Review of Construction Safety Studies from a Behavioral Perspective: New Evidence from Mapping Knowledge Domains

Yuan Fu, Gui Ye, Xiaoyu Tang, and Lijuan Yang

***Abstract*—Both practice and research have manifested that studying construction safety from the perspective of human behavior is the main direction to effectively prevent accidents. Scholars have carried out a series of studies on this subject. HistCite and CiteSpace two knowledge map analysis tools were used to visually and quantitatively analyze 256 articles in the field based on WOS. The results demonstrate that key journals are classified into safety science and building science. Key authors concentrate on universities, with Tsinghua university as the core, forming a relatively close network of institutional cooperation. The USA, China and Australia have made great contributions. Furthermore, the review indicated that hotspots focus on six topics: safety climate and culture, safety performance, safety risk perception etc. The development trend includes four stages: 1) relationship between safety climate and safety performance; 2) effect of organizational safety culture on behavior; 3) influence of safety cognition and occupational risk assessment on construction safety; 4) and application of computer technology. Future research may further explore construction safety behavior under interaction of individual, group and environment, and consider the influence of informal groups. Meanwhile, research methods of simulation and experiment and the application of intelligent technology in construction safety deserve attention.**

***Index Terms*—CiteSpace, construction industry, HistCite, mapping knowledge domains, safety behavior.**

I. Introduction

There are frequent safety accidents in the construction industry. Although the overall accident rate has declined in the past 20 years, it is still about three times of the average accident rate of all industries [1], [2]. According to statistics, there were 3,523 accidents and 3,806 deaths in Chinese construction industry in 2016, an increase of 124.8% and 101.3% respectively. In 2017, there were 3,594 construction safety accidents and 3,843 deaths in China [3]. It can be seen that the safety accident rate has been deteriorating in the past two years and it is urgent to strengthen management.

Heinrich [4] once put forward that in 100 accidents, nearly 98% of accidents could be controlled and prevented by people with appropriate measures. Some scholars pointed out that behavioral choice error is the main cause of safety accidents [5], [6]. It can be seen that the main inducers and victims of construction safety accidents are both human[7]. It is particularly vital to study the methods of safety management from the perspective of human behavior, which is the main direction of improving safety management theory of construction. Relevant scholars have conducted a series of studies on construction safety from the perspective of behavior [8], [9]. Nevertheless, previous studies failed to provide an overall framework [10]. Therefore, it is emergency to conduct a systematic and comprehensive review, summarize the past, understand the current situation, and seek for new breakthrough points in the future, so as to improve the efficiency of follow-up research and thus curb the high incidence of accidents. However, the existing reviews are basically limited to qualitative analysis [11]-[14] and rely on the amount of reading and summarizing ability of researchers which is highly subjective, and lack extensive and objective quantitative analysis.

Knowledge map is a kind of graph to exhibit knowledge resource and its relation visually, which is conducive to making the overall literature clear and logical. In addition, it can be employed to draw, mine and analyze the interrelationship between knowledge, and help to understand the research status and hot spots, as well as predict the future research direction [15]. The analysis content includes co-citation analysis, co-occurrence analysis, cluster analysis, etc. In recent years, knowledge map plotting tools emerge in endlessly. After comparison and screening of existing tools, HistCite has powerful statistical functions to quickly generate lists of years, authors, and journals [16]. Meanwhile, CiteSpace is widely used for its formidable co-citation analysis, which can focus on the research process of a knowledge field on the citation network diagram and can detect sudden and transitional literature [15]. The two tools complement each other, combined use to achieve the purpose of comprehensive analysis.

In view of this, two major tools CiteSpace and HistCite were utilized in this paper to systematically review the literature on construction safety from the behavioral perspective based on WOS, so as to obtain three research objectives: research status (key authors, key journals, key institutions, key countries and key articles); current research hotspots and frontiers; future research directions. The paper provides a reference for the future research on construction safety to effectively curb the high incidence of accidents.

II. Methods and Data

In this paper, a two-stage research scheme as shown in Fig. 1 is designed.

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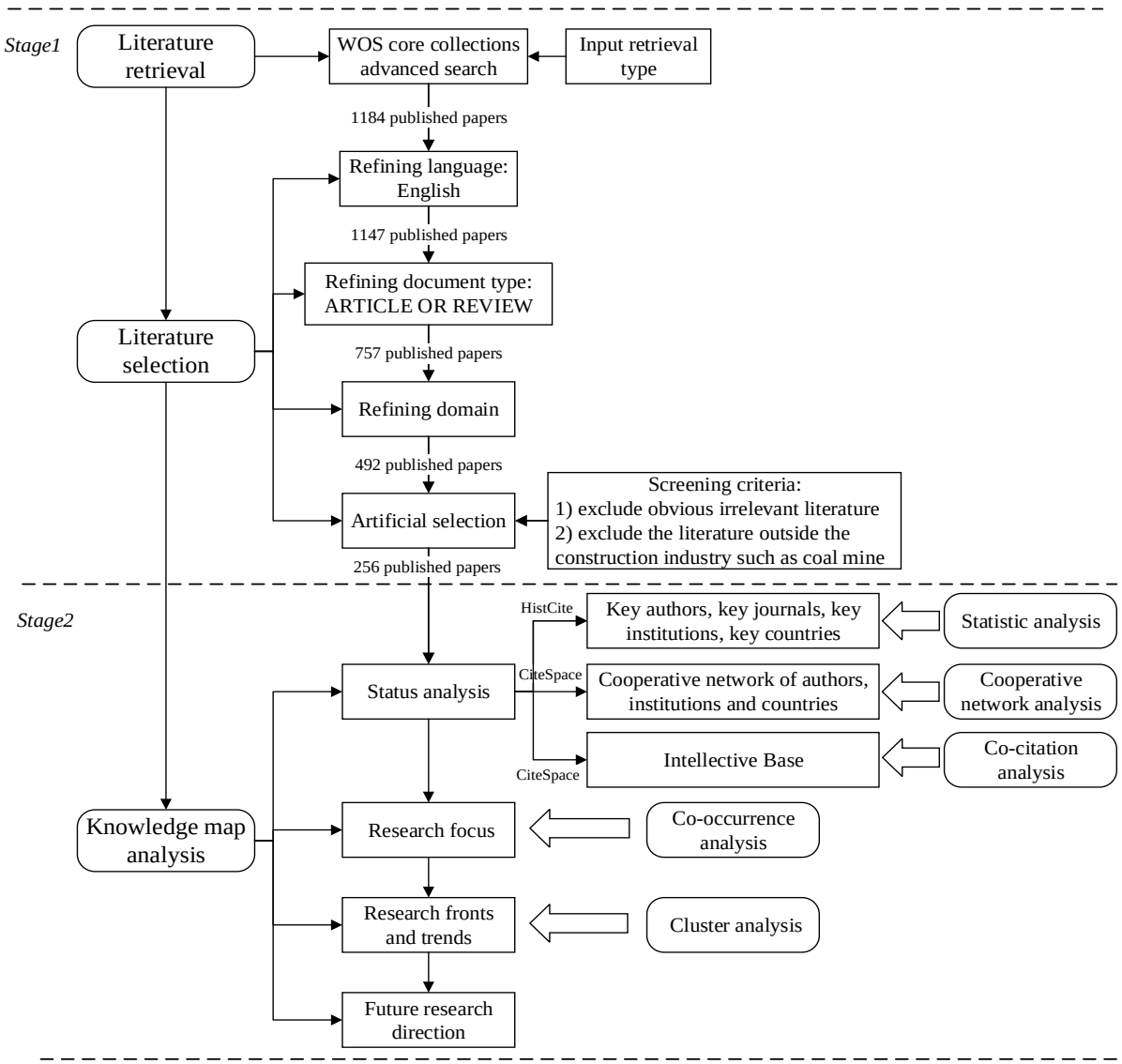

Fig. 1. Review plan.

Stage 1 aims to obtain accurate literature data. The literature comes from WOS core collections to ensure comprehensive and high-impact data. Two key words of construction and building are used to define the industry, according to the retrieval type: TS= (construction OR building) AND ((“safe* conscious*”) OR (“safe* awareness”) OR (“safe* climate”) OR (“safe* culture”) OR (“*safe* behavio*”) OR (“*safe* act*”)) perform a search. The retrieval time was 2018.1.8, and the time span was all years. Domain refinement is determined through the analysis function provided by WOS. 757 papers are sorted according to WOS categories, and each category is selected in turn to identify whether such papers are related to research on building safety behavior, and lastly relevant fields are reserved. When WOS database was searched by subject, due to the existence of Keywords Plus and the fuzzy search method adopted, the search results and research topics were not matched[17], so manual screening was carried out and 256 pieces of analysis data were finally obtained. Stage 2 is the core of this article. The literature metrology method of combining HistCite and CiteSpace was conducted to comprehensively analyze the three major objectives. The “key” in the figure refers to the authors, journals, institutions and countries with the highest statistical frequency.

III. Knowledge Map Analysis of Construction Safety Research from the Perspective of Behavior

A. Research Status

1) Literature growth trend analysis

As shown in Fig. 2, in general, literature in the field of construction safety from the perspective of behavior has experienced three development stages, with an overall upward trend. Namely, there was little change in the number of papers before 2007, and the overall number was small. This testifies that scholars at this stage have not generally recognized that human behavior is the main cause of building safety accidents. From 2008 to 2014, the number of articles increased significantly compared with that before. Since 2015, it has been a period of rapid development, especially in 2015, which indicates that more and more scholars have paid attention to the influence of behavior on construction safety in recent years. Therefore, it is expected that the volume of literature in this field will continue to increase in the future.

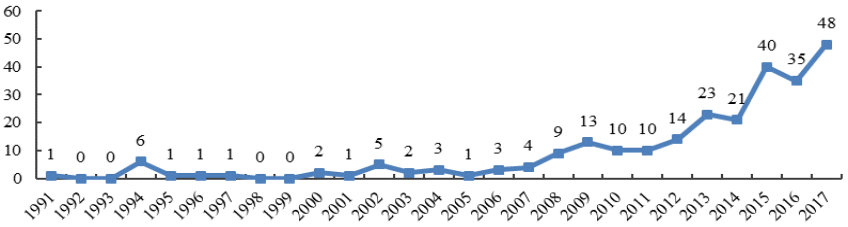

Fig. 2. Literature growth trend.

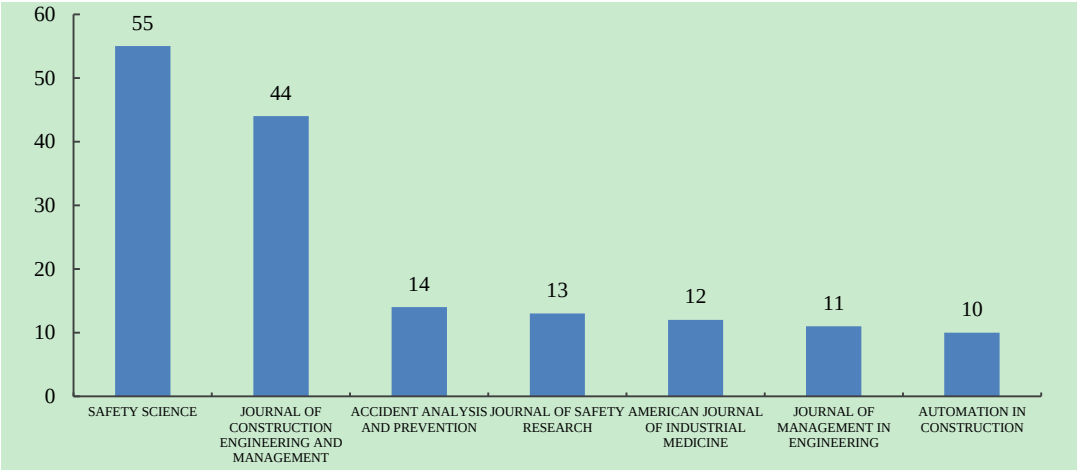

Fig. 3. Key journals.

2) Key journals

Fig. 3 lists the journals with a number of documents $\geqslant$10. It can be seen that the key journals fall into two categories, namely, safety science and building science. Meanwhile, the distribution of articles is relatively concentrated. The literature published by *Safety Science* and *Journal of Construction Engineering and Management* is significantly higher than that of other journals, accounting for 38.67 percent of the total analysis literature. These key journals are the main publications in the field of construction safety and are important windows for exploring the progress and trends of research. Subsequently, scholars should concentrate on their latest developments

3) Key authors

TABLE I: KEY AUTHORS

Recs	Author	Num
17	Fang DP	1
10	Chan APC	1
8	Lee S	1
7	Feng YB; Li H	2
6	Chen PY; Choudhry RM; Mohamed S; Pousette A; Torner M; Wu CL; Zou PXW	7
5	Cigularov KP; Dale AM; Ding LY; Han S	4
4	Arcury TA; Choi B; Gao R; Grzywacz JG; Hon CKH; Jha KN; Kaskutas V; Kines P; Li QM; Lipscomb HJ; Patel DA; Quandt SA; Rowlinson S; Skitmore M; Summers P; Sunindijo RY; Utama WP; Zahoor H	18

According to the square root law proposed by the American scholar Price, among all the core authors, the author with the lowest contribution shall publish 0.749 times the square root of the highest contribution, that is, $N_{min}=0.749\sqrt{N_{max}}$ [18]. By calculation, authors with contributions $\geqslant$4 were selected for statistical analysis. As shown in Table I, Fang DP and Chan APC contributed the most. The further tracking of core authors displays that only two key authors, Kines P and Patel DA, are from research laboratory, while the remaining 32 core authors are from universities. It can be seen that universities are the main force of the research in this field, and the contributions from institutions such as research laboratory and companies are quite insufficient.

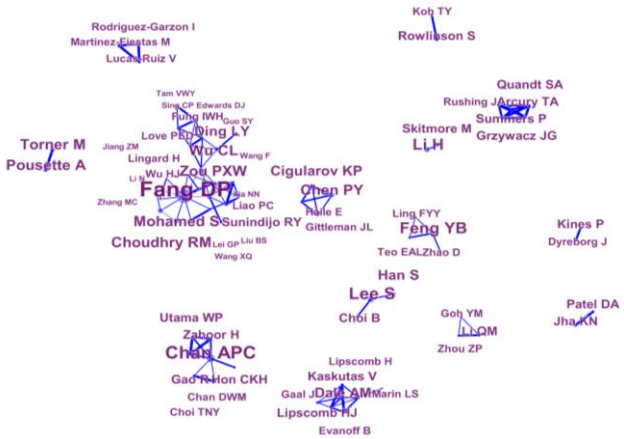

Fig. 4. Author cooperative network.

Further generate the author's cooperative network map, as shown in Fig. 4. In general, the entire map is composed of scattered small groups, and there is no large network of close cooperation. Among them, the cooperation network with Fang DP as the core is relatively close. It has constituted a cooperative *relationship* with many people such as Choudhry RM, Mohamed S, and Jiang ZM, but the lines between them are relatively thin, which indicates that there are not many articles for cooperation, most of which are one or two. Secondly, the five teams of Chan APC, Dale AM, Cigularov KP, Quandt SA and Feng YB are closely related, but the overall cooperation is not much, and the cooperation network

is very small, lacking the bridge of communication between scholars.

4) Key institutions

The institutions with a number of documents ⩾6 are shown in Table II. All 16 key institutions are universities. The affiliated institutions of literature are all intensive, and Hong Kong Polytech Univ and Tsinghua Univ account for a large proportion.

TABLE II: KEY INSTITUTIONS

Recs	Institution	Num
19	Hong Kong Polytech Univ; Tsinghua Univ	2
13	Queensland Univ Technol	1
9	City Univ Hong Kong	1
8	Griffith Univ; Natl Univ Singapore; Univ Michigan	3
7	Colorado State Univ; Duke Univ	2
6	Curtin Univ; Huazhong Univ Sci & Technol; Natl Univ Sci & Technol; Univ Gothenburg; Univ Illinois; Univ Western Sydney; Virginia Polytech Inst & State Univ	7

The cooperation network of research institutions is shown in Fig. 5. Centering on Tsinghua university, there develops a close collaboration network with Hong Kong Polytechnic University, City University Hong Kong and Georgia Institute of Technology. The nodes marked by purple circle in the figure manifest that their betweenness centrality is⩾0.1, which has a control effect on the whole network. They were Tsinghua University (0.22), Georgia Institute of Technology (0.20), University of Washington (0.18), Oregon State University (0.17), University of Colorado (0.16), City University of Hong Kong (0.15), University of Western Sydney (0.11) and Southeast University (0.11) respectively.

Fig. 5. Institutional cooperation network.

5) Key countries

According to the statistical results of HistCite, all the authors of 256 articles were from 41 different countries (regions). Countries (regions) with extraction frequency⩾7 are shown in Table III. The research in this field mainly focuses on four countries: USA, China, Australia and UK, and the number of published articles is significantly higher than that of other countries or regions. Only four countries account for 66.67% of the total statistics. In addition, the frequency of publications in China is less than that in USA, but TLCS (the total citations of published literature in local) and TGCS (the total citations of published literature in WOS) are both higher than that in USA. It can be seen that the literature published by Chinese authors has been internationally recognized and widely cited, among which the citation amount in WOS is 20 times of the published amount, as well as the citation amount in local is also 5 times.

TABLE III: KEY COUNTRIES

Ranking	Country	Recs	TLCS	TGCS
1	USA	80	200	1212
2	Peoples R China	71	356	1454
3	Australia	56	333	1166
4	UK	17	38	219
5	South Korea	9	19	66
6	Singapore	8	25	114
7	Sweden	7	65	218

National collaboration network is shown in Fig. 6. Three prominent nodes can be seen, namely, USA, China, and Australia. Among them, USA (0.22) and Australia (0.27) are marked with a purple outer ring, while China has a higher number of publications than Australia, Scotland and many other countries, but the centrality is only 0.07, indicating that despite the large number of documents in China, there is still a lack of communication and collaboration. Particularly, China has established cooperation with six countries, including Canada, USA and Australia primarily, especially with Australia and Pakistan. In view of time axis, UK, USA, China and Australia started the research in this field at the earliest, followed by Denmark, Singapore, Scotland, Sweden and so on. In recent years, South Korea, Iran, India and other countries also joined the field.

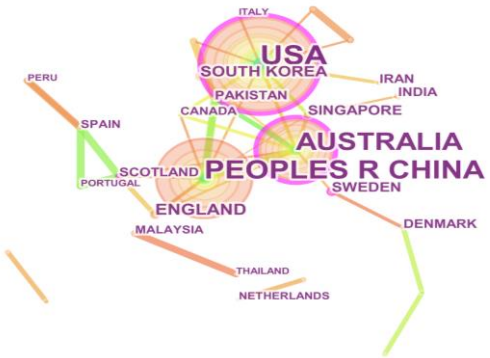

Fig. 6. National cooperative network

TABLE IV: CLASSIC ARTICLES

Freq	Author	Year	Title
70	Mohamed S	2002	Safety Climate in Construction Site Environments
67	Zohar D	1980	Safety climate in industrial organizations: Theoretical and applied implications
48	Flin R	2000	Measuring safety climate: identifying the common features
47	Guldenmund FW	2000	The nature of safety culture: a review of theory and research
45	Neal A	2000	The impact of organizational climate on safety climate and individual behavior
44	Glendon AI	2001	Safety climate factors, group differences and safety behavior in road construction
41	Fang DP	2006	Safety Climate in Construction Industry: A Case Study in Hong Kong
41	Cooper MD	2004	Exploratory analysis of the safety climate and safety behavior relationship
40	Dedobbeleer N	1991	A safety climate measure for construction sites
39	Zohar D	2000	A group-level model of safety climate: Testing the effect of group climate on microaccidents in manufacturing jobs

TABLE V: TRANSIENT ARTICLES

Freq	Cen	Author	Year	Title
37	0.19	Gillen M	2002	Perceived safety climate, job demands, and coworker support among union and nonunion injured construction workers
44	0.14	Glendon AI	2001	Safety climate factors, group differences and safety behavior in road construction
67	0.09	Flin R	2000	Measuring safety climate: identifying the common features
48	0.09	Zohar D	1980	Safety climate in industrial organizations: Theoretical and applied implications
28	0.09	Pousette A	2008	Safety climate cross-validation, strength and prediction of safety behavior
38	0.08	Choudhry RM	2008	Why operatives engage in unsafe work behavior: Investigating factors on construction sites
70	0.06	Mohamed S	2002	Safety Climate in Construction Site Environments
22	0.06	Clarke S	2006	The relationship between safety climate and safety performance: A meta-analytic review
12	0.06	Aksorn T	2008	Critical success factors influencing safety program performance in Thai construction projects
47	0.05	Guldenmund FW	2000	The nature of safety culture: a review of theory and research
18	0.05	Abdelhamid TS	2000	Identifying Root Causes of Construction Accidents
12	0.05	Fang DP	2013	Development of a Safety Culture Interaction (SCI) model for construction projects
8	0.05	Menzel NN	2010	Latino worker perceptions of construction risks

6) Intellective base

Through literature co-citation analysis, classical and transient literature were identified, jointly constituting intellective base of construction safety field from the perspective of behavior [19]. Classic articles are usually determined according to citation frequency, and the top 10 cited literatures are selected as shown in Table IV. Transient articles which has a turning significance and a bridging effect are usually found out according to betweenness centrality. Literatures with betweenness centrality⩾0.05 are shown in Table V.

B. Research Focus Analysis

According to the left node information of keyword co-occurrence network, there are 14 nodes with betweenness centrality⩾0.1. They are safety climate (0.22), framework (0.22), performance (0.21), system (0.20), construction (0.19), work (0.17), communication (0.12), injury (0.1), safety behavior (0.1), cross validation (0.1), construction project (0.1), questionnaire (0.1), visualization (0.1), and cognitive analysis (0.1). The co-occurrence of many keywords is to build bridges through them. Keywords with extraction frequency⩾15 are shown in Table VI. It can be found that the literature studying construction safety from the perspective of behavior mainly focuses on six hot topics, including safety climate and culture, safety behavior, safety performance, accident and injury, occupational safety and health, and safety risk perception. The research object mainly includes three dimensions: construction industry, construction site or construction workers. It is further found that the frequency of "model" is extremely high, which demonstrates that most of the researches in this field build models to analyze and confirm the problems studied.

TABLE VI: KEYWORDS FREQUENCY

Count	Keywords	Count	Keywords
69	safety climate	29	safety
68	behavior	26	Hong Kong
66	performance	26	occupational safety
65	model	25	worker
54	climate	22	safety culture
52	accident	21	health
45	construction	21	site
44	culture	21	perception
43	industry	19	safety behavior
41	management	18	risk
34	injury	16	safety management
34	construction safety	16	environment
31	construction industry	15	construction worker

C. Research Frontier and Development Trend Analysis

The concept of "research frontier" was first proposed by Price to describe the dynamic nature of research topic, and the research frontier of a topic includes about 40-50 recently published articles [18]. In CiteSpace, literature co-citation cluster analysis is usually used to explore research frontiers and development trends [19], [20]. Cluster analysis is to clarify the affinity between research objects by dividing the network graph into subgroups, and to extract naming marks from the title, keywords or abstract of citing literature for each subgroup.

Fig. 7. Timeline.

1) Research front

Different standards and clipping algorithms were selected to draw the map for many times, so that both the module value Q and the index Mean Sihouette to evaluate the internal homogeneity of the cluster meet the requirements [15]. Ultimately, set the time slice =2, TopN=20, Pathfinder is the cutting algorithm, and clip each slice network and the merged network. The results demonstrate Modularity (0.7931) $>$0.3 and Mean Silhouette (0.5384) $>$ 0.5, that is, the whole network constitutes a relatively obvious and concerned cluster.

The research frontier terms are usually represented by cluster information labels [19]. Accordingly, Sihouette value of each cluster is larger than 0.7, revealing good cluster effect and high homogeneity. The largest #0 cluster label is "multiple source", which mainly studies the different levels of cognition of safety culture and safety climate among different levels of personnel. The #1 cluster label is "occupational risk assessment", which introduces risk assessment into the construction industry, and points out that occupational risk assessment is crucial to construction safety. The #2 cluster tag is "supervisors safety response", which is mainly about the impact of managers on the safety performance of the working groups. The #3 cluster label is "safety culture", revealing the impact of safety culture on the behavior of construction workers. The #4 label refers to "safety behavior", demonstrating that factors influencing workers' safety behaviors contain social standards, risk perception, environmental conditions, etc.

2) Development trend analysis

Select Timeline view, as shown in Fig. 7. Timeline view puts all the documents in the same cluster on the same horizontal line, so that the number and co-citation relationship of each cluster can be clearly seen, and the time span of the documents in each cluster is clear at a glance [20]. Apparently, there are significantly more reference relationships within the cluster than between the clusters, which is also the basis for classify each cluster. Meanwhile, the arcs represent the co-citation relationship, and the color of arcs represents the year of publication of the citing literature [15]. Accordingly, #5 cluster "safety behaviour" started early, which is the core of research in the field of construction safety from the perspective of behavior. It mainly discusses the relationship between safety climate and safety performance and its influence on safety behavior. Two clusters, #3 "safety culture" and #9 "construction safety culture", have appeared since 2007. At this stage, scholars began to focus on introducing the concept of safety culture into the construction industry, and studied the huge influence of safety culture on workers' behaviors and attitudes. Subsequently, four clusters including #0 multiple source, #1 occupational risk assessment, #2 "supervisors safety response" and #6 "safety culture perception" have been formed since 2010. The main research topic is the impact of safety perception and occupational risk assessment on construction safety. Recently, two major clusters, #7 "proactive behavior-based safety management" and #4 "safety behavior", have been established, exploring the application of computer technology in the field of construction safety management from the perspective of behavior, and achieving wonderful consequence.

IV. Discussion and Future Research Directions

In the past two years, there has been a rebound after years of continuous reduction in the building safety accident rate. Unfortunately, the current situation may be out of control at any time. Fang DP manifested that the research of construction safety should be an interdisciplinary field, and the knowledge of various disciplines must be considered comprehensively, and the influence of human factors on safety management should be fully considered [11]. Therefore, this paper summarizes that human behavior is the main object of construction safety management, and interprets a new perspective.

Khosravi *et al.* made a qualitative analysis of the factors affecting unsafe behaviors and accidents in construction, and outlined eight influencing factors including individual characteristics, working environment, working group, contractor, supervisor, project management, organization and society [14]. In summary, it can be generalized into three perspectives: individual, organizational management, and environmental perspective. While the research on organizational management factors such as safety climate and safety culture has been relatively mature, few scholars have been involved in the behavior research under the interaction of individual, group (organization) and environment. Furthermore, groups are classified into formal groups and informal groups, and most scholars do not distinguish when studying the influence of groups on building safety behavior. However, two types of groups have different group characteristics and are completely different group forms, and there should be some distinctions in the action mechanism of individual behaviors [21], [22]. On the other hand, a small number of studies that have differentiated groups only crowd formal groups such as owners, contractors, supervisors, and administrative departments. Scholars does not consider the crowd formed spontaneously due to the consistency of their interests, hobbies, habits and aspirations in their interactions. The crowd has not been approved by the organization, namely informal groups. Furthermore, informal groups may have a greater impact on the safety behavior of construction workers [23], [24]. Consequently, special attention should be paid to the introduction of informal group factors in the future.

Speak of research methods, scholars mainly use the traditional self-report methods such as questionnaire survey and interview to collect data in this field, and then analyze and verify the data through the model presently. Relatively objective research methods, such as experiment and simulation, are seldom employed, which should be intensified later. Fang DP also stated that the development of computer technique will provide new methods and means for safety management, and attention should be paid to the application of new technology in construction safety [11]. Zhou ZP *et al*. also analyzed that construction safety can be studied from two perspectives, one is management-oriented and the other is technology-oriented. The management perspective is to control from the safety climate, safety culture, workers' behavior, etc., and the technical orientation is to set up the last layer of protection barrier for human error

[13]. This paper discovered that the current research on management perspective is quite fruitful, and in recent years, more and more scholars turn to study the application of intelligent technology in construction management [12], but it is still in the stage of theoretical research, rarely applied to practical safety management, which needs to be further reinforced.

To sum up, the research hot topics obtained by more objective quantitative analysis method in this paper are basically consistent with the conclusions of related literature review. In addition, five "key points" are identified in this paper, and the content is more objective and abundant, which is beneficial for scholars to have a systematic and accurate understanding of this field, so as to improve the research efficiency.

V. Conclusions

In this paper, 256 literature on construction safety from the perspective of behavior based on WOS were visualized and quantitatively analyzed by knowledge mapping analysis tools Citespace and HistCite. The results display that research on building safety from the perspective of behavior has been increasingly recognized by scholars in recent years, and this field is an interdisciplinary subject, covering two categories of safety science and building science, with the two journals of *Safety Science* and *Journal of Construction Engineering and Management* publishing the most literatures. The authors centralize on colleges, and the contributions of research laboratories and companies are quite insufficient. The authors' cooperative network is characterized by huddle. Two research institutions, Hong Kong Polytech Univ and Tsinghua Univ, have offered a lot, and a relatively close network of institutional cooperation has been formed with Tsinghua University as the core. Moreover, USA, China and Australia are the three countries with the largest contribution, which have an overwhelming advantage compared with other countries. Attentively, although China has a large number of publications, it is relatively deficient in communication and collaboration. Eventually, classic literature and key literature in this field are further obtained through co-citation analysis.

At present, scholars from the perspective of behavior mainly pay close attention to six themes: safety climate and culture, safety behavior, safety performance, safety risk awareness and so on. Research frontiers concentrate on occupational risk assessment, regulator safety response, safety culture, safety behavior and other topics. The development trend can be roughly divided into four stages: the research on the relationship between safety climate and safety performance; the influence of organizational safety culture on behavior; the effect of safety cognition and occupational risk assessment on construction safety; and the application of computer technique in the field of building safety behavior. This study reveals the current situation of building safety research from the perspective of behavior, and indicates the possible future research direction, which is conducive to provide references for further research.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Y. Fu And G. Ye conceptualized the framework of this study. Y. Fu contributed to the methodology and results analysis. X. Tang and L. Yang revised the original manuscript. All authors had approved the final version.

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