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Review

Measuring Safety Climate in the Construction Industry: A Systematic Literature Review

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Abstract: Recent studies on safety in various fields use the concept of safety climate to explain the causes of safety accidents. Many studies attempt to measure the safety climates and identify the causes for accidents in the high-risk construction industry. Studies have shown that the higher the level of the safety climate, the lower the accident rate at construction sites. Methods of measuring safety climate, including the NOSACQ-50 survey, have been presented. Studies on the methodology of measuring safety climate should be continued to improve reliability and precision. Although many studies have been conducted to measure safety climate, such as questionnaires, regression analysis, and suggestions for safety climate measurement methods, there are few studies on a systematic literature review of them. This requires a systematic literature review (SLR) of the studies conducted so far. This study conducted an SLR on the definition and measurement methods of safety climate in the construction industry published since 2000, when safety climate's impact on accidents began to be established. This review study utilized the PRISMA method, analyzed 735 studies, and selected 57 papers finally. SLR was carried out for selected research works, and the results were summarized. There are three methods to measure safety climate: literature survey, questionnaire, and data analysis. Factor analysis, development of measuring model, development of questionnaire, statistical analysis, and machine learning were investigated as their sub-methods. This study's results can be used as fundamental sources for improving existing methods and developing new methods of measuring safety climate in the construction industry.

Keywords: measuring safety climate; construction industry; systematic literature review

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1. Introduction

The construction industry, in particular, goes through changes in the working environment and changes of managers and workers depending on the construction site. It is a high-risk industry with a high probability of fatal accidents, such as falls or being crushed by objects [1–4]. According to the data from the Ministry of Employment and Labor (2021), the analysis of the accident status in 10 industries in 2019 showed that the construction industry had the highest workplace accident rate with 25,298 (26.9%), as shown in Figure 1a, followed by 23,684 (25.18%) in manufacturing, and 5464 (5.8%) in transit, warehouse, and telecommunication. The industry-specific mortality rate was overwhelmingly high in the construction industry at 428 (50.1%). The mortality rate was 206 (24.1%) in manufacturing, 118 (13.8%) in others (service industry), and 59 (7.0%) in transit, warehouse, and telecommunication [5].

The death toll at construction sites worldwide is also at a serious level. According to the number of workers killed at construction sites in Organisation for Economic Co-operation and Development countries (International Labor Organization, 2016; Figure 2), the largest number was from Israel, with 24.8 per 100,000, followed by Mexico (19.5), South Korea (17.6), Portugal (15.6), Estonia (13.8), Turkey (13.4), Slovenia (12.5), and the Czech

Republic (12.4). The construction site death toll in Israel, which has the highest death toll, is more than 2000 a year, calculated by the total population [6].

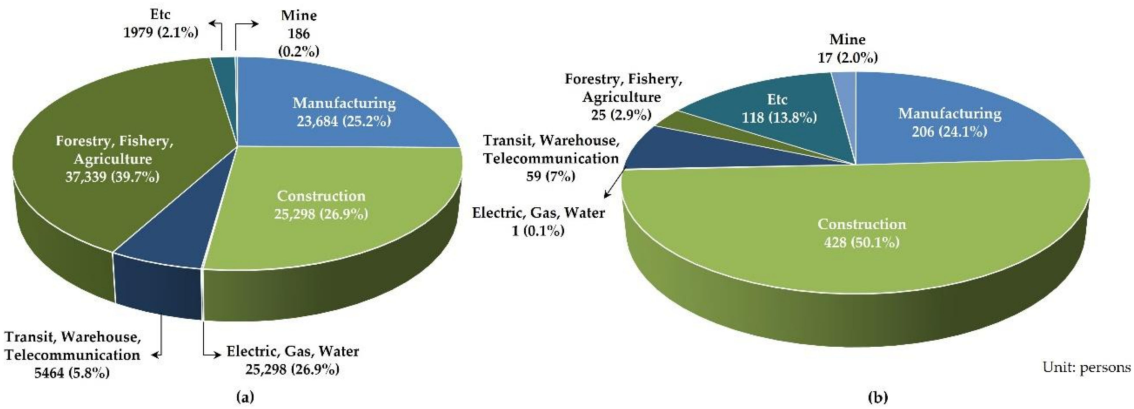

Figure 1. Industry-specific distribution of accidents: (**a**) accident rate; (**b**) mortality rate.

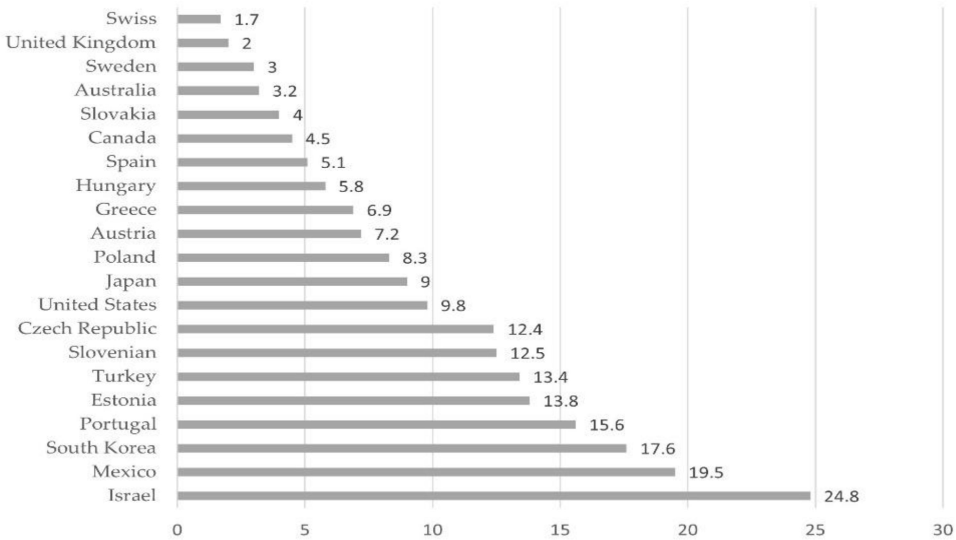

Figure 2. Construction site death tolls in Organisation for Economic Co-operation and Development countries (per 100,000 population).

Therefore, it is crucial to identify the underlying causes of such safety accidents and measure the safety climate to minimize accident rates in the construction industry [7–10].

Recent studies on safety in various fields have used the concept of "safety climate" to determine fundamental causes of safety accidents. This concept was first introduced by Zohar, and its impact on safety accidents was established by Clarke [11,12]. Safety climate has received much academic attention, and in recent years, safety climate has been actively studied in various industries [13], such as health [14–18], engineering [19–25], construction [26–29], social science [30–33], and business management [34–37].

Many researchers have also conducted research on safety climate to establish a relationship between safety climate and accidents. Fernández et al. [38] surveyed 455 Spanish companies to establish a relationship between safety culture and safety accidents and analyzed the results using statistical techniques. The role of managers in promoting the safety behaviors of workers based on the safety management system in an organization was found to be important in minimizing safety accidents.

Research on the safety climate was also conducted in the medical and nuclear fields, which are industrial fields where safety accidents can lead to serious accidents. Hessels et al. [39] defined safety climate in the medical field and established its relationship with medical accidents. Patient safety climate (PSC) is an important factor in reducing the rate of infection between patients and healthcare workers and that PSC and standard precaution are highly correlated statistically. Navarro et al. [40] created a method of measuring safety climate to establish a relationship between safety climate and safety accidents in the nuclear field. They developed "group safety climate" (GSC) by upgrading the ZGSC scale developed by Zohar and Luria. A survey of GSC with 566 nuclear plant employees in Spain found that safety climate is highly correlated with formalized procedure, safety behavior, and time pressure.

There are several methods of measuring the level of safety climate, among which the NOSACQ-50 survey is the representative one. Based on theories of psychology, safety culture, and safety climate, as well as accumulated databases and international research activities, the National Research Center for Work Environment developed a questionnaire, which was made available worldwide. NOSACQ-50 consists of 50 items across seven dimensions, i.e., shared perceptions of: (1) management safety priority, commitment, and competence; (2) management safety empowerment; and (3) management safety justice; as well as shared perceptions of (4) workers' safety commitment; (5) workers' safety priority and risk non-acceptance; (6) safety communication, learning, and trust in co-workers' safety competence; and (7) workers' trust in the efficacy of safety systems. NOSACQ-50 was found to be a reliable instrument for measuring safety climate, and valid for predicting safety motivation, perceived safety level, and self-rated safety behavior [41]. Studies measuring safety climate using NOSACQ-50 have been actively carried out. Marin et al. [42] divided 353 survey participants into three groups of workers, field supervisors, and field managers to measure safety climate in the construction industry and conducted a survey using NOSACQ-50. They found that the higher the level of awareness of safety climate in each group, the lower the accident rate at the construction site. A questionnaire is the most frequently used method to measure safety climate. In some cases, the NOSACQ-50 was used, or seven items of NOSACQ-50 were changed according to country and construction site characteristics. In other ways, many studies have been conducted to measure safety climate, such as regression analysis and the development of safety climate measurement methods. The details are described in Section 3.3.

Several studies measure safety climate and identify the cause and mechanism of safety accidents. Further, studies have shown that the higher the level of safety climate, the lower the accident rate at the construction site. Various methods of measuring safety climate, including the NOSACQ-50 survey, have been presented, and studies on the methods of measuring safety climate should be continued to improve reliability and precision. Although many studies have been conducted to measure safety climate, such as questionnaires, regression analysis, and suggestions for safety climate measurement methods, there are few studies on a systematic literature review of them. This requires a systematic literature review (SLR) of the studies that have been conducted so far. Therefore, this study conducted an SLR of research on the definition and measurement methods of safety climate in the construction industry that were published since 2000, when the safety climate's impact on safety accidents began to be established. To this end, this study is structured as follows: analysis of trends in safety climate in all industries (i.e., keywords, industries, countries, years, and journals); review of definitions of safety climate in the construction field; and review of measurement methods of safety climate in the construction field. First, in order to analyze the research trend of safety climate, it should be analyzed for all industrial fields, and it can be more accurate to analyze the definition of safety climate in the construction industry. Finally, a review of safety climate measurement methods in the construction industry is conducted for the purpose of this study. The results of this study will be used as foundational data for developing new methods of measuring safety climate in the construction industry and improving existing ones; thus, it can aid in lowering the safety accident rate in the construction industry.

2. Data Sources and Methodology

2.1. Data Sources

First, data related to safety climate measurement were searched using Web of Science and Google Scholar, which are representative integrated search platforms. Then, articles were searched through related journals such as ASCE, ScienceDirect, Scopus, SpringerLink, Taylor & Francis, and Wiley Online Library. Google Scholar was used for some of the theses or documents published in journals that were not internationally accredited. As most of the materials searched in Web of Science and Google Scholar were overlapping, Google Scholar was used as a main research platform for this research.

The concept of safety climate was first introduced by Zohar in 1980, and the impact of safety climate on safety accidents was established by Clarke in 2006 [11,12]. The research on safety climate in the construction industry began 1991 by Dedobbeleer and Beland, but most of the literature on the impact of safety climate on safety accidents was after 2000 and more systematic. Therefore, this study searched the literature published after 2000, when research on the relationship between safety climate and safety accidents began in earnest.

2.2. Systematic Literature Review

Numerous studies on this topic have been published worldwide, and after the 1990s, with the development of computer science, it was possible to obtain these works in a short time using search tools on the internet. The use of the SLR as a research tool began in this context. SLR is a systematic way of collecting, critically evaluating, integrating, and presenting findings from across multiple research studies on a specific research question or topic of interest. SLR provides a way to assess the quality level and magnitude of existing evidence on a question or topic of interest. It offers a broader and more accurate level of understanding than a traditional literature review [43]. SLR is an exact and reproducible method for identification, evaluation, and interpretation of predefined fields of study [44].

Looking at the literature review articles published on the construction industry, most of the review articles published since 2010 were based on SLR [45–58]. Since 2018, there have been a number of review articles using preferred reporting items for systematic review and meta-analysis (PRISMA) [55–58]. This study also follows PRISMA for systematic review. PRISMA is a method that collects and analyzes data by employing systematic and explicit ways to identify, select, critically evaluate, and review relevant studies [43].

2.3. Methodology

In the aforementioned literature databases, the study sequentially searched the literature using the Boolean operator 'AND' with keywords such as safety climate or culture, safety climate or culture definition, measurement or measuring safety climate, safety climate factors, and safety climate indicators. As shown in Table 1, many documents were searched for safety climate as a keyword. However, many documents were about case studies of group or individual behavior, perceptions, and culture that are related to the safety climate, but are not related to the definition or measurement method of the safety climate. Therefore, if the search scope was narrowed down to 'safety climate or safety culture definition', 'safety climate and safety culture definition', 'measurement or measuring safety climate', the number of records was greatly reduced. Additionally then, records subject to this study were significantly reduced, except for documents that collect some construction site data and analyze the relationship between single factors and safety accidents or performance, such as worker's behavior and manager's acceptance.

Table 1. Search by keyword in literature databases.

Literature Database	Literature Keywords				
	Safety Climate	Safety Climate Definition	Measurement or Measuring Safety Climate	Safety Climate Factors	Safety Climate Indicators
Google Scholar	1,250,000	25,800	17,800	667,000	166,000
ScienceDirect	7318	3082	5516	6445	2605
SpringerLink	3802	1674	3078	3122	1305
ASCE Library	4760	3334	3920	3965	3588
Wiley Online Library	7627	5005	6692	6289	6285
Taylor & Francis Online	1276	1424	1316	1905	1352
Scopus	69	75	118	124	96

As a result, since 2000, on Google Scholar, as shown in Table 1, about 1,250,000 studies related to safety climate in the construction field, 25,800 on safety climate definition, 17,800 on measurement or measuring safety climate, 667,000 on safety climate factors, and 166,000 on safety climate indicators were found. Google Scholar contains a variety of reports, including books, patents, and dissertations, and academic papers in most of the databases listed in Table 1. For example, if "measurement of safety climate" is searched as a keyword, multiple studies containing only the term "safety climate", excluding "measurement" are found. Therefore, it is inefficient to search and review all relevant literature in Google Scholar. Since measuring safety climate in the construction field, which is covered in this review article, is a specific topic, most studies were retrieved from databases such as ScienceDirect, SpringerLink, and ASCE Library. However, Google Scholar was used when searching for specific sources such as books, magazines, and dissertations that were not easily found in databases such as ASCE Library and when the original text was not downloadable in other databases.

As shown in Table 1, many studies were searched in the selected databases in the following order after Google Scholar: Wiley Online Library, ScienceDirect, and ASCE Library. In particular, since ASCE Library covers only the construction field, many studies related to this review paper were searched, while those in Scopus were searched relatively little. Additional search conditions were as follows: (1) published in English, from 1 January 2000, to 31 December 2020 and (2) the subject area was limited to engineering because of a large mix of safety climate-related literature in other fields, including agriculture, biology, medicine, and environment. Finally, gray literature with uncertain publishing information was excluded, and the search was based on data granted a digital object identifier.

Based on the literature retrieved on 1 July 2021, 735 records were finally identified, as shown in Figure 3, after excluding those unrelated to the topic of this study. Among them, 250 records unrelated to the construction industry were excluded after the screening process and the removal of 345 duplicates, and 140 full text articles were selected. Then, the full texts of 105 studies were reviewed, after excluding 35 papers that were unrelated to safety climate definition and measuring safety climate. Among them, the following studies were excluded: (1) analyzing the accidents with single factors, such as worker's behavior, manager's perception [59–82], and performance [83–91], (2) applying the safety climate to the construction industry and analyzing the effect [92–98], (3) comparing the safety climate of the nation or worker's race [99–102].

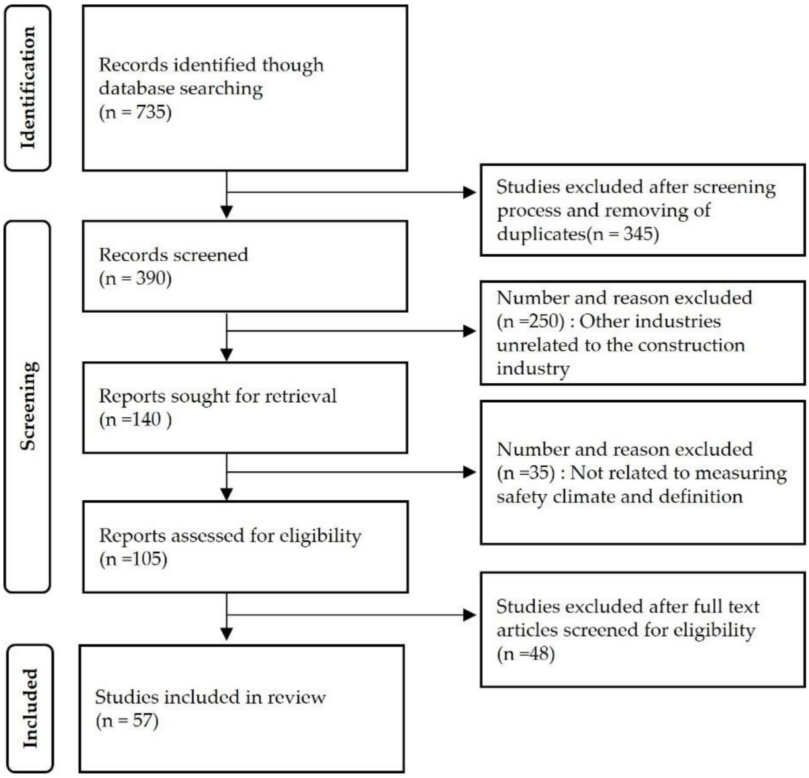

Figure 3. PRISMA flowchart.

Additionally, to evaluate the qualitative reliability of the finally selected 57 studies, a word cloud generator program was utilized to derive keywords and examine frequencies and relevance (Figure 4).

Figure 4. Frequency and relevance analysis.

3. Results

3.1. Analysis of Safety Climate Trend

The 390 studies on safety climate, published from 1 January 2000, to 31 December 2020, were analyzed by keyword, country, industry, year of publication, and publication journal. First, the frequency analysis of keywords showed that excluding safety climate, the keywords with the highest frequency were safety culture (n = 158, 17.7%), safety performance (n = 135, 15.2%), construction (n = 89, 10%), indicators (n = 58, 6.5%), safety management (n = 55, 6.2%), safety behavior (n = 53, 5.9%), structural equation (n = 35, 4.1%), occupational safety (n = 33, 3.9%), factors analysis (n = 30, 3.6%), patient safety (n = 28, 3.3%), construction site (n = 24, 2.8%), construction project (n = 22, 2.6%), workers safety, safety response (n = 18, 2.1%), and organizational climate (n = 17, 2.0%). Other keywords included occupational health, safety perception, safety attitude, and accident prevention (Figure 5).

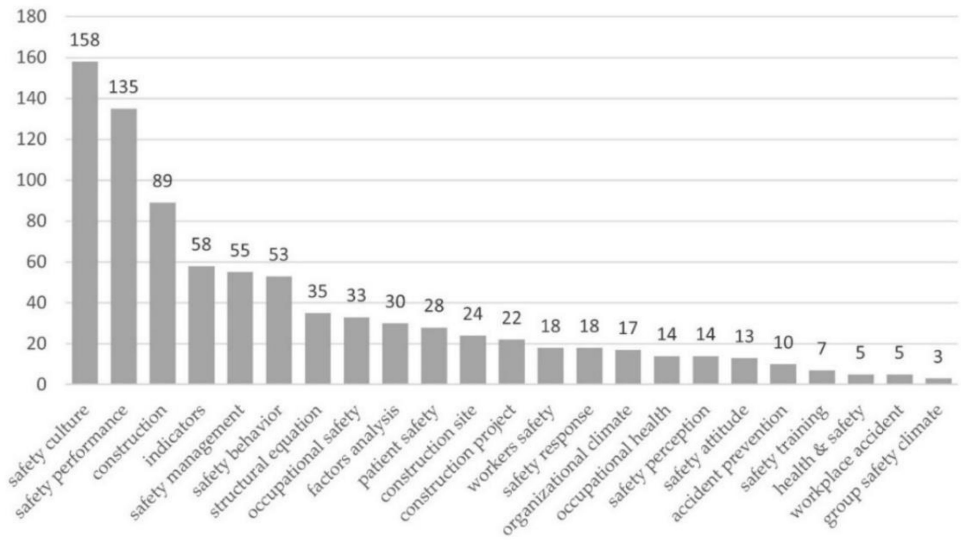

Figure 5. Keywords in safety climate literature.

Second, the analysis of the country of publication showed that the highest number of studies—approximately 21% (n = 84)—were conducted in the United States (Figure 6), followed by China (n = 63, 16.2%) and Australia (n = 62, 15.9%). The percentage of studies carried out in other countries is as follows: the United Kingdom (n = 25, 6.4%), Norway (n = 17, 4.4%), South Korea (n = 13, 3.3%), and Canada (n = 10, 2.6%).

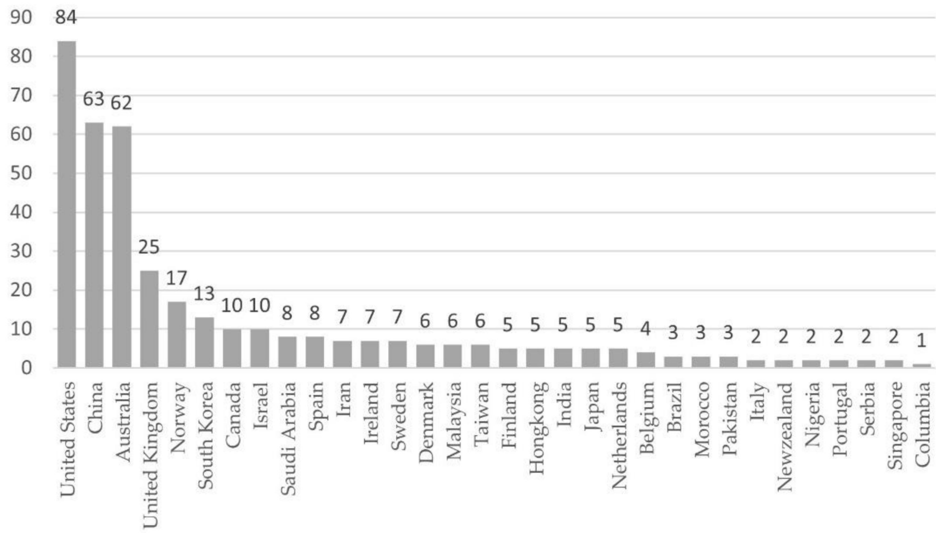

Figure 6. Number of safety climate studies by country.

Third, the analysis of industries with regard to safety climate literature showed that the highest proportion of studies—about 36% (n = 40)—was on the construction industry, followed by all industry (n = 102, 26.2%), medicine (n = 87, 22.3%), and manufacturing (n = 36, 9.2%) (Figure 7). Other industries included chemical (n = 12, 3.1%), transportation (n = 5, 1.3%), and aviation (n = 4, 1.0%). Studies without mention of specific industrial fields, such as construction, medicine, and manufacturing, were defined as all industries.

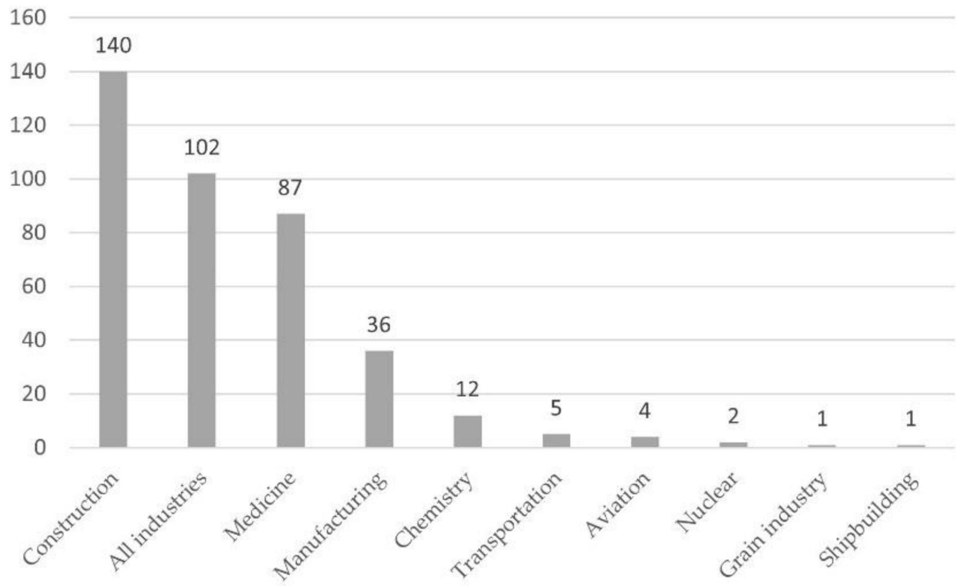

Figure 7. Safety climate literature by industry.

Fourth, as shown in Figure 8, the analysis of the publication years of safety climate literature from 2000 to 2020 showed that most studies were published in 2017 and 2018, at approximately 7.2% (n = 28) followed by 2016 and 2019 (n = 26, 6.7%), 2020 (n = 25, 6.4%), 2015 (n = 24, 6.2%), and 2010 (n = 22%, 5.6%). Since 2000, the number of safety climate publications has been increasing steadily.

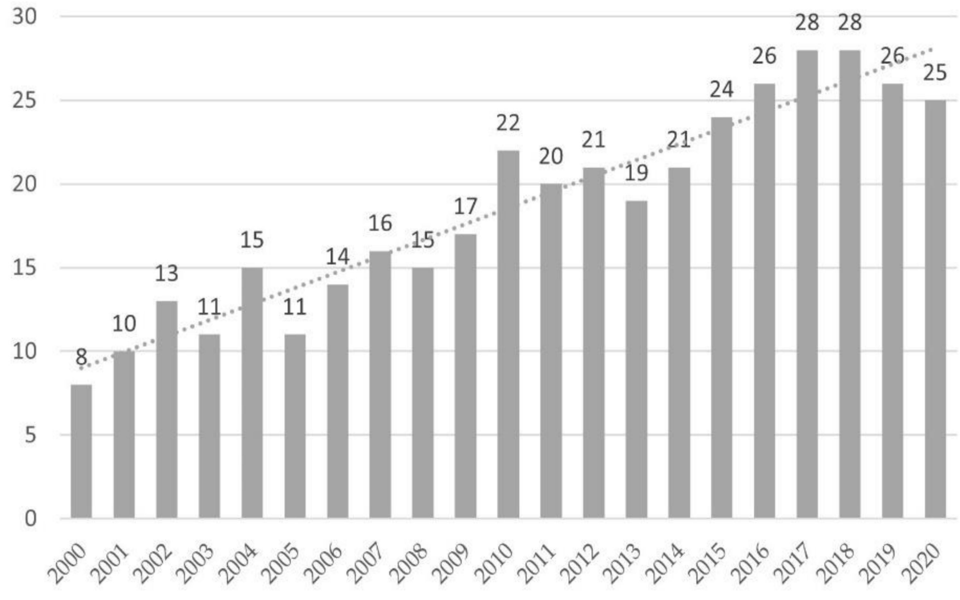

Figure 8. Publication years of safety climate studies.

Finally, as shown in Figure 9, the analysis of publication journals showed that ScienceDirect had the most literature, with approximately 28.7% (n = 112), followed by Google Scholar (n = 83, 21.3%), ASCE Library (n = 64, 16.4%), Taylor & Francis Online (n = 53, 13.6%), Wiley Online Library (n = 35, 9.0%), SpringerLink (n = 25, 6.4%), and Scopus (n = 18, 4.6%).

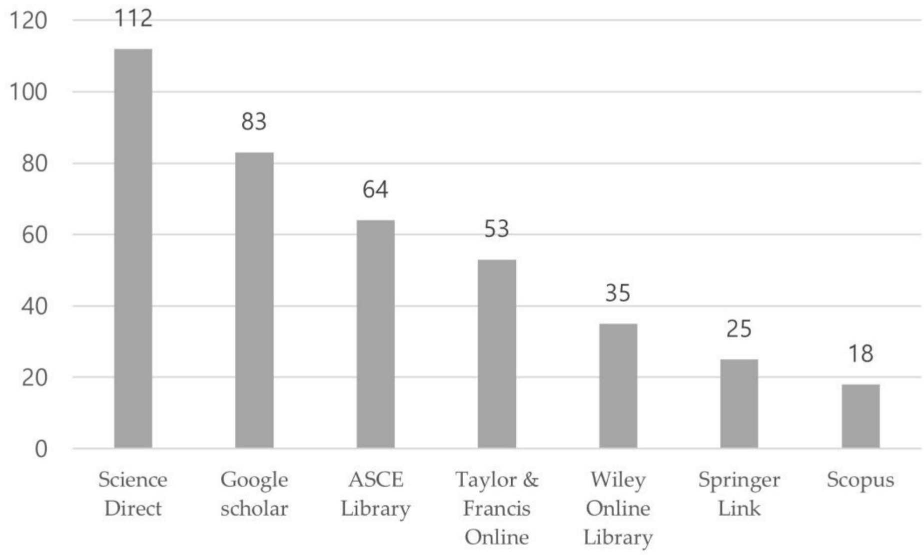

Figure 9. Search platforms and journals of safety climate studies.

3.2. Safety Climate and Culture in the Construction Industry

The construction industry is considered the most dangerous industry [103]. In the United States, there are approximately 900 fatal injuries at construction sites each year. The mortality rate accounts for 4.4% of all industries, but it is the highest rate found in construction industries of other countries [104]. In the UK, about 2.9% of construction workers are injured each year, which is significantly higher than the average of all industries [105], and the industry with the highest mortality rate in South Korea among ten industries was found to be the construction industry (50.1%) [5].

As such, the construction industry of each country is a high-risk industry with high safety and fatal accidents rates, and many studies have been conducted by introducing the concept of safety climate to reduce the safety accident rate at construction sites. Several studies have demonstrated the value of safety climate and culture in reducing the safety accident rate at the sites [106–108]. Therefore, building a positive safety climate and culture is accepted as a fundamental strategy to effectively manage the safety of construction sites [109–111].

However, despite decades of research on safety climate and safety culture, there is still considerable ambiguity with respect to the definition and measurement methods [112]. There is a lack of clarity and existence of confusion about the definition and measurement of safety climate and safety culture [113]. Some researchers have strived to clearly distinguish the meaning of safety climate from safety culture, while some other researchers use the two terms interchangeably [114,115]. As a single example of this ambiguity, Al-Bayati et al. [104], as shown in Table 2, organized the concept of safety climate and safety culture defined in the NCA (National Construction Agenda, 2008), OSHA (Occupational Safety and Health Administration, 2000), NRC (US Nuclear Regulatory Commission, 2018), and CPWR (Center for Construction Research and Training, 2014). For safety climate, there is a difference in the meaning provided by NCA and CPWR. While the definition of safety climate presented by NCA is generally considered a common perception and attitude of employees in the workplace, CPWR focuses on consistency and adequacy with actual conditions compared to the organization's safety policies. Moreover, OSHA and NRC do not even provide a definition of safety climate. For safety culture, NCA defines it to be the underlying organizational principles, norms, commitments, and values, while OSHA defines it to be beliefs, practices, and attitudes. NRC defines it as the core values and behaviors derived from leaders and individuals, and CPWR focuses on unspoken safety-related beliefs, attitudes, and values that interact with an organization's systems.

Table 2. Current proposed safety climate and safety culture definition [104].

Agency	Safety Climate	Safety Culture
NCA (2008)	Safety climate is generally viewed as shared employee perceptions and attitudes about safety at a workplace. It reflects the safety culture at a particular point in time	In general, safety culture is viewed as the underlying organizational principles, norms, commitments, and values that relate to how safety and health is operationalized and its relative importance in comparison with other workplace goals
OSHA (2000)	-	Safety cultures consist of shared beliefs, practices, and attitudes that exist at an establishment. Culture is the atmosphere created by those beliefs, attitudes, etc., which shape behavior.
NRC (2018)	-	The core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure the protection of people and the environment.
CPWR (2014)	The shared perceptions of safety policies and procedures by workers of an organization at a given point in time, particularly regarding the adequacy of safety and consistency between actual conditions and espoused safety policies and procedures. Homogeneous subgroups tend to develop shared perceptions, while between-group differences are not uncommon within an organization.	Deeply held but often unspoken safety-related beliefs, attitudes, and values that interact with an organization's systems, practices, people, and leadership to establish norms about how things are done in the organization. Safety culture is a subset of organizational culture and is clearly influenced by it. Organizations often have multiple cultures or subcultures; this may be particularly true in the construction industry.

Schwatka et al. [116] selected and analyzed 56 studies to investigate the definition of safety climate in the construction industry. The most frequent definition of safety climate was analyzed to be workers' perception of safety at construction sites (n = 38, 68%), and in some studies, safety climate reflected workers' attitudes (n = 5, 9%) or it was defined as safety indicators (n = 10, 18%). Li et al. [117] defined safety climate as workers' attitudes at construction sites and as a belief in one's ability to identify safety accidents. Marquardt et al. [118] defined safety climate as including safety culture that reflects implicit and explicit social perceptions.

Other definitions were also found: (a) safety climate is a sub-concept of safety culture [119–122] and reflects the actual safety culture [123–126]; (b) safety culture is a sub-facet of organizational culture that affects workers' attitudes and behavior in relation to an organization's ongoing safety performance [111]; (c) safety climate/culture have an impact on safety performance [127,128], and safety climate/culture will be influenced in multiple stages according to the position of workers at construction sites [129,130]; (d) safety culture is defined as those aspects of the organizational culture that will impact on attitudes and behavior related to increasing or decreasing risk [131]; and (e) safety culture is "that observable degree of effort by which all organizational members direct their attention and actions toward improving safety on a daily basis" [132]. The purpose of this section is to review the definitions of safety climate and culture, and their implications as described by various authors. The definitions for safety climate and safety culture are summarized as follows: Safety culture and safety climate can be seen similarly in that they describe an organization's approach to safety, not only the visible efforts or attitudes its members chose to adopt, but also every mental function that defines their overall behavior. However, to be more specific, there are differences. "Safety culture" mostly refers to individual and group values, attitudes, perceptions, and competencies regarding safety, while "safety climate" is mainly used to describe the expressed ideas, the tools, and techniques used in general by the organization in order to confirm its compliance to safety. In other words, the climate is an item which is easily perceived by others while culture is the basis that lies hidden under the surface.

3.3. Measuring Safety Climate

As shown in Figure 3, 57 studies were finally selected through the process of identification, screening, and eligibility. In Sections 3.1 and 3.2, the trends and definitions of safety climate or culture were analyzed. In this section, the literature on safety climate measurement methods in the construction industry are analyzed. The result can be largely divided into three ways: literature survey, questionnaire, and data analysis. The measuring methods of these three methodologies included factor analysis, development of measuring model, and statistical analysis, and it can be seen that some measured safety climate using the methods of machine learning and development of a questionnaire. For example, when explaining the development of measuring model, the main factors suitable for the characteristics of the construction site are derived through a literature survey or a questionnaire. Development of individual indicators for main factors and development of safety climate measurement models is undertaken by applying measurement scales and weights to indicators. In addition, taking factor analysis through a questionnaire as an example, the researchers conduct a survey on construction site workers and derive the factors they consider most important to measure safety climate. The derived factors are used to measure the safety climate. The summary is shown in Table 3.

Table 3. Summary of measuring methods of safety climate.

Classification	Measuring Method	References
Literature survey	Factor analysis	[116,133–143]
	Development of measuring model	[26,128,144–146]
	Development of questionnaire	[147,148]
Questionnaire	Factor analysis	[117,126,149–164]
	Development of measuring model	[165–168]
	Statistical analysis	[7,40,104,127,169–174]
	Machine learning	[175]
Data analysis	Factor analysis	[176–179]
	Machine learning	[180]

The methodology for measuring safety climate included literature survey (n = 19, 33%), questionnaire (n = 33, 58%), and data analysis (n = 5, 9%) (Figure 10). The most commonly used methodology for measuring safety climate was a questionnaire. Most of these studies carried out surveys with construction site workers and derived the most important factors for safety climate. Then, the derived factors were modified and used as a measurement tool for safety climate. The most frequently employed measuring method in the rest of the literature survey and data analysis was factor analysis, which suggests that many researchers use factors as a method to measure safety climate.

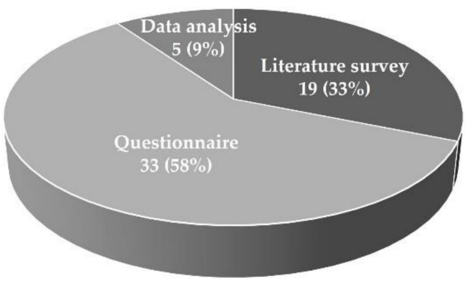

Figure 10. Measuring methods for safety climate.

Looking at the details of the three methodologies for measuring safety climate, 19 literature survey studies were analyzed by factor analysis (n = 12, 63.1%), development of measuring model (n = 5, 26.3%), and development of questionnaire (n = 2, 10.6%), as shown in Figure 11. Factor analysis, which accounts for the highest frequency, was used to derive factors through consideration of previous studies and to measure safety climate by modifying the factors according to the characteristics of each country and construction sites.

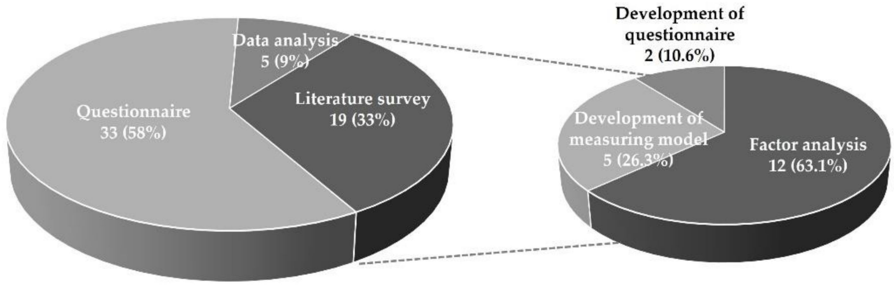

Figure 11. Measuring methods of literature survey.

Questionnaires were employed with the highest frequency among the three methodologies for measuring safety climate. Thirty-three studies were analyzed using factor analysis (n = 18, 54.6%), development of measuring model (n = 4, 12.1%), statistical analysis (n = 10, 30.3%), and machine learning (n = 1, 3.0), as shown in Figure 12.

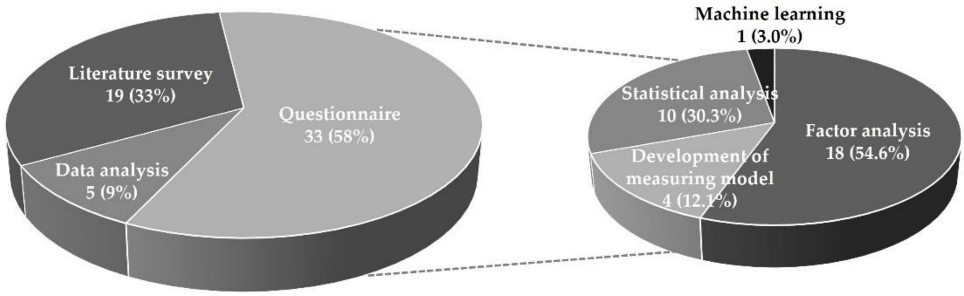

Figure 12. Measuring methods of questionnaires.

Finally, five data analysis studies were analyzed by factor analysis (n = 4, 80%) and machine learning (n = 1, 20%) (Figure 13). In factor analysis, which accounts for the highest frequency, previous safety data from construction sites were collected and analyzed, and factors related to safety climate were derived. The derived factors were modified and used to measure safety climate.

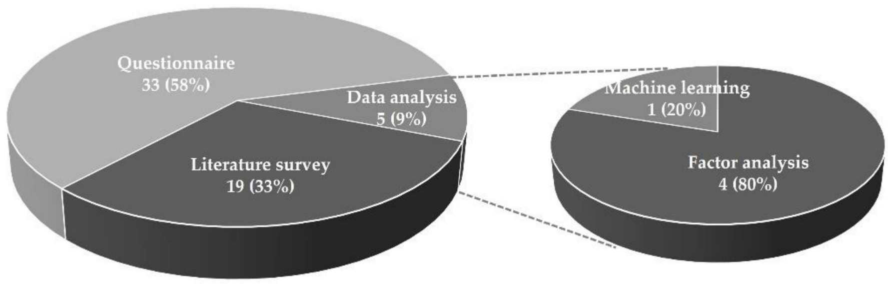

Figure 13. Measuring methods of data analysis.

Figure 14 shows the number of studies using the methods of literature survey, questionnaire, and data analysis for measuring safety climate.

Factor analysis (n = 34, 59.7%) had the highest frequency, followed by development of measuring model (n = 9, 15.8%), statistical analysis (n = 10, 17.5%), development of questionnaire (n = 2, 3.5%), and machine learning (n = 2, 3.5%).

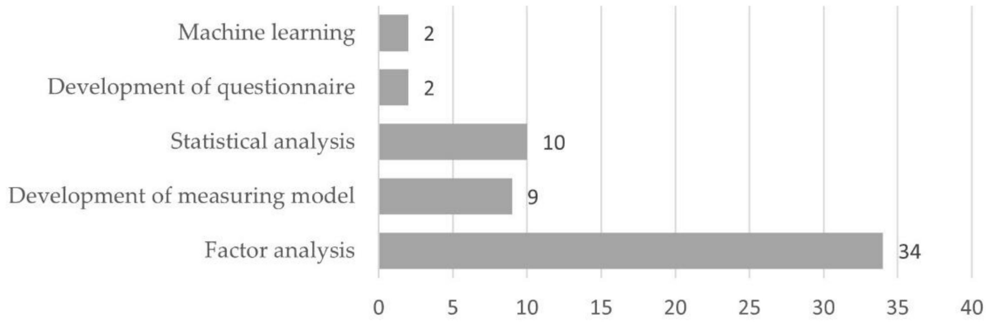

Figure 14. Analysis of measuring methods.

Looking at the literature on factor analysis, which had the highest frequency, the factors for measuring safety climates include some similar items, but most of them are presented slightly differently by different authors. This is the result that reflects the characteristics and environment of each country and construction site. However, the upper categories of factors mentioned in each study can be divided into human and environmental factors. Human factors include belief and value, safety behavior, safety perception, safety attitude, and worker's involvement and commitment and relationship. Environmental factors include rules and procedures, supervisory environment, and organizational management and training. The representative literature on these are shown in Table 4.

Table 4. Analysis of safety factors.

	Author	Safety Climate Factors	References
1	Niu et al. (2016)	Management commitment, rules and procedures, workers' involvement, personal risk appreciation, communication, and supervisory environment	[134]
2	Chan et al. (2017)	Safety climate commitment and concern for OSH by organization and management, resources for safety and its effectiveness, risk-taking behavior and perception of work risk, workers' perception of safety rules and procedures, workers' personal involvement in safety and health, safety working attitude and workmates' influence, and safety promotion and communication	[143]
3	Wang et al. (2018)	Individual safety awareness and safety behavior to examine multilevel relationships	[150]
4	Mosly et al. (2019)	Organization management team, worker colleges, and worker background	[135]
5	Lingard et al. (2012)	Top management commitment to safety, organizational priority placed on safety, supervisors' safety actions, supervisors' safety expectations, coworkers' actual safety response, coworkers' ideal safety response, and lost time/medical treatment injury rate	[152]
6	Zhou et al. (2015)	Safety management process, worker behavior, worker perception, and accident/incident data	[136]
7	Alruqi et al. (2018)	Supervisor's safety role, management commitment to safety, safety rules and procedures, individual responsibility to health and safety, and training	[137]

Table 4. *Cont.*

	Author	Safety Climate Factors	References
8	Glendon et al. (2001)	Communication and support, adequacy of procedures, work pressure, personal protective equipment, relationships, safety rules, and percent safe behavior	[161]
9	Fang et al. (2006)	Safety attitude and management commitment, safety consultation and safety training, supervisor's role and workmate's role, risk-taking behavior, safety resources, appraisal of safety procedure and work risk, improper safety procedure, worker's involvement, workmate's influence, and competence	[126]

4. Conclusions

This study analyzed the safety climate/culture trends in research papers on all industries published since 2000 and carried out an SLR on the definition and measuring methods of safety climate in the construction industry. The findings identified through literature review are as follows.

(1) In this study, 390 studies on safety climate, published from January 1, 2000, to December 31, 2020, were analyzed by keyword, country, industry, year of publication, and publication journal. First, the analysis of keyword frequencies showed that excluding safety climate, the keyword with the highest frequency was safety culture (n = 158, 17.7%), followed by safety performance (n = 135, 15.2%), construction (n = 89, 10%), indicators (n = 58, 6.5%), safety management (n = 55, 6.2%), safety behavior (n = 53, 5.9%), structural equation (n = 35, 4.1%), occupational safety (n = 33, 3.9%), factors analysis (n = 30, 3.6%), patient safety (n = 28, 3.3%), construction site (n = 24, 2.8%), construction project (n = 22, 2.6%), workers safety, safety response (n = 18, 2.1%), and organizational climate (n = 17, 2.0%). Second, the analysis of the country of publication showed that the highest number of approximately 21% (n = 84) were conducted in the United States, followed by China (n = 63, 16.2%) and Australia (n = 62, 15.9%).

Third, the analysis of industries of safety climate literature showed that the highest proportion of about 36% (n = 40) was in the construction industry, followed by all industries (n = 102, 26.2%), medicine (n = 87, 22.3%), and manufacturing (n = 36, 9.2%). Fourth, the analysis of publication year of safety climate literature from 2000 to 2020 showed that the greatest number of studies were published in 2017 and 2018 at approximately 7.2% (n = 28), followed by 2016 and 2019 (n = 26, 6.7%), 2020 (n = 25, 6.4%), 2015 (n = 24, 6.2%), and 2010 (n = 22%, 5.6%). Finally, the analysis of publication journals showed that ScienceDirect had the greatest number of studies with approximately 28.7% (n = 112), followed by Google Scholar (n = 83, 21.3%), ASCE Library (n = 64, 16.4%), Taylor & Francis Online (n = 53, 13.6%), Wiley Online Library (n = 35, 9.0%), SpringerLink (n = 25, 6.4%), and Scopus (n = 18, 4.6%).

(2) The purpose of this section was to review the definitions of safety climate and culture, and their implications as described by various authors. The definitions for safety climate and safety culture are summarized as follows: Safety culture and safety climate can be seen similarly in that they describe an organization's approach to safety, not only the visible efforts or attitudes its members chose to adopt, but also every mental function that defines their overall behavior. However, to be more specific, there are differences. "Safety culture" mostly refers to individual and group values, attitudes, perceptions, and competencies regarding safety, while "safety climate" is mainly used to describe the expressed ideas, the tools, and techniques used in general by the organization in order to confirm its compliance to safety. In other words, the climate is an item which is easily perceived by others, while culture is the basis that lies hidden under the surface.

(3) As a result of the analysis of measurement methods of safety climate/culture in the construction industry, the methods used could be divided into three: literature

survey, questionnaire, and data analysis. The frequency analysis results of these three methodologies were as follows: literature survey (n = 19, 33%), questionnaire (n = 33, 58%), and data analysis (n = 5, 9%). Looking at the details of the methodologies, 19 with literature survey studies were analyzed by factor analysis (n = 12, 63.1%), development of measuring model (n = 5, 26.3%), and development of questionnaire (n = 2, 10.6%). Thirty-three studies with questionnaire were analyzed by factor analysis (n = 18, 54.6%), development of measuring model (n = 4, 12.1%), statistical analysis (n = 10, 30.3%), and machine learning (n = 1, 3.0%). Finally, five data analysis studies were analyzed by factor analysis (n = 4, 80%) and machine learning (n = 1, 20%).

The analysis of the measuring methods of literature survey, questionnaire, and data analysis for measuring safety climate showed that factor analysis (n = 34, 59.7%) was most frequently used, followed by the development of measuring model (n = 9, 15.8%), statistical analysis (n = 10, 17.5%), development of questionnaire (n = 2, 3.5%), and machine learning (n = 2, 3.5%).

The factors for measuring safety climates included some similar items, but most of them were presented slightly differently by different authors. This is believed to be the result that reflects the characteristics and environment of each country and construction site. However, the upper categories of factors mentioned in each study can be divided into human factors and environment factors. Human factors include belief and value, safety behavior, safety perception, safety attitude, worker's involvement, and commitment and relationship, while environment factors include rules and procedures, supervisory environment, organization management, and training.

Many studies attempt to measure the safety climates and identify the causes for accidents in the high-risk construction industry. Studies have shown that the higher the level of the safety climate, the lower the accident rate at construction sites. Studies on the methodology of measuring safety climate should be continued to improve reliability and precision. Although many studies have been conducted to measure safety climate, such as questionnaires, regression analysis, and suggestions for safety climate measurement methods, there are few studies on a systematic literature review of them. This requires a systematic literature review (SLR) of the studies conducted so far. A construction site is the place where the most safety accidents occur. However, the characteristics of construction sites change according to many factors, such as country, site, and type of construction. Therefore, there will be various methods for measuring the safety climate and reducing safety accidents. To this end, this study provides summarized data to researchers who want to study the safety climate measurement method.

The results of this systematic literature review will be used as foundational data for improving existing methods and developing new methods of measuring safety climate in the construction industry, further contributing to lowering the safety accident rate in the construction industry.

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