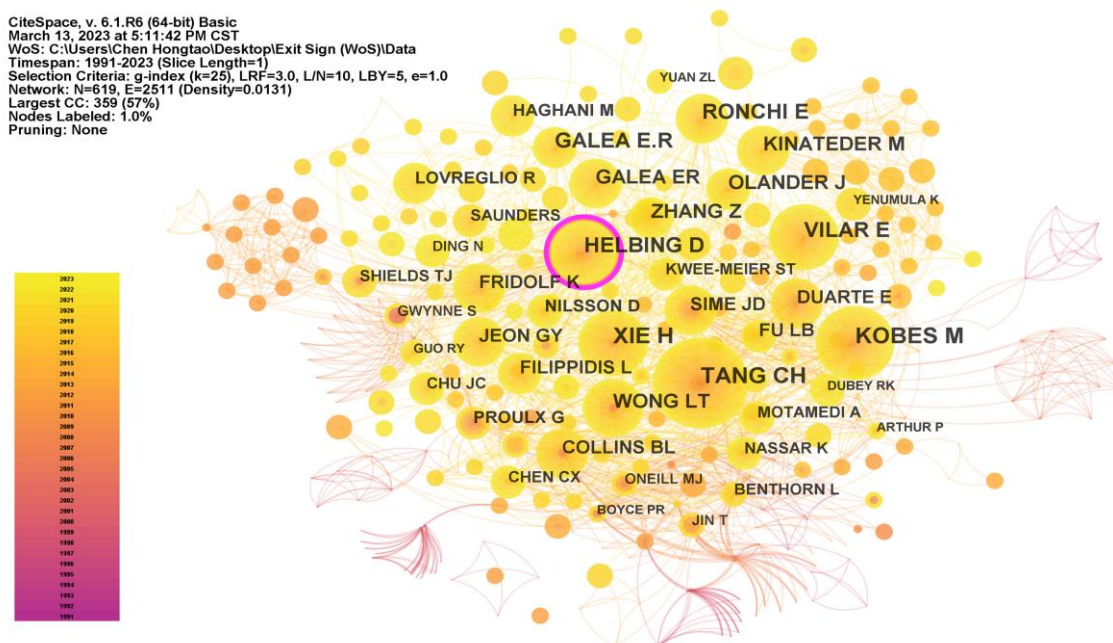


Figure 7. Map of the author co-citation network of emergency exit signs research.

Table 6. Top 10 most co-cited authors of emergency exit signs research.

Rank	Author	Number	Centrality	Year
1	Edwin R. Galea	51	2016	0.03
2	Hui Xie	39	2012	0.02
3	Margrethe Kobes	35	2011	0.08
4	Chieh-Hsin Tang	34	2009	0.07
5	Dirk Helbing	33	2008	0.13
6	Enrico Ronchi	30	2016	0.02
7	Elisângela Vilar	26	2014	0.02
8	Max Kinateder	26	2017	0.05
9	L.T. Wong	24	2009	0.02
10	Joakim Olander	22	2017	0.03

3.3. Keyword Co-Occurrence Analysis of Emergency Exit Signs Literature

Keywords summarize the core ideas in an article and can help the readers to quickly understand the research content in the article [32]. Over time, many keywords accumulate within a research field. Research focuses in a certain domain can be found through a keyword co-citation analysis [70,71], and research frontiers in a certain domain can be found through burst keywords [72]. A map of the keyword co-occurrence network of emergency exit signs research is shown in Figure 8. Each node represents a keyword, and the size of a node indicates the co-occurrence frequency of that keyword. Table 7 lists the top 10 keywords with the strongest citation bursts in emergency exit signs research.

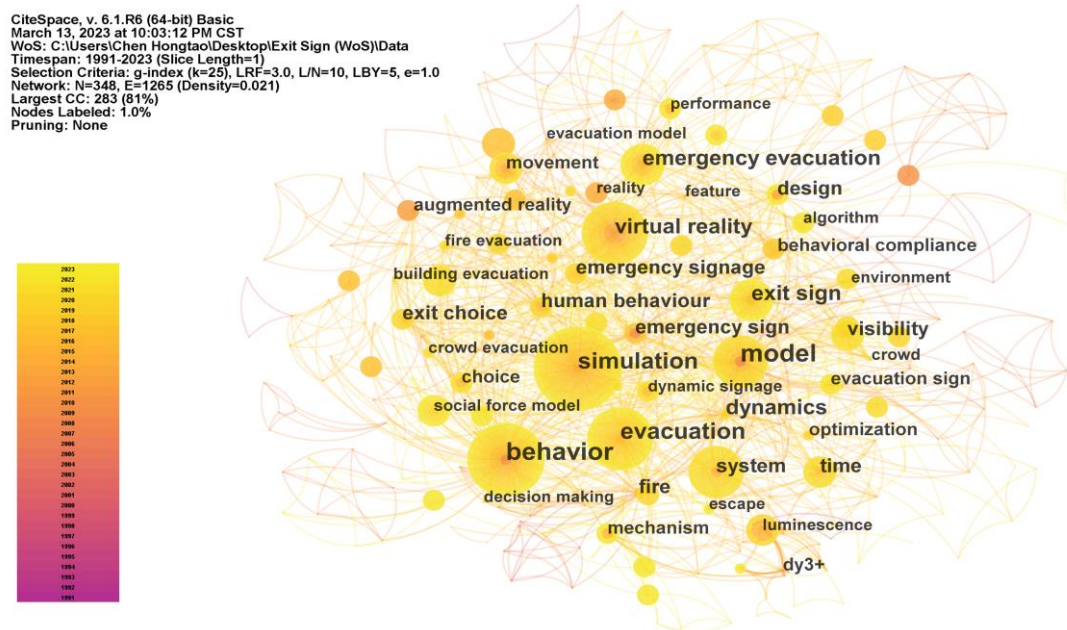


Figure 8. Map of the keyword co-occurrence network of emergency exit signs research.

Table 7. Top 10 keywords with the strongest citation bursts.

Rank	Keyword	Strength	Begin	End	1991–2023
1	Evacuation simulation	1.94	2001	2007	
2	Social force model	2.60	2020	2023	
3	Time	2.07	2018	2021	
4	Behavior	3.97	2021	2023	
5	Emergency egress	2.17	2012	2014	
6	System	3.08	2020	2021	
7	Emergency signage	2.80	2019	2020	
8	Visibility	2.58	2020	2021	
9	Reality	2.40	2013	2014	
10	Luminescence	2.22	2015	2016	

3.3.1. Research Focuses

Research focuses reflect the research development status in a certain field as well as reflect the topics that researchers are most interested in. From the information in Figure 8 and by reading the articles retrieved during this study, the research focuses within the emergency exit signs research field were summarized into three sections:

- (1) Research regarding effectiveness. Effectiveness is the fundamental and core issue in emergency exit signs research. The effectiveness of a sign usually refers to its visibility during emergencies and its comprehensibility in normal environments [73]. It means the ability to see, recognize, read, and follow [74], reflecting in the likelihood of people using emergency exits [75,76]. The effectiveness of signs is a popular topic in the study of resident behavior in emergency situations [77]. Tang et al. tested the effectiveness of old and new versions of emergency signs [58]. Galea et al. conducted evacuation experiments to evaluate the effectiveness of the dynamic signs

system [64,78]. D’Orazio et al. analyzed the effectiveness of photoluminescent exit signs in the historical theaters [79].

- (2) Research method. In the emergency exit signs research field, models and experiments are the most common research methods. Among them, social force models [80] and cellular automata models [81] are the most common models for sign effectiveness during evacuation. In addition, questionnaires [82], eye tracking [60,83,84], and virtual reality [85] are common experimental methods used in emergency exit signs research. Yuan and Ma et al. studied the effect of emergency signage on the evacuation process based on the social force model [80,86]. Liu et al. confirmed the necessity and rationality of computing the effective distance of emergency evacuation signs based on cellular automata [81]. A more widely used method in questionnaire surveys is the theory of affordances [62]. Eye-tracking devices are an effective tool for analyzing the optimal location of emergency exit signs [60,87]. Compared to ordinary questionnaires, the results of virtual reality studies are more valid [66].
- (3) Research content. Location and color are the two primary objectives in emergency exit signs research. The horizontal or vertical position of a sign [55], as well as whether it is placed high, in the middle, or low [1,65], has different effects on evacuation. In China, the standard color for emergency exit signs is green, but it is often red in the United States and Canada [88]. Ma et al. studied the optimal position of escape signs with different views [86]. Zhang et al. proposed a location model of the signage system and the optimal number and best locations of signs to optimize the locations of signs [24]. The “Green and black” combination proved to have the best escape performance [25].

3.3.2. Research Frontiers

Research frontiers are the latest developments that predict the trends of future developments in the research. According to the information in Table 7, by combining the strengths of burst keywords and their corresponding red lines, the research frontiers in emergency exit signs research can be summarized into three primary sections.

- (1) Virtual reality. Virtual reality is a new technology that first appeared in emergency exit signs research in 2000 [89]. Due to its immersive, interactive, and imaginative qualities, many scholars have applied it to relevant sign research in recent years [57]. Virtual reality technology enables high experimental control and cost-effectiveness for comparisons of emergency exit signs [90]. Feng et al. used virtual reality to study pedestrian exit choice behavior [91]. Zhang et al. used a virtual reality experiment to investigate the influence of route turning angle on compliance behavior and evacuation performance [92]. Lin et al. simulated the cognition effectiveness of emergency signs through virtual reality experiments [57]. Kubota et al. conducted a virtual reality experiment to investigate the effect of sign and viewer placement on compliance information [85].
- (2) Visibility. Visibility has always been an important issue in emergency exit signs research, and it is one of the most important indicators of sign effectiveness. Sign visibility in emergency situations has attracted increasing attention from scholars in recent years. Wong and Lo studied the visibility of exit signs in both English and Chinese in an internal corridor [93]. Wan et al. proposed a smart design method of evacuation signage layout based on visibility [2]. When visibility is poor, changes in the environment around exit signs can influence evacuation speeds [94]. In thick smoke, signs can provide accurate escape directions for pedestrians [80].
- (3) Emergency evacuation. Emergency evacuation is the premise and background on which emergency exit signs research is based. A need for people to evacuate by following signs indicates that a situation is very dangerous. Emergency exit signs, as a mandatory and essential element for the prevention and planning of evacuation, are the last guarantee of personnel safety. The International Society of Fire Safety notes that fire safety is one of the most urgent short-term research areas [95]. Tang et al. studied the impacts of exit sign color, lightness, and flashing on evacuation time in a

virtual fire scenario [96]. Yasufuku K et al. studied the noticeability of illuminated route signs for tsunami evacuation [97]. Kim Y et al. evaluated the effective cognitive area of a signage system with backlighting under smog conditions [98].

We find some overlaps of content in the research focuses and research frontiers; for example, visibility is one of the important indicators of effectiveness, and virtual reality is one of the key research methods. This shows that the emergency exit signs research is moving towards technology and refinement.

4. Conclusions

Based on the co-authorship, co-citation, and keyword co-occurrence analyses of the emergency exit signs research literature presented in this paper, several conclusions were obtained.

The co-authorship analysis showed that at a macroscopic level (countries/regions), China and the United States are the two countries that have made the most outstanding contributions to emergency exit signs research. At a mesoscopic level (institutions), the University of Greenwich, Beijing Jiaotong University, Ghent University, the National Taiwan University of Science and Technology, and Lund University are the primary research institutions that have made outstanding contributions. At the microscopic level (authors), Edwin R. Galea, Lazaros Filippidis, Ning Ding, and Ching-Yuan Lin et al. are the authors who have made the most outstanding contributions. The country, institution, and author co-authorship analyses provided a display of the primary contributors at the macroscopic, mesoscopic, and microscopic levels, which can enable researchers to quickly identify the differences in the research among countries and to recognize the institutions and authors that have made outstanding contributions.

The co-citation analysis illustrated the formation of the knowledge structure in emergency exit signs research. During the process, the Fire Safety Journal, Fire Technology, and Environment and Behavior were determined to be important journals, since they are eminent platforms for the research. “Dissuasive exit signage for building fire evacuation” and “Optimal number and location planning of evacuation signage in public space” are important documents that form the theoretical basis for the research. Edwin R. Galea, Hui Xie, and Margrethe Kobes et al. are important authors who have promoted the development of the research. Through a keyword co-occurrence analysis, the research focuses were determined to be regarding effectiveness, methods, and content. The research frontiers were identified as virtual reality, visibility, and emergency evacuation. These analyses have helped researchers to reduce time consumption and avoid disorder during research by enabling them to quickly understand the contributors, knowledge structure, and research focuses of the field so that they can better contribute to the development of the research.

Certain achievements have been made in emergency exit signs research, such as research regarding the effectiveness of dynamic signs and the application of virtual reality. In future research, in addition to buildings, we can also focus on emergency exit signs in transportation. Experimental studies can be carried out using techniques such as the use of electroencephalogram equipment. At the same time, research on the cognition of the elderly and children in emergency exit signs should be emphasized. Last but not least, the authorities should pay sufficient attention to the uniformity of signs.

In summary, this paper provides an overview of emergency exit signs research and supplies valuable information for understanding the current status of the research. However, despite certain meaningful results obtained through visualization analysis of the related literature, some limitations cannot be overlooked in this research. First, the research only selects documents from the WoSCC, which may ignore some documents from other databases. Second, the filtered data may be slightly different due to manual factors.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/buildings13102497/s1>, Details of the 219 articles selected as data for analysis.

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