

The Pathway to Enhancing Construction Performance Through Risk Management: A Knowledge Graph Analysis Using CiteSpace

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Abstract

Risk management is essential to enhance construction performance. This study aims to systematically reveal the pathways for improving construction performance through risk management. Academic literature from 2016 to 2025 was selected using the Web of Science core database. Next, CiteSpace knowledge graph analysis was conducted to identify the temporal and spatial distribution and the frontier hotspots of research on risk management and construction performance enhancement, as well as to explore the evolution path of risk management. The study finds that over the past decade, research on the use of risk management to enhance construction performance has evolved from slow accumulation to significant growth, followed by a stable high plateau. Research topics have gradually focused on performance evaluation and risk governance, with “sustainable construction,” “machine learning,” and “risk assessment” emerging as future research hotspots. The study identifies the evolution path of risk management, which advances from the exploration and application of digital technologies to the integration and optimization of the entire lifecycle, and

ultimately towards the achievement of project resilience and the strategic goals of enhancing construction performance. The findings of this study provide insights for future academic research, offering directions, focal points, and methodological strategies for related studies.

Keywords: risk management, construction performance, CiteSpace, knowledge graph

1. Introduction

The construction industry, as a core pillar of the global economy and social infrastructure, faces a highly complex and dynamic risk environment, with potential issues including cost overruns, schedule delays, safety accidents, supply chain disruptions, environmental impacts, and energy inefficiency (Al Qudah et al., 2024). These risks not only increase the probability of project failure but also directly undermine performance throughout the entire life cycle of construction (from design to construction to operation), including economic benefits, sustainability, and user satisfaction (Ghodosi et al., 2025). In the context of digital transformation, the integration of emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and Building Information Modeling (BIM) has provided strong support for risk management. These technologies have not only improved the accuracy of risk identification and forecasting (Mohamed et al. 2025) but also enabled a closed-loop mechanism for risk response and performance enhancement through real-time data analysis and simulation optimization, thereby laying the foundation for resilient and long-term value creation of construction projects (Tian et al., 2025).

In the recent years, national policies and international standards (such as the ISO 31000 risk management framework and green building evaluation systems) have emphasized embedding risk management into construction performance evaluation to address challenges posed by climate change, resource shortages, and digital disruption (Rojas-Sánchez et al., 2023). Meanwhile, academic research on construction risk management has shifted from traditional qualitative assessments to quantitative models and big data-driven approaches. The literature shows that research hotspots include lifecycle risk governance, AI-assisted decision-making, and BIM-supported collaborative risk mitigation (Li et al., 2025). Samarasinghe (2024) stated that these innovations have significantly improved project performance indicators such as cost control, quality assurance, and environmental sustainability. At the same time, research on construction performance has become increasingly multidimensional, covering energy consumption optimization, operation and maintenance, and user health performance (Junjia et al., 2023) and emphasize the mediating role of risk factors in performance degradation (Moradabadi et al., 2024).

Existing research is mainly divided into three branches: 1) innovations in risk management methodology, such as AI-based predictive models and IoT real-time monitoring applications in the construction phase. Numan (2024) aimed at reducing accident rates and improving operational efficiency; 2) the creation of construction performance evaluation systems (Alshehri et al., 2024), integrating BIM data to minimize life-cycle costs (LCC) and maximize performance (Wong et al., 2026); and 3) the exploration of coupling mechanisms

(Manu, 2024), revealing how risk management mediates performance improvement through digital tools, such as BIM-driven conflict detection reducing rework risks, thereby indirectly improving time and cost performance (Sharma, 2025). Despite the richness of research in these branches, however, comprehensive analysis from a global and temporal perspective remains insufficient (Zimmermann et al., 2021). Existing literature is often limited to single-case or method verification (Savaş., 2025). As such, it lacks a macro knowledge structure or exploration of visual evolutionary paths for the “risk management → digital mediation → performance improvement” pathway, thus failing to form a complete system (Abbas, 2025).

To address this gap, this paper uses a sample of academic literature related to “risk management” and “construction performance” from 2016 to 2025, collected through the Web of Science core database. The paper applies CiteSpace for knowledge graph analysis, including the spatial and temporal distribution of literature output, keyword co-occurrence clustering, author/institution cooperation networks, co-citation analysis, and burst term detection. The goal of this study is to reveal the frontier hotspots, academic collaboration patterns, and development trajectories of this field and explore the pathway through which risk management drives construction performance enhancement (Amoah, 2025). Through this visualized bibliometric method, the paper aims to provide methodological strategy references for the academic community and offer targeted suggestions for policymakers and practitioners, such as enhancing the integration of AI-IoT-BIM to build predictive risk governance systems, thereby helping to optimize the sustainable performance of construction projects.

2. Research Design

This section outlines the overall blueprint of the study, detailing the data and methods employed to address the research questions. It provides a clear description of how the research was conducted, ensuring transparency and replicability of the study.

2.1 Data Sources and Processing

The data for this study were sourced from core journals indexed in the Web of Science (WOS). Advanced search techniques were applied to select core journals in the database, using the following keywords associated with the concept of risk management driving construction performance improvement: “risk management,” “risk management + construction performance,” “risk assessment + construction performance,” “risk control + construction efficiency,” and “risk governance + construction performance”, pruning by using Pathfinder and Pruning the Merged Network. The time period was set from 2016 to 2025 with one year per slice, as this period captures a continuous body of research on risk management and construction performance. A total of 489 literature records were retrieved through a literature search conducted on October 1, 2025. Non-target records, including conference papers, newspapers, special issues, and academic journals, were manually screened and excluded to ensure that only relevant and reliable literature related to the

research topic was retained. Ultimately, 370 papers were selected as the operational dataset for the software. The data downloaded from WOS were then converted into RefWorks format, and a database suitable for processing by CiteSpace was constructed to ensure the smooth operation of the CiteSpace software.

2.2 Research Methodology

Drawing on the work of Al Qudah et al. (2024), and Junjia et al. (2023) and other scholars, CiteSpace was selected as the tool for bibliometric and visualization analysis. This study uses knowledge graph analysis, an analytical technique originating from information science and widely applied in management fields. Knowledge graphs display the internal structure of scientific knowledge and its dynamic relationships, integrating various bibliometric and visualization methods to reveal the overall pattern of field development (Li & Li, 2024). CiteSpace, as an efficient and multi-dimensional temporal analysis software, has become one of the preferred tools for constructing knowledge graphs (Mohamed et al., 2025). By quantitatively examining citation and co-citation relationships, CiteSpace enables the researcher to explore the distribution of literature output, core authors/institutions networks, journal influence, and the evolution of research themes, thus providing reliable scientific evidence to understand the evolution of the field and identify potential future research directions (Li et al., 2022). This study uses CiteSpace to conduct knowledge graph analysis of the literature on risk management and construction performance, summarizing its research characteristics across three dimensions: temporal and spatial distribution, frontier hotspots, and evolutionary paths. Using this information, the study distills the pathway through which risk management drives the enhancement of construction performance. Finally, the study presents conclusions and future research prospects.

3. Research on Risk Management Driving Construction Performance Enhancement: Temporal and Spatial Distribution

3.1 Temporal and Spatial Distribution Characteristics

Annual publication output, as a core indicator in bibliometrics, objectively quantifies the academic vitality, evolutionary dynamics, and influence of external driving factors within a specific research field (Al-Qudah et al., 2024). By examining the annual publication trends of literature related to risk management and construction performance from 2016 to 2025 (as shown in Figure 1), the overall development trajectory of this field can be clearly identified: from the early slow accumulation of a low base, to a significant surge in the middle period driven by external events (e.g., the global pandemic and the wave of digital transformation), and then to the recent high and stable growth. Mohamed et al. (2025) mentioned that this trend not only reflects the increasing academic emphasis on risk management as an intermediary mechanism for improving construction performance but also is highly correlated with technological innovations in industry practice (e.g., the integration of BIM and AI) and policy orientations (e.g., sustainable building standards and risk governance regulations).

Specifically, this trend can be divided into three distinct stages. The first stage (2016–2019)

was an exploratory starting phase, with an average annual publication volume of about 19 papers (14 in 2016, 22 in 2017, 24 in 2018, and 16 in 2019), exhibiting a low level of fluctuation as shown in Figure 1. The research during this period was largely limited to traditional risk identification and basic performance evaluation, with limited output, likely due to insufficient penetration of digital tools in the construction field and the fact that the global sustainable building agenda (e.g., the UN Sustainable Development Goals SDG 9 and 11) had not yet received full academic focus (Koc et al., 2023). The second stage (2020-2021) was an accelerated transformation phase, with the annual publication volume rapidly rising to an average of 38.5 papers (41 in 2020 and 36 in 2021). This surge is closely related to the increased demand for remote collaboration during the COVID-19 pandemic and the accelerated application of BIM/IoT technologies, which strengthened the predictive and resilience-oriented aspects of risk management, shifting research from static assessments to dynamic simulations and performance optimization (Khan et al., 2024). The third stage (2022-2025) is the mature expansion phase, with annual publication volume stabilizing above 50 papers and continuing to increase (53 in 2022, 50 in 2023, 53 in 2024, and 61 in 2025), indicating that the field has entered a high-output and steady state. This growth is driven by green building policies (e.g., the EU Green Deal and the U.S. Infrastructure Act) and emerging technologies (e.g., AI-driven risk prediction models), with significant expansion in both depth and breadth of research (Säwén et al., 2024).

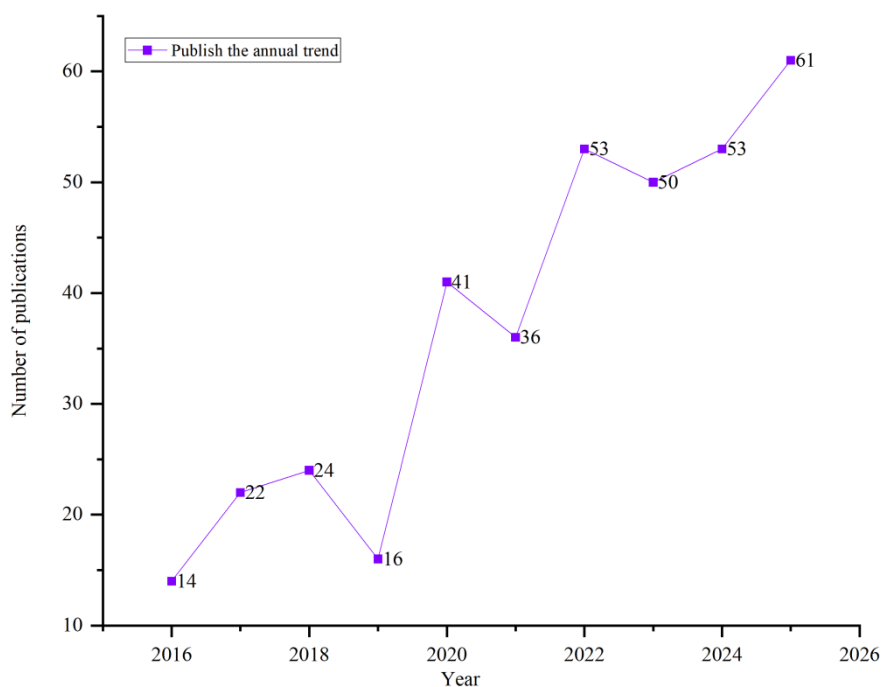


Figure 1. Trend chart of the number of publications

Overall, the temporal and spatial distribution reveal the shift of risk management research from the periphery to the mainstream, where it has now permeated several subfields of construction engineering (e.g., lifecycle governance and sustainable performance), showing strong growth momentum. This evolution not only provides a temporal and spatial

benchmark for subsequent hotspot analysis but also suggests that future research should further integrate interdisciplinary perspectives (e.g., engineering and data science) to address the increasingly complex risk landscape and achieve systemic improvements in construction performance.

3.2 Author Distribution Characteristics

The author collaboration network map presented in Figure 2 visually reflects the intensity and pattern of academic collaboration on the topic of risk management driving construction performance enhancement. The network map focuses on the 20 authors who have published more than two papers. The statistical results show that, first, the field overall has a large research community, with 370 papers involving 1,382 authors and 2,974 connections, with a collaboration network density of 0.0031. Second, in terms of publication quantity, the overall number of publications by authors in the field is relatively low, with only a few authors publishing more than three papers. Among these, Zhao, Chan, and Shen are the authors with the highest publication numbers. Additionally, while there is some scale in the collaboration between authors, the network density remains low, and a highly concentrated research collaboration group has not yet been formed. Third, from a temporal perspective, most of the primary authors published their first works after 2016. This indicates that the research field is currently in an active expansion phase, with substantial development potential in the future.

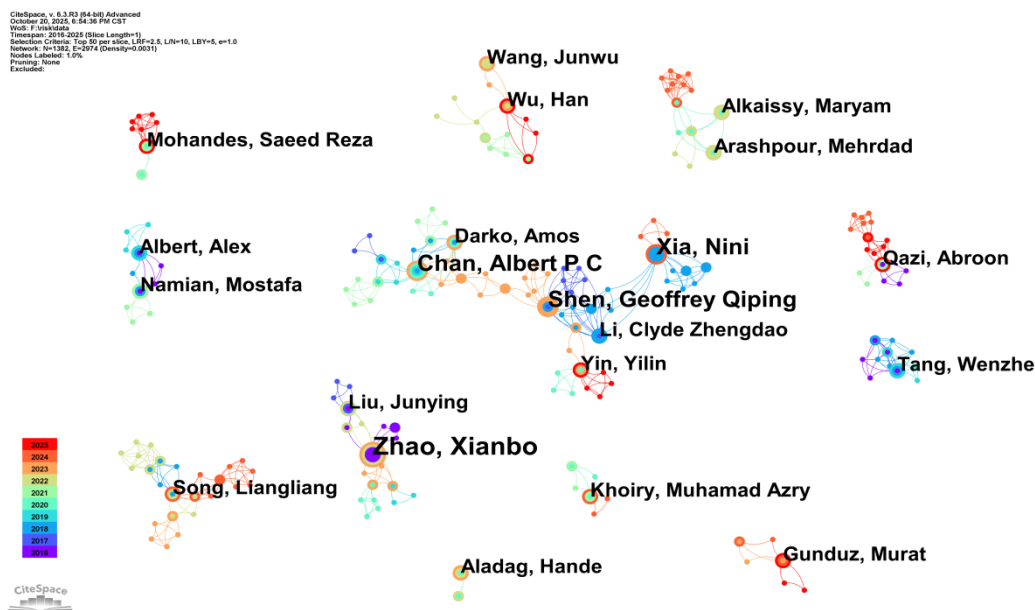


Figure 2. Network map of the collaboration among research authors

3.3 Institutional Distribution Characteristics

The analysis of institutional distribution reveals resource allocation patterns, collaboration mechanisms, and knowledge production dynamics within the field. Figure 3 shows the cooperation network map, with 507 nodes and 788 connections, reflecting moderate connectivity and the coexistence of globalization and local agglomeration trends.

First, regarding institutional distribution, research institutions in this field include universities, research institutes, a few companies and government-affiliated organizations. Universities dominate, accounting for about 70% of nodes, forming close collaboration networks with research institutes. Notably, an Asia-dominated cluster, centered on Hong Kong Polytechnic University, Tsinghua University, and Southeast University, exhibits significant regional agglomeration. The Chinese Academy of Sciences and Tehran University are key hubs at the research institute level, facilitating cross-border collaboration with international institutions like the University of Sydney and Monash University. This promotes resource sharing, interdisciplinary integration, and collaborative innovation.

Second, regarding temporal perspective, major institutions published their first works in this area mainly between 2016 and 2018, coinciding with the global digital transformation wave and policy-driven initiatives like China’s “13th Five-Year Plan.” Recent years have seen increased publications from institutions like Central Queensland University, reflecting a growing academic emphasis on integrating risk management and performance. For future work, AI-driven risk prediction and green building policies offer vast development potential.

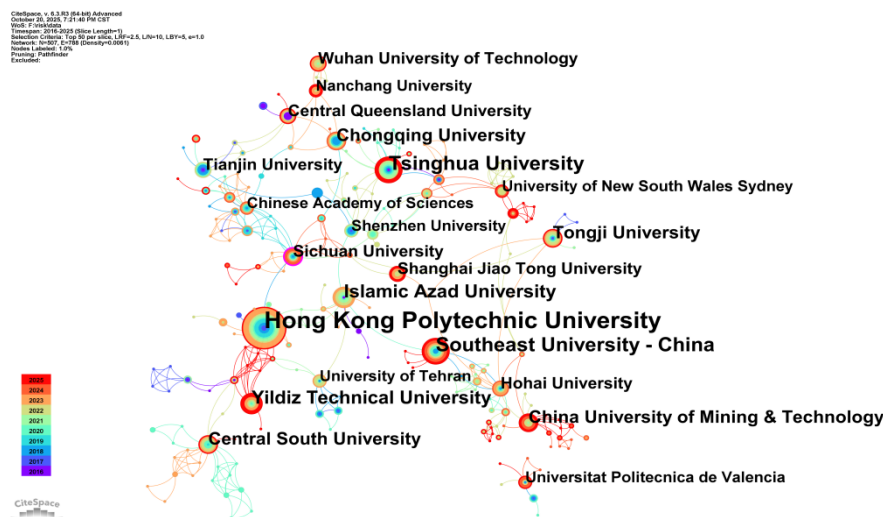


Figure 3. Network map of research institution collaboration

4. Research on Risk Management Driving Construction Performance Enhancement: Frontier Hotspots

This section employs scient metric methods to map the intellectual landscape of the field. By analyzing keyword co-occurrence, emergence, and clustering, the study identifies and visualizes the current research frontiers and evolving topics in risk management for construction performance enhancement.

4.1 Keyword Co-occurrence Network Analysis

Using CiteSpace software, a keyword co-occurrence map was generated for the topic of risk management driving construction performance enhancement from 2016 to 2025, showing key

terms' frequency, centrality, and first occurrence. The map includes 248 nodes ($N = 308$) and 613 connections, with a density of 0.013. Key concepts such as risk assessment, model building, system framework, impact analysis, and project identification emphasize the strategic role of risk management in improving construction performance. These keywords reflect the shift from static risk identification to dynamic performance optimization, highlighting the mediating role of digital tools like BIM, AI, and IoT in linking risk governance with performance indicators.

Risk management uses integrated models and system frameworks to optimize risk responses throughout the construction lifecycle, reducing costs, accidents, and environmental impacts while improving energy efficiency, sustainability, and user satisfaction. Risk assessment identifies potential threats and translates them into actionable strategies for performance improvement, promoting project resilience. The integration of systems like BIM further supports green building standards (e.g., LEED, BREEAM) and avoids performance degradation.

Impact analysis and project identification highlight the external effects of risk management, optimizing resource allocation in scenarios like supply chain disruptions or climate change while driving the industry towards refined, sustainable transformation. This fosters innovation (e.g., digital twin technology), improves long-term performance and industry competitiveness, and contributes to national sustainability goals (e.g., the “dual carbon” strategy).

From a temporal perspective, the keywords “performance” and “management” appeared early (2016), forming the core of the research area. Keywords like “impact” (2020) and “framework” (2017) indicate a shift towards impact analysis and framework construction, with the growing role of AI and performance quantification in risk prediction. “Risk assessment” first emerged in 2016, aligning with the global digital transformation in construction and policy directions.

CiteSpace v. 5.3.R3 (64-bit) Advanced
October 20, 2025, 6:30:53 PM CST
Vid: F-VNA424a
TimeSpan: 2016-2025 (slice Length=1)
Selection Criteria: g-index (k=25), LRF=2.5, LN=10, LBY=5, e=1.0
Network: N=205, E=1013 (Density=0.912)
Largest CCs: 285 (95%)
Modularity: 0.96
Pruning: Pathfinder
Modularity Q=0.7753
Weighted Mean Silhouette S=0.9107
Harmonic Mean(Q, S)=0.8376
Excluded:

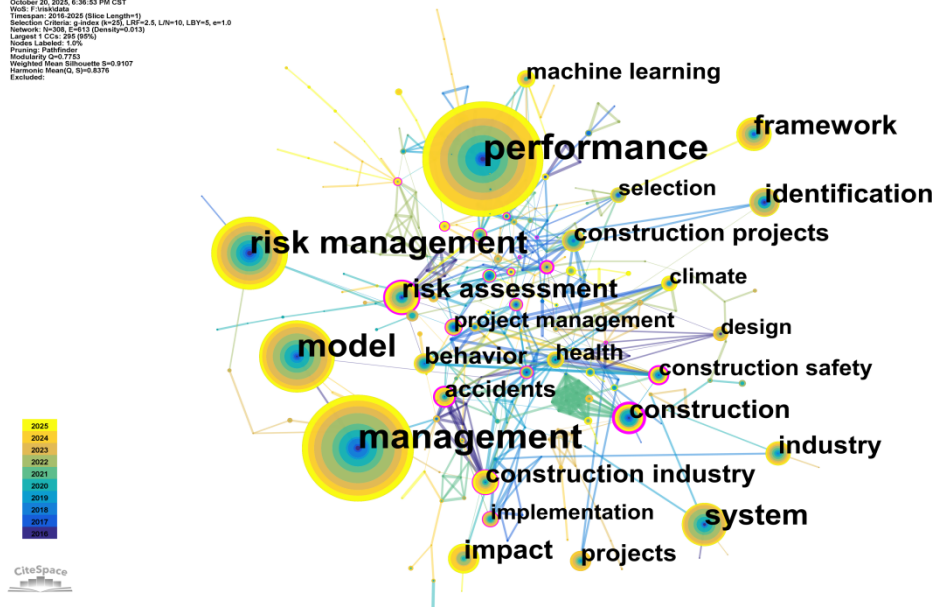


Figure 4. Co-occurrence network graph

Table 1. Frequency, central mediation, and year of first appearance of top 10 keywords

Count	Centrality	Year	Keywords
120	0.09	2016	Performance
111	0	2016	Management
76	0.06	2016	Risk Management
75	0.04	2016	Model
45	0.03	2016	System
35	0	2017	Framework
33	0.21	2016	Risk Assessment
31	0.02	2020	Impact
30	0.02	2016	Identification
28	0.43	2016	Construction

4.2 Keyword Burst Analysis

Figure 5 shows the start/end years and burst intensity of the top 10 keywords (2016–2025), with 60% having an intensity ≥ 2.0 , indicating a period of rapid innovation. The strong burst of “safety performance” (3.30, 2017-2020) marks a shift from passive accident response to proactive safety quantification, likely driven by stricter regulations and BIM adoption, extending risk management to a lifecycle framework. The burst of “critical success factors” (intensity = 2.67, 2018-2021) reflects efforts to identify key drivers in risk governance, such as leadership and information sharing, which can reduce project delays by 25% and enhance sustainability, possibly influenced by post-pandemic supply chain concerns.

Meanwhile, “sustainable construction” (intensity = 2.40, 2020-2023) and “machine learning” (intensity = 2.13, 2022-2025) highlight the role of digital transformation in green performance. The former links risk management to carbon reduction and resource efficiency, driven by policies like the EU Green Deal and China’s “dual carbon” goals, while their integration forms a “smart risk–green performance” pathway. The burst of “supply chain”

(2.31, 2019-2022), closely related to “project performance” (2.32), underscores growing attention to resilience, with tools like blockchain potentially reducing disruption losses by 30%, likely due to COVID-19 impacts.

Overall, the temporal and spatial evolution path of these burst keywords can be summarized in three stages: 2016-2018, basic safety-oriented stage (dominated by safety performance); 2019-2021, system optimization stage (critical success factors and supply chain in parallel); and 2022-2025, frontier digital stage (dominated by machine learning and sustainable construction). This path not only validates the empirical mechanism of risk management as a mediator in performance enhancement but also provides directions for future research, which can focus on strengthening AI–IoT integration to achieve predictive risk governance and ultimately constructing a dynamic performance optimization system throughout the entire lifecycle of buildings.

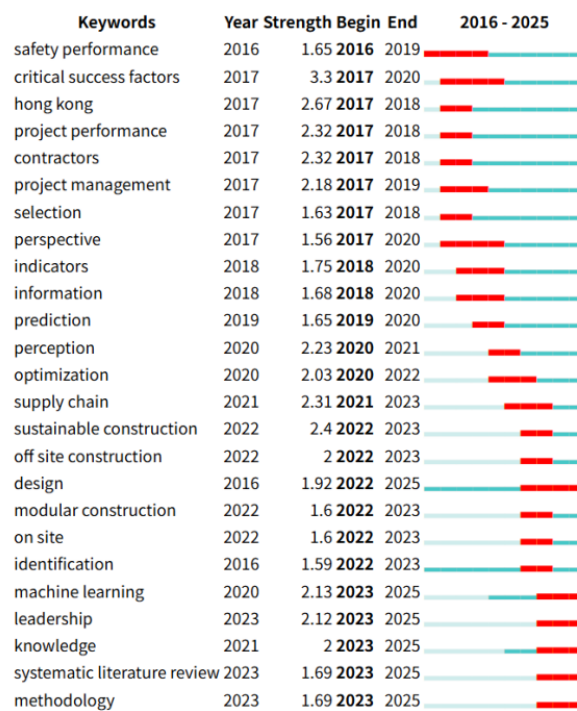


Figure 5. Top 25 keywords with the strongest citation bursts

4.3 Keyword Clustering View Analysis

Through a comprehensive analysis of the cluster names (Figure 6) and internal keywords (Table 2), this study finds that the research in the field of risk management driving construction performance enhancement primarily focuses on the following three areas.

First, research on *key elements of risk management* includes clusters such as “construction safety,” “risk management,” “risk assessment,” and “construction firms.” These keywords emphasize risk identification, assessment, and safety management as key elements that drive performance enhancement in construction. Risk management uses advanced data analysis, automation tools, and intelligent decision support to improve efficiency and sustainability.

The development of organizational models, such as enterprise-level risk frameworks, helps optimize supply chains and reduce delays. Safety management expands risk information exchange, facilitating real-time monitoring and enhanced performance through digital platforms. Risk assessment is crucial in supporting technological innovation and the digital transformation of the construction industry, enhancing resilience and accelerating modernization.

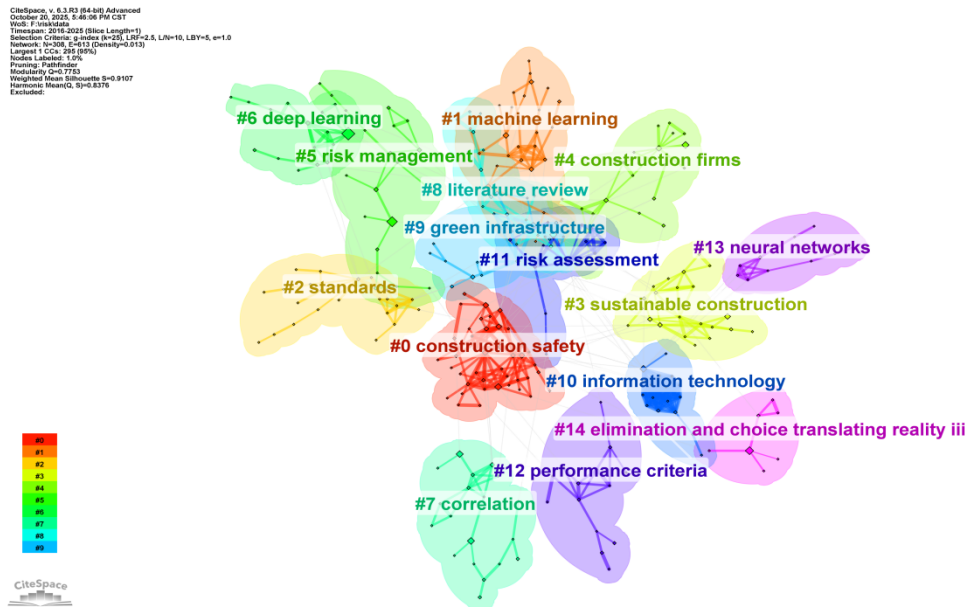


Figure 6. Keywords of cluster network map

Second, research on *practical outcomes of risk management* includes keywords like “machine learning,” “deep learning,” “information technology,” and “neural networks,” which reflect the integration of risk management with digital technologies. Machine learning and deep learning enhance construction efficiency and project quality by predicting and managing risks. These technologies enable real-time monitoring, data analysis, and optimized decision-making, driving the construction industry toward smarter, more sustainable development.

Lastly, research on *methods to achieve performance improvement* includes keywords such as “sustainable construction,” “green infrastructure,” and “ELECTRE III,” which highlight strategies to improve construction performance. Sustainable construction promotes green buildings, digital governance, and resource optimization through IoT, big data, and AI. These innovations not only enhance project efficiency and sustainability but also drive the diversification of the building economy and improve performance. The implementation of strategies like “ELECTRE III” bridges the gap between theory and practice, providing practical solutions for sustainable development in construction.

5. Research on Risk Management Driving Construction Performance Enhancement: Evolutionary Path

Figure 7 presents the timeline map of clustered keywords for risk management driving construction performance enhancement from 2016 to 2025. The map shows the evolution of key terms, with node rings reflecting keyword popularity cycles and node size quantifying centrality. The connections between nodes display the strength and frequency of semantic correlations. “Risk management” appears as the most frequent and central keyword, linking early safety-oriented research with later developments in digitalization and sustainable performance. This indicates a paradigm shift in risk management from passive response to active performance optimization.

Key concepts related to risk management, construction performance enhancement, and mediation effects are extracted from the timeline map. Keywords related to risk management, including “construction safety,” “risk management,” “risk assessment,” and “construction firms,” emphasize risk identification, assessment, and governance across different levels, from project safety control to enterprise-level strategy. Keywords related to performance enhancement, such as “performance criteria,” “sustainable construction,” and “green infrastructure,” focus on multi-objective performance quantification, with sustainability and decision optimization as strategic goals. Mediation effect keywords like “machine learning,” “deep learning,” and “information technology” bridge risk inputs to performance outputs through data-driven prediction and association analysis, enhancing resilience and reducing risk probabilities.

The timeline reveals three stages of research evolution. First, the Early Stage (2016-2019) is dominated by basic risk factors, such as “construction safety” and “risk management,” likely driven by global safety regulations and major accidents. Second, in the Middle Stage (2020-2021), technological factors like “information technology” and “correlation” gained prominence, reflecting the maturity of BIM and IoT and the pressure from supply chain disruptions post-pandemic. This led to a focus on digital mediation mechanisms to optimize risk–performance links. Finally, in the Later Stage (2022-2025), performance-oriented and frontier innovation keywords like “machine learning,” “deep learning,” and “sustainable construction” have been prominent, aligning with green building policies and AI technology advancements.

By analyzing the semantic network, we see how “risk management” links with early keywords like “construction safety,” reducing accident rates and improving initial performance benchmarks. Its co-occurrence with “machine learning” and “information technology” highlights the amplification effect of digital tools, such as IoT and deep learning, which predicts risks with high accuracy. This forms a closed-loop path: “risk identification → technology mediation → sustainable performance.” Additionally, the intersection of “correlation” and “neural networks” illustrates the use of statistical association in green infrastructure, optimizing resource allocation and enhancing decision-making with the ELECTRE III method.

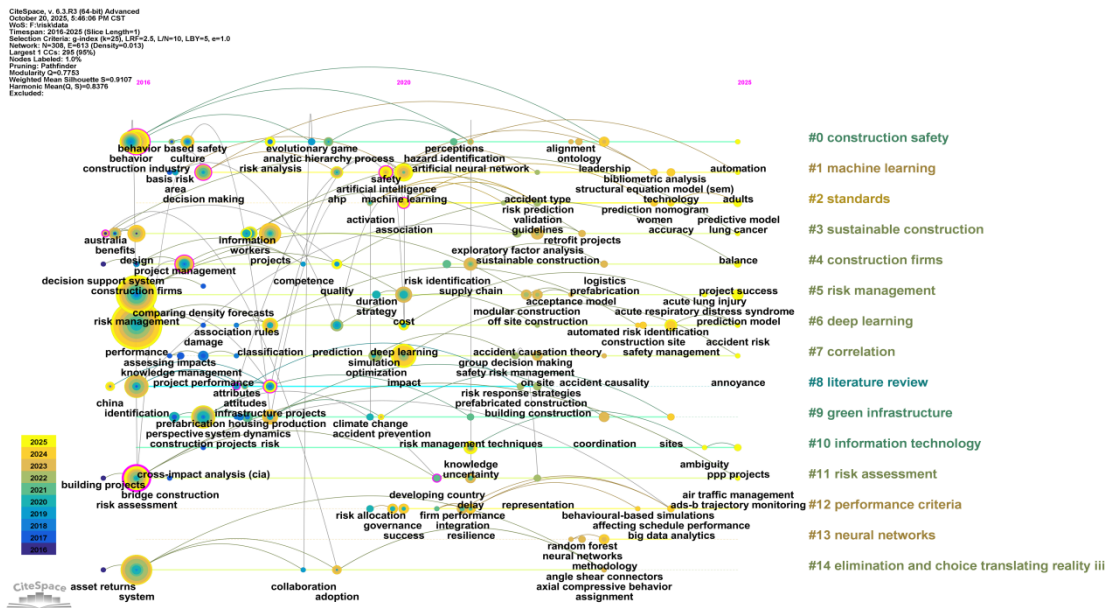


Figure 7. Timeline map of clustering keywords

Through analysis and summarization, this paper identifies the following three pathways through which risk management drives the enhancement of construction performance.

5.1 Technology Introduction and Innovative Application

The starting point of the pathway through which risk management drives construction performance enhancement lies in the introduction and innovative application of digital technologies. Digital technologies, including Building Information Modeling (BIM), Artificial Intelligence (AI), the Internet of Things (IoT), and Machine Learning (ML), have triggered fundamental transformations in the field of construction risk governance. Specifically, BIM enhances the accuracy and spatial-temporal positioning capabilities of risk identification through multi-dimensional data integration and visualization simulations, reducing design phase conflicts and optimizing resource allocation. AI and ML algorithms integrate historical data with real-time inputs, providing predictive risk assessment models and enabling early interventions for potential threats. IoT sensor networks enable continuous monitoring and automated response of construction and operation environments, reducing the incidence of safety accidents and enhancing system resilience. Big data analysis further integrates climate, supply chain, and environmental variables, offering evidence-driven performance optimization suggestions for decision-makers. In summary, digital technologies provide a strong methodological foundation and an innovative engine for risk management, forming the basis for the modernization of construction and the sustainable enhancement of performance. As technology continues to evolve and applications deepen, risk management will present broader development prospects and play an increasingly significant driving role.

5.2 Full Lifecycle Integration and Optimization

Full lifecycle integration and optimization represent a key link in risk management driving

construction performance enhancement, aiming to improve the overall efficiency and value creation capacity of the construction project chain through technological integration and process re-engineering. This process involves all stages from design and construction to operation, as well as the associated information, resource, and decision flows. In the design phase, digital risk management involves the pre-simulation of potential conflicts and multi-criteria evaluations, enhancing the robustness of plans and initial performance benchmarks. In the construction phase, risk management drives automated monitoring and dynamic adjustments, optimizing schedule control and reducing cost deviations. In the operation and maintenance phase, predictive maintenance models allow for equipment failure prediction and energy consumption minimization, greatly enhancing long-term sustainability. In terms of information flow, integrated platforms such as BIM cloud systems facilitate multi-party collaboration and data sharing, allowing project participants to grasp real-time risk dynamics and make accurate predictions. In terms of resource flow, digital tools such as Monte Carlo simulations and correlation analysis achieve supply chain risk diversification and efficient resource allocation, reducing disruption losses. Finally, in terms of decision flow, risk management frameworks like the ELECTRE III method provide multi-objective optimization tools, promoting fairness in fund allocation and strengthening project resilience, offering solid governance support and flexible adaptive mechanisms for improving construction performance. Overall, full lifecycle integration and optimization is an important way to achieve efficiency leaps and value maximization in risk management. Through technology application and process re-engineering, it drives the modernization of the construction chain and provides strong support for the implementation of performance improvement strategies.

5.3 Comprehensive Development of Project Resilience and Construction Performance Enhancement

The ultimate goal of risk management in enhancing construction performance is to strengthen project resilience and achieve strategic performance outcomes. It plays a multi-dimensional role and aligns with five core requirements. Firstly, the core requirement is *efficiency prosperity*: risk management integrates digital technologies to improve automation and intelligence, optimize resource allocation, enhance predictive capabilities, and support full lifecycle integration. This drives standardization and marketization, improving efficiency, economic benefits, and sustainable development. Second, environmental livability: digital risk management promotes green and sustainable construction. Smart monitoring reduces energy waste, while environmental risk assessment lowers emissions and protects resources. Digital tools also support low-carbon, livable building environments.

Third, *cultural civilization*: digital platforms enable collaboration, knowledge sharing, and simulation, enriching professional culture and strengthening the industry's soft power while fostering innovation. Fourth, *effective governance*: risk management enhances governance through intelligent decision-making systems, optimized response processes, and streamlined management, improving efficiency, transparency, and service delivery via tools like remote monitoring and data sharing. Finally, *value enrichment*: risk management improves

efficiency while creating new value through predictive analysis and resilience optimization. Digital tools enable precise risk control, ensure investment returns, and promote equitable resource distribution, supporting social equity and common prosperity.

6. Conclusion

This section summarizes the main findings of this research and puts forward relevant suggestions based on the study's results and limitations.

6.1 Conclusion

Risk management driving construction performance enhancement is a modern construction development model that uses new digital technologies, such as Building Information Modeling (BIM), Artificial Intelligence (AI), the Internet of Things (IoT), and Machine Learning (ML), to systematically upgrade traditional construction risk governance. It achieves a full-lifecycle, networked, data-driven, and predictive management approach, serving as a crucial lever and pathway to promote building sustainability and resilience strategies, while providing solid technical support and governance foundations for the modernization of construction and project value maximization. By conducting bibliometric analysis and mapping of relevant literature from 2016 to 2025 on the topic of risk management driving construction performance enhancement using CiteSpace, this paper identifies the temporal and spatial distribution, frontier hotspots, and evolutionary paths of research in this field.

First, regarding temporal and spatial distribution, in terms of total publication volume, research on risk management driving construction performance enhancement shows a trend of slow accumulation followed by significant growth and then stabilization at a high level. Based on the keyword analysis, the research is divided into three stages: 2016-2019 as the exploratory start phase, 2020-2021 as the accelerated transformation phase, and 2022-2025 as the mature expansion phase. The distribution of authors shows that there is a large research group in this field, but the collaboration network density between authors is low, and no significant collaborative research groups have formed. Universities and research institutes are most represented among the types of research institutions, with a deepening trend of collaboration between them.

Second, regarding hotspot frontiers, the study analyzed keyword co-occurrence networks, burst terms, and clustering to identify the dynamic research hotspots in the field of risk management driving construction performance. "Performance" and "risk management" are the core keywords, forming the basic framework that connects risk governance to construction performance enhancement. Next, "sustainable construction," "machine learning," and "risk assessment" continue to show bursts in 2025, indicating the future research frontiers. Overall, the focus of research on risk management driving construction performance enhancement is on the key elements of risk management, practical outcomes, and methods for achieving construction performance improvement.

Third, the evolutionary path of risk management driving construction performance enhancement from 2016 to 2025 shows distinct stages of development. Initially, research

focused on the core concepts and theoretical exploration of risk management. Thereafter, it gradually transitioned to in-depth research on digital technologies such as AI, IoT, and ML, which began to be widely applied throughout the construction lifecycle, promoting a shift toward smart and predictive transformations in construction. Subsequently, the focus of research shifted to full lifecycle integration and optimization, exploring how technological integration and process reengineering can enhance the efficiency and value creation capacity of the construction chain. Finally, the research focuses on the comprehensive development of project resilience and the multi-dimensional goals of construction performance enhancement: efficiency prosperity, environmental livability, cultural civilization, effective governance, and value enrichment. This emphasizes the important role of risk management in promoting building modernization, project sustainability, and industry resilience. This evolutionary path not only reflects technological progress and deepening applications but also demonstrates the trend of risk management closely aligning with national construction sustainability strategies.

In addition, the findings highlight the need for construction firms to transition from reactive risk control to proactive, data-driven risk management across the entire project lifecycle in the perspective of managerial implication. Managers should leverage digital technologies such as BIM, machine learning, and smart monitoring to strengthen risk assessment, improve predictive capabilities, and support performance evaluation. Emphasis should also be placed on critical success factors particularly leadership, information sharing, and supply chain resilience to minimize delays and enhance project outcomes. As the field evolves toward sustainability and digital integration, aligning risk management with green construction goals and lifecycle optimization is crucial. In addition, adopting intelligent governance systems can improve decision-making, transparency, and operational efficiency. Ultimately, an integrated “smart risk–performance” approach will enable organizations to enhance resilience, achieve strategic performance goals, and sustain long-term value creation in a complex and dynamic construction environment.

6.2 Future Research Directions

This paper outlines the research framework for risk management driving construction performance enhancement and identifies future research directions. Future studies can focus on deeper integration of risk management with multi-dimensional construction performance goals (e.g., efficiency, sustainability, governance), exploring how digital technologies can enhance productivity, environmental sustainability, and stakeholder benefits. Additionally, research should examine specific pathways and targeted strategies for risk management in construction, considering the adaptability of these strategies for various projects. Lastly, in-depth case analyses are needed to assess implementation mechanisms, effectiveness, and challenges, thereby providing insights into the application of digital technologies and informing the development of more precise policies and standards.

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Author contributions

Teng Lin and Hamrila binti Abdul Latip were responsible for study design and revising. Teng Lin was responsible for data collection. Teng Lin drafted the manuscript and Hamrila binti Abdul Latip revised it. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Macrothink Institute.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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