INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN ECONOMICS & MANAGEMENT SCIENCES

OPEN ACCESS JOURNAL

Vol 14, Issue 4, (2025) E-ISSN: 2226-3624

Mapping the Nexus between Organizational Culture, Workforce Skills and Construction Safety: Insights from CiteSpace Analysis

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DOI Link: http://dx.doi.org/10.6007/IJAREMS/v14-i4/27000

Published Online: 03 December 2025

Abstract

Organizational culture and workforce skills play a crucial role in enhancing construction safety performance and reducing accident rates. This paper aims to systematically analyze the internal connection between organizational culture, workforce skills, and their impact on construction safety performance. Using CiteSpace knowledge mapping software, academic literature related to construction safety from 1991 to 2023 was selected for bibliometric analysis to identify the spatial and temporal distribution and emerging research hotspots. By positioning construction safety within broader social science debates on organizational behavior and human capital, the study explores the evolutionary path of the role of organizational culture and workforce skills in construction safety. The findings reveal that research in construction safety has shifted from a focus on technical aspects to an increasing emphasis on factors such as organizational culture and workforce skills. "Safety culture", "workforce skills", and "behavior management" are identified as key future research areas. The interplay between organizational culture and workforce skills is shown to mirror wider social scientific concerns regarding how organizational environments shape worker behavior, and is recognized as a crucial factor in improving safety performance. The results of this study provide new theoretical support and practical guidance for future research on soft factors in construction safety management.

Keywords Organizational Culture, Workforce Skills, Construction Safety, CiteSpace, Knowledge Mapping

Introduction

The construction industry, a cornerstone of the global economy, continues to be plagued by high risks and frequent accidents. According to 2020 data from the U.S. Bureau of Labor Statistics (BLS), fatal injuries in the construction sector accounted for 21.16% of all workplace fatalities in the United States (Chen, Long, Yang, & Xu, 2023). Despite growing attention to

safety management in recent decades, accident and fatality rates remain persistently high. Traditional research has predominantly emphasized technical and regulatory solutions, yet there is increasing recognition of the vital role played by soft factors—particularly Organizational Culture (OC) and Workforce Skills (WS). This shift reflects a broader trend in social science, where organizational culture, human capital development, and behavioral governance have become central to explaining performance outcomes in high-risk industries. In China, construction safety research emerged in the 1980s, though most studies have been confined to specific databases or limited timeframes—for instance, relying solely on American Society of Civil Engineers (ASCE) data from 2015 to 2017. While such studies provide useful insights, their narrow scope limits generalizability and global relevance.

To address these gaps, this study employs CiteSpace software to construct a knowledge map visualizing the relationship between Construction Safety Performance (CSP), Organizational Culture (OC), and Workforce Skills (WS). Based on a comprehensive analysis of core English-language journals from the Web of Science (WOS) database, this research offers a systematic and global perspective. By explicitly linking construction safety to ongoing social science debates about how organizational environments and skill structures influence collective behavior and risk outcomes, the study clarifies its research problem and significance. The findings are intended not only to advance scholarly understanding but also to inform practical strategies for the construction industry and safety policymakers worldwide.

Data Sources and Research Methods

To ensure the reliability and validity of the knowledge mapping analysis, this study adopts a systematic approach encompassing data collection and analytical techniques. The following sections detail the specific data sources utilized and the research methods employed.

Data Sources

The validity of knowledge mapping is fundamentally dependent on the quality of the underlying data, making a comprehensive and accurate literature collection essential for this study. Data were retrieved from the Web of Science (WOS) core collection database. A systematic search was conducted using the topic query "TS=(Construction Safety)" for publications between 1991 and 2023. The results were then screened, limiting the document type to "ARTICLE". This process yielded an initial corpus, which was further refined to a final dataset of 5,113 publications for subsequent analysis.

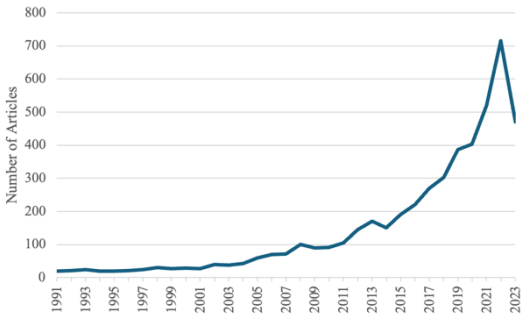

Figure 1. Publication Trends from 1991 to 2023

Research Methods

Knowledge mapping serves as a visual representation of the development and structural

relationships within a scientific domain, helping to reveal underlying trends and patterns. In this study, CiteSpace software was employed to map the relationships between construction safety performance and its influencing factors. The analytical process included: (1) constructing collaboration networks among authors and institutions; (2) conducting a descriptive analysis of the current research landscape; (3) performing keyword co-occurrence analysis to identify research hotspots; and (4) applying cluster and timeline views to trace thematic evolution. Together, these methods provide a systematic overview of the intellectual structure and emerging trajectories in construction safety research.

Bibliometric Analysis

This section presents a quantitative and visual overview of the construction safety literature, examining publication trends, research hotspots, and the field's intellectual structure.

Annual Publication Trends

Research output in "Construction Safety" has varied considerably over the years, reflecting evolving academic and industrial attention. Between 1991 and 1995, publication numbers remained low, averaging only 15 to 20 articles per year, indicating an initial, exploratory phase of research. By 2002, annual output had risen to approximately 40 papers, marking a period of gradual growth. A notable surge occurred after 2018, with publications reaching 374 that year, signaling intensified focus on the topic.

From 2019 to 2022, the field entered a high-growth phase, with annual output consistently exceeding 399 publications and peaking at 710 in 2021. Although publications declined to 465 in 2023, research activity remains vigorous. Based on these trends, construction safety research can be divided into three distinct stages: the Initial Stage (1991–1995), the Gradual Attention Stage (2002–2018), and the High Attention Stage (2019–2023). These phases reflect the growing recognition and steady maturation of construction safety as a research domain.

Keyword Co-occurrence Analysis

Keywords concisely represent the core content of a document and play a vital role in information retrieval and knowledge mining. In academic publishing, authors provide keywords to improve the discoverability of their work. These terms should accurately capture a study's central themes. Keyword frequency indicates how often a term appears within a dataset. High-frequency keywords typically correspond to active or prominent research topics. In bibliometric studies, frequency serves as an important indicator of research focus.

Centrality, a concept from network analysis, measures the importance of a node based on its connections. A node with high centrality functions as a hub, linking different parts of the network. In keyword co-occurrence analysis, high-centrality terms often represent core concepts that connect multiple research themes, highlighting their interdisciplinary or foundational role. By examining both the frequency and centrality of keywords, researchers can identify major research themes, conceptual relationships, and emerging trends within a field. This analysis helps pinpoint current interests and potential future directions. In this study, keyword co-occurrence analysis was conducted using CiteSpace under default parameters. The resulting network consists of 640 nodes and 1,477 links, with a network density of 0.0072, as illustrated in Figure 2.

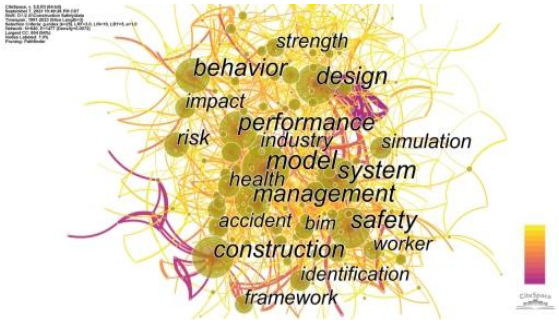

Figure 2. Knowledge Map of Key Words

As revealed in Table 1, research in "Construction Safety" exhibits evolving trends and a multidimensional focus, with keywords spanning domains such as "model," "design," "behavior," and "culture." These terms reflect the interdisciplinary nature of the field, intersecting with engineering, information science, and design. Notably, human factors and behavioral sciences-emphasized by keywords like "behavior" and "culture"-are emerging as critical research streams. Keywords such as "cost" and "tracking" underscore the practical and economic dimensions of safety management, while terms like "injury" and "soil" highlight concerns related to risk mitigation, particularly under specific environmental conditions.

Table 1
Top 10 Keywords by Frequency Ranking

Frequency	Centrality	Year	Keywords
610	0.09	1997	model
397	0.09	1994	construction
379	0.08	1991	design
56	0.08	1991	soil
451	0.07	2004	system
97	0.07	2009	tracking
57	0.07	2002	culture
394	0.06	2006	behavior
86	0.06	2002	injury
65	0.06	2004	cost

The temporal shifts in keyword frequency further illustrate evolving research priorities: "model" peaked in 1997, "system" in 2004, and "behavior" in 2006. Keywords with both high frequency and high centrality help delineate current research hotspots and signal emerging frontiers, providing valuable direction for subsequent studies. In summary, this co-occurrence analysis captures the complexity and multidimensionality of construction safety research, while also identifying knowledge gaps and offering theoretical and practical insights to guide future advancements.

Keyword Clustering Analysis

A clustering analysis was performed using the Log-Likelihood Ratio (LLR) algorithm to further elucidate the connections among research topics and reveal the underlying structure of thematic clusters. The analysis identified five coherent clusters. The validity of this clustering solution is supported by a modularity (Q) value of 0.6077 and a mean silhouette (S) value of 0.7923, indicating a strong and reliable cluster structure, as visualized in Figure 3.

Cluster 1: Safety Climate

This cluster centers on themes such as safety climate, labor and personnel issues, safety behavior, and safety management systems. Early foundational work examined how organizational culture shapes workers' safety behavior, establishing a key theoretical framework that underscores the importance of organizational-level safety climate (Lingard, Cooke, & Blismas, 2012). Subsequently, from a human factor engineering perspective, Fargnoli and Lombardi (2019) proposed a Proactive Human Safety Assessment (PHSA) method to improve the safety climate, offering a novel approach to understanding and enhancing safety from the worker's standpoint. Further research expanded this scope by exploring the link between construction workers' personality traits and safety behavior, revealing that responsibility is positively correlated with safety compliance, whereas extroversion and neuroticism exhibit negative correlations (Gao, González, & Yiu, 2020). Building on these individual-level findings, later studies began to emphasize the role of leadership, highlighting how organizational-level leadership factors moderate individual safety behavior (Xia, Tang, Li, & Pan, 2021). Most recently, machine learning techniques, specifically Adaptive Neuro-Fuzzy Inference Systems (ANFIS), have been applied to assess how leadership perception influences construction employees (Keles, Haznedar, Kaya Keles, & Arslan, 2023). This latest development not only introduces advanced analytical methods but also further elucidates the mechanisms through which leadership affects both productivity and safety behavior.

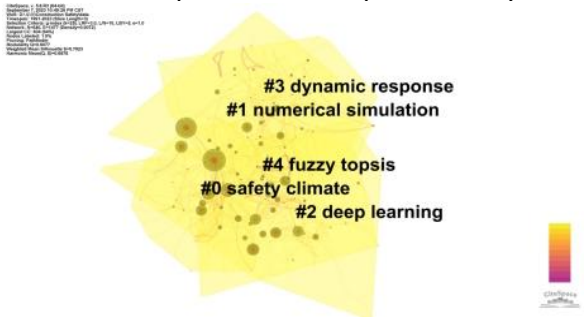

Figure 3. Visual Map of Keyword Clusters

Cluster 2: Numerical Simulation

This cluster is characterized by a focus on numerical simulation, deep excavation, shield tunneling, and ground settlement. The initial research primarily analyzed ground deformation caused by shield tunnel construction, establishing a theoretical basis for tunnel engineering safety (Shi, Cao, & Lei, 2017). Subsequent work broadened the scope to include construction site safety, particularly investigating how optimized planning can mitigate the impacts of explosive attacks (Schuldt & El-Rayes, 2018). By 2020, research advanced to analyze deformation and structural stress in large-scale tunnel projects in greater depth (Hou et al., 2020). More recent investigations have placed increasing emphasis on the effects of varying ground conditions, and the failure mechanisms of arch supports on structural stability (Z. Sun et al., 2022; Sun et al., 2023). From a temporal perspective, the evolution of this cluster shows a clear trajectory: starting from foundational ground deformation analysis and expanding toward more comprehensive considerations of safety, optimized planning, and stability under diverse geological conditions. This progression reflects a deepening of research in the field and suggests that future studies will likely continue to integrate interdisciplinary approaches and advanced analytical techniques.

Cluster 3: Deep Learning

This cluster encompasses deep learning, computer vision, object detection, equipment, and tracking. In recent years, construction safety research in this domain has evolved from basic safety management toward more complex and diverse perspectives. Early efforts focused on using robotics and visual recognition technologies to optimize lifting processes (Li, Luo, & Skitmore, 2020). Soon after, text mining and visualization techniques were employed to transform complex construction reports into intuitive graphics, aiding managerial decision-making (J. Sun et al., 2020). By 2021, a comprehensive safety, health, and environmental management maturity model was introduced to assess capabilities in these areas within construction firms (Asah-Kissiedu, Manu, Booth, Mahamadu, & Agyekum, 2021). The most recent research has explored the factors influencing the adoption of safety technologies, particularly in the context of developing countries (Yap et al., 2023). This evolution illustrates a shift from early operational optimization and information visualization toward a more holistic view that integrates safety, health, environmental management, and technology adoption. This broadening of focus not only reflects the maturation of the field but also indicates that future research will increasingly leverage interdisciplinary methods and advanced analytics. Collectively, these studies provide the construction industry with multi-faceted safety management strategies, supporting continued industry development and safety enhancement.

Cluster 4: Dynamic Response

This cluster encompasses dynamic response, structural optimization, creep behavior, and tunnel-induced risk prediction and control. Research in this domain has progressively evolved from foundational performance prediction and safety assessment toward more complex and diversified directions. Early studies primarily employed system dynamics models to forecast multi-dimensional project performance-including cost, time, and quality (Leon, Osman, Georgy, & Elsaid, 2018). Subsequent work expanded into deformation and support structure analysis in large-span highway tunnels, validating proposed models using experimental and field data (Hou et al., 2020). Further developments introduced heuristic optimization techniques to enhance safety while reducing cost and time in construction processes (Buitrago et al., 2016). More recent contributions have examined the deformation behavior of hidden frame-supported glass curtain walls under wind loads (Yuan et al., 2021) and, from a psychological perspective, explored how supervisor-worker relationships predict safety behavior (Ashraf et al., 2022). This trajectory illustrates a shift from early performance and safety modeling toward integrative analyses that incorporate structural mechanics, human factors, and relational dynamics. Such evolution not only reflects a deepening of the research scope but also signals a growing trend toward interdisciplinary methodologies and sophisticated analytical techniques. Collectively, these studies provide comprehensive theoretical and empirical support for enhancing safety and optimizing performance in construction engineering.

Cluster 5: Fuzzy TOPSIS

This cluster centers on fuzzy TOPSIS, ranking methods, AHP, road safety, and quality management. Research in this area has progressed from basic risk assessment and equipment selection toward more nuanced and integrated decision-making frameworks. Early efforts focused on Material Handling Equipment (MHE) selection, introducing a Quality Function Deployment (QFD)-based software prototype to aid construction engineers in preliminary

decision-making (Prasad, Zavadskas, & Chakraborty, 2015). Later studies advanced toward more sophisticated risk modeling, such as a tunnel collapse assessment method using Dempster–Shafer evidence theory (Ou et al., 2021) and a multi-criteria framework for Occupational Health and Safety (OHS) risk analysis in dam construction (Celik & Gul, 2021). Between 2020 and 2022, research began integrating human and organizational factors, applying multi-agent modeling to analyze safety performance in shield tunneling (Lu et al., 2020) and examining the influence of stakeholders on small and medium enterprise success from a leadership perspective (Cai, Gura, & Kurilova, 2022). Recent work continues to broaden the field, introducing a five-dimensional safety risk assessment model (5D-SRAM) that extends beyond conventional probability and severity metrics (Mohandes et al., 2023), and analyzing risk propagation mechanisms of unsafe behaviors in urban rail construction (Tang, Guo, Li, & Lu, 2022). This evolution highlights a continuous refinement of decision-support tools and a growing emphasis on human–system interaction, indicating that future studies will likely adopt increasingly interdisciplinary and computationally advanced approaches.

Existing research in construction safety management has predominantly emphasized hard factors and technical aspects, such as simulation, equipment, and standardized procedures. In contrast, soft factors-including organizational culture and workforce skill levels-have received comparatively limited attention. Traditional studies often lack comprehensive and in-depth analysis, overlooking the interactive effects among these soft factors and their collective influence on safety performance. Moreover, much of the current literature remains theoretical or model-oriented, with limited direct applicability to real-world engineering practice or policy formulation.

To address these gaps, this study employs Partial Least Squares Structural Equation Modeling (PLS-SEM) to conduct a systematic and in-depth investigation into how organizational culture and workforce skills individually and jointly affect construction safety performance. Furthermore, it examines the mediating and moderating mechanisms among these variables, offering a holistic perspective for understanding and enhancing safety outcomes. Through carefully designed survey instruments and conceptual modeling, this research provides not only academic innovation but also actionable insights for industry practitioners and policymakers. By integrating soft factors into a coherent safety management framework, this study bridges a critical theoretical gap and delivers practical support for advancing safety performance in the construction sector.

Authorship Analysis of Collaborative Institutional Relationship Graph

The main academic institutions contributing to construction safety management research are primarily from China, including Hong Kong Polytechnic University, Tongji University, Huazhong University of Science and Technology, and Tsinghua University, as well as international institutions like the Georgia Institute of Technology and the University of Alberta. As summarized in Table 2, Hong Kong Polytechnic University leads with 155 publications, followed by Tongji University and Huazhong University of Science and Technology with 134 and 109, respectively. Research activity increased notably between 2002 and 2016, with a peak in 2013. The collaborative relationships among these institutions are mapped in Figure 4, which reveals that the Georgia Institute of Technology and Tongji University have high centrality scores, indicating their core positions in the research network. This analysis

highlights the significant role of Chinese institutions and the growing international collaboration in the field, underscoring the need to study soft factors in construction safety management.

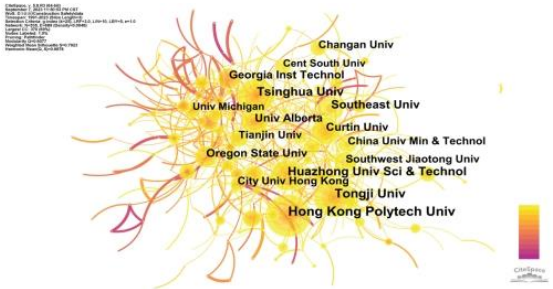

Figure 4. Institutional Partnership Map

Table 2
Top 10 Collaborating Institutions

Frequency	Centrality	Year	Institution
155	0.04	2002	Hong Kong Polytech Univ
134	0.07	2009	Tongji Univ
109	0.05	2013	Huazhong Univ Sci & Technol
99	0.03	2006	Tsinghua Univ
77	0.03	2012	Southeast Univ
64	0.08	2007	Georgia Inst Technol
63	0.04	2007	Univ Alberta
62	0.06	2013	Curtin Univ
61	0.05	2002	Oregon State Univ
59	0.02	2016	Southwest Jiaotong Univ

Analysis of Author Collaboration Network Graph

The main contributing authors in construction safety management research include Heng Li, Sanghyun Lee, and Jochen Teizer, as detailed in Figure 5 and Table 3. Among them, Heng Li leads with 60 published papers. Their work primarily spans from 2006 to 2018, with peak publications in 2007 and 2012. Jochen Teizer has a centrality score of 0.05, suggesting a core position in the research network, while Heng Li and Sanghyun Lee have scores of 0.04, indicating their influence. Research activity has grown in recent years, especially in 2007 and 2012, with these authors playing key roles in international collaborations, highlighting the importance of studying soft factors in construction safety management.

Figure 5. Author Collaboration Network Analysis

Table 3
Authors by Publication Count

Frequency	Centrality	Year	Author
60	0.04	2007	HENG LI
35	0.04	2012	SANGHYUN LEE
27	0.05	2006	JOCHEN TEIZER
25	0.04	2009	MATTHEW R HALLOWELL
24	0.01	2010	PETER E D LOVE
23	0.02	2012	MARTIN SKITMORE
23	0.01	2018	PINCHAO LIAO
23	0	2015	LIMAO ZHANG
22	0.02	2008	ALBERT P C CHAN
19	0.01	2016	JOHN GAMBATESE

Analysis and Findings

This chapter builds on the keyword analysis, research hotspots, and collaboration networks identified through CiteSpace in previous sections to explore in depth the specific roles and interrelationships between organizational culture and workforce skills in construction safety. By synthesizing literature and mining data, this section aims to clarify the pathways through which organizational culture and workforce skills influence safety outcomes and to offer both theoretical grounding and practical recommendations for construction safety management, supported by real-world cases and research findings.

The Role of Organizational Culture in Construction Safety

Organizational culture plays a critical role in construction safety management. Studies indicate that a strong safety culture within an organization significantly shapes employees' safety behaviors, work attitudes, and risk perception, which in turn helps reduce accident rates and improve overall safety performance. Organizations that foster a positive safety climate enhance safety awareness among workers and promote proactive responses to potential hazards.

Keyword and co-occurrence analyses reveal that "safety culture" and "behavior management" are among the central themes in current construction safety research. This reflects growing scholarly interest in how organizational culture contributes to raising safety standards in construction. Key elements in cultivating a robust safety culture include leadership commitment, teamwork, effective communication, and continuous training.

Improving Workforce Skills in Construction Safety

Workforce skills are a direct determinant of the effectiveness of safety practices on construction sites. The competencies of construction workers affect not only their personal safety but also the overall safety management of projects. As skill requirements in the industry continue to rise, workers' safety proficiency has become a crucial factor in improving safety performance.

Recent literature highlights "workforce skills" and "safety training" as emerging research priorities. These studies stress the need for differentiated training programs tailored to various worker roles and site conditions. They also recommend the use of modern technological tools-such as virtual reality (VR) and simulation-based training-to improve

workers' operational awareness and emergency response capabilities. Moreover, skill development is closely linked to safety culture; both elements work synergistically to enhance safety outcomes.

The Interplay between Organizational Culture and Workforce Skills

Organizational culture and workforce skills are interdependent. A supportive safety culture creates an enabling environment for skill development, while a skilled workforce is better equipped to enact safety standards and behavioral norms embedded in the organizational culture. CiteSpace analysis shows a strong co-occurrence between "organizational culture" and "workforce skills" in construction safety literature, underscoring their collaborative contribution to safety performance.

For instance, in high-risk projects, teamwork, leadership support, and ongoing training not only improve workers' competencies but also reinforce a shared safety culture, leading to greater compliance with safety protocols. Therefore, construction firms should strive to strengthen both safety culture and workforce skills in tandem, fostering a mutually reinforcing cycle that supports a safer and more productive work environment.

Current Research Hotspots and Future Trends

A thorough review of the literature confirms that the intersection of organizational culture and workforce skills has become a prominent research direction in construction safety. Recent studies increasingly focus on how organizational culture can be leveraged to improve safety competencies and optimize safety-related behaviors through integrated management strategies.

Looking ahead, research should investigate how organizational culture and workforce skills can be enhanced through information technology and intelligent systems. For example, the application of big data, IoT, and artificial intelligence can support real-time safety monitoring and enable personalized safety training, thereby raising the overall effectiveness of safety management in construction.

Conclusion

This section summarizes the key findings of this study regarding organizational culture and workforce skills in construction safety and suggests productive avenues for future research.

Conclusion

The influence of organizational culture and workforce skills on construction safety has attracted considerable research attention in recent years, particularly regarding their role in improving safety performance and reducing accidents. Using CiteSpace-based knowledge mapping, this study analyzed construction safety literature from 2014 to 2024, identifying spatiotemporal distributions, research hotspots, and evolutionary trends related to these factors.

Firstly, regarding the spatial and temporal distribution, research output in construction safety has grown steadily over the years. Early studies emphasized technical aspects, whereas recent work has increasingly addressed soft factors such as organizational culture and workforce skills. Based on publication trends, research evolution can be divided into three phases: the initial stage (2014-2017), the attention stage (2018-2020), and the high-growth

stage (2021-present). Collaboration networks are concentrated within academic and industrial organizations, with high collaboration density reflecting rising academic interest in human and organizational aspects of safety.

Secondly, analysis of research hotspots through keyword co-occurrence, burst detection, and clustering techniques reveals dynamic research themes. "Safety culture" and "workforce skills" have emerged as core topics, forming the foundation for safety enhancement. As the field has matured, keywords such as "behavior management," "leadership," and "safety training" have gained prominence. These trends confirm that organizational culture and workforce skills are now at the forefront of construction safety research.

Thirdly, the evolutionary path of organizational culture and workforce skills in construction safety shows a clear trajectory. Early research emphasized technical and regulatory solutions, later shifting to examine how organizational culture shapes worker behavior and safety outcomes. As recognition of workforce skills grew, scholars began focusing on the combined effect of training and cultural development. Most recently, studies have centered on optimizing safety management through the synergy of organizational culture and workforce skills, contributing to accident reduction and continuous safety improvement.

Future Directions

This study has systematically examined the roles of organizational culture and workforce skills in construction safety and analyzed their spatial-temporal distribution, research hotspots, and evolution. Recent empirical studies have increasingly demonstrated that soft factors—such as safety climate, leadership behavior, and skill-based interventions—significantly shape safety outcomes in construction projects, underscoring the need for more integrated and evidence-based approaches. Based on the conclusions, future studies should focus on the following areas:

Firstly, future work should investigate the deep integration of organizational culture and workforce skills to improve safety management. This includes examining how organizational culture reinforces safety behaviors, how skill training translates into practice, and how their synergy fosters comprehensive adoption of safety culture. Emerging empirical evidence showing that organizational norms directly influence training effectiveness suggests that this integration deserves further systematic exploration.

Secondly, research should identify practical implementation pathways for these soft factors in construction safety. While the significance of organizational culture and workforce skills is well established, their practical implementation remains underexplored. Future studies should develop actionable strategies for embedding these factors into safety management systems while ensuring effectiveness and adaptability across different contexts. Recent field studies indicating inconsistent implementation outcomes across regions highlight the urgency of this inquiry.

Thirdly, detailed case-based research is needed to examine implementation mechanisms and challenges in improving organizational culture and workforce skills. Such studies would help assess the real-world applicability of safety measures across different regions and projects, supporting the development of tailored policy interventions. By building on new

case-based empirical work, future research can better clarify context-specific barriers and facilitators.

Finally, future research should explore how emerging technologies—including IT, big data, and artificial intelligence—can enhance the effectiveness of organizational culture and workforce training. This line of inquiry will support the transition toward intelligent and data-driven construction safety management. Recent empirical applications of AI-enabled behavior monitoring and digital training platforms demonstrate promising pathways that merit deeper investigation.

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