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Safety in the Construction Industry: A Literature Review

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Abstract

The construction industry remains one of the most hazardous sectors of the global economy, consistently reporting disproportionate rates of fatal and non-fatal injuries relative to its share of employment. Over the past two decades, research on construction safety has expanded from traditional accident statistics and compliance-based approaches toward a more holistic understanding of safety performance, safety culture and climate, safety leadership, and the growing role of digital technologies such as Building Information Modeling (BIM), wearable sensors, virtual reality (VR), and computer vision. This paper presents a literature review of twenty peer-reviewed studies published in leading construction, safety, and engineering management journals, including Safety Science, Automation in Construction, the Journal of Construction Engineering and Management, Construction Management and Economics, the Journal of Applied Psychology, and other well-regarded outlets. The review synthesizes findings across seven thematic areas: safety performance conceptualization and measurement, safety culture and climate, safety management systems and leading indicators, safety leadership, BIM-enabled safety risk management, wearable and IoT-based monitoring, and immersive and AI-based training and detection technologies. The review finds that while measurement and management frameworks have matured considerably, persistent gaps remain in standardizing definitions, integrating human and technological factors, and translating digital innovations into consistent field-level safety outcomes, particularly in developing-country contexts. The paper concludes by outlining directions for future research aimed at closing these gaps.

Keywords: Construction safety, safety climate, safety leadership, safety management systems, Building Information Modeling, wearable sensors, virtual reality training, computer vision, occupational health and safety.

INTRODUCTION

Construction activity underpins economic development worldwide, yet it continues to expose workers to disproportionately high risks of injury and death compared with most other industries. National labor statistics repeatedly show construction among the leading contributors to fatal occupational injuries, and the indirect costs of accidents — including delays, rework, litigation, and reputational damage — extend well beyond the immediate human toll. In response, a substantial and rapidly growing body of academic literature has sought to understand the determinants of construction safety performance and to develop tools, systems, and interventions that reduce risk on site.

This growth in research output has produced several parallel streams of inquiry. One stream focuses on the conceptual and organizational dimensions of safety, including how safety

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performance is defined and measured, how safety climate and culture develop, and how leadership styles shape worker behavior. A second stream is technology-driven, examining how digital tools such as BIM, wearable sensing devices, virtual and augmented reality, and artificial intelligence (AI) can be used to identify hazards, monitor compliance, and train workers more effectively. This review brings twenty studies from both streams together, discussing each in turn and drawing out the cross-cutting patterns that emerge when they are read side by side.

REVIEW METHODOLOGY

Twenty studies were selected to represent a cross-section of the construction safety literature published predominantly over the last decade, prioritizing outlets recognized as leading venues in the field, including Elsevier's Safety Science and Automation in Construction, the American Society of Civil Engineers' Journal of Construction Engineering and Management, Taylor & Francis's Construction Management and Economics and International Journal of Construction Management, Springer's International Journal of Civil Engineering, the American Psychological Association's Journal of Applied Psychology, Elsevier's Journal of Safety Research, MDPI's Sustainability, IOS Press's Work, and Frontiers in Built Environment. Selection prioritized studies that were themselves systematic reviews, meta-analyses, or well-cited empirical contributions, so as to capture aggregated, higher-confidence findings wherever possible. The studies are discussed below in seven thematic clusters; each study is introduced by its lead author(s) and reference number, following the practice used in this journal format, before its methodology and key findings are summarized Table 1.

LITERATURE REVIEW

Conceptualizing and Measuring Safety Performance

Orvik, Albrechtsen, and Kongsvik [1] conducted a systematic review of 231 scientific articles to examine how "safety performance" has been defined, applied, and measured in construction safety research, following PRISMA guidelines. Their analysis distinguished two broad views of safety underlying the literature: safety as the absence of unwanted events, typically operationalized through loss-based metrics such as Total Recordable Injury Rates (TRIR) and Lost Time Injury Rates (LTIR), and safety as the presence of positive organizational qualities, reflected in proactive and leading measures such as toolbox talks, safety inspections, training, and safety climate. The authors found that although loss-based metrics remain the most widely used, there is a clear and growing shift toward proactive, leading indicators, and they concluded that no single, agreed conceptualization of safety performance currently exists in the literature.

Complementing this, Bhagwat and Delhi [2] undertook a science-mapping review of construction safety performance (CSP) measurement methods and practices, using bibliometric tools to identify influential contributors, research levels, project types, and measurement instruments across the field. Their study identified 11 safety dimensions comprising 109 distinct safety practices and observed a clear paradigm shift in CSP research from reactive to proactive management approaches, ultimately proposing an integrated, proactive CSP management framework based on their findings.

Safety Climate and Safety Culture

Mosly [3] reviewed journal articles indexed on the Web of Science to identify the factors influencing safety climate in the construction industry, drawing on 28 articles from 10 journals, with Safety Science and the Journal of Construction Engineering and Management contributing the largest share. The review identified 18 distinct safety climate factors, which the author grouped broadly into management-related factors — including management commitment to safety, communication, supervision and guidance, education and training, and safety resources — and worker-related factors, concluding that management-related factors dominate the literature relative to worker-level determinants.

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Table 1. Summary of the twenty reviewed studies.

Ref.	Study (Authors, Year)	Method / Sample	Key Focus
1	Orvik, Albrechtsen & Kongsvik (2025)	Systematic review (231 articles, PRISMA)	Conceptualizing and measuring safety performance
2	Bhagwat & Delhi (2023)	Science-mapping / bibliometric review	CSP measurement methods and practices
3	Mosly (2019)	Review (28 articles, 10 journals)	Factors influencing safety climate
4	Alkaissy, Arashpour, Ashuri, Bai & Hosseini (2020)	Review (20 years of literature)	Quantitative safety risk modeling
5	Golabchi, Abellanosa, Lefsrud, Pereira & Mohamed (2024)	Systematic review (PRISMA, 3-stage)	Safety leading indicators
6	Newaz, Ershadi, Jefferies, Pillay & Davis (2023)	Systematic review + bibliometric mapping (180 studies, 21 journals)	Trending safety management research domains
7	Berglund, Johansson, Johansson, Nygren & Stenberg (2023)	Structured review (Scopus, Web of Science)	Safety culture research and models
8	Sarvari, Edwards, Rillie & Posillico (2024)	Scientometric analysis (35 papers)	Safety-I vs. Safety-II paradigms
9	Jazayeri & Dadi (2017)	Narrative review	Evolution of safety management systems
10	Awolusi, Marks & Hallowell (2018)	Technology review	Wearable technology for safety monitoring
11	Ahn, Lee, Sun, Jebelli, Yang & Choi (2019)	Review (5 use cases)	Wearable sensing in safety and health
12	Fasoyinu et al. (2025)	Bibliometric + content analysis (107 / 92 studies)	WSD applications, limitations, barriers
13	Dadashi Haji, Behnam, Sebt, Ardeshir & Katooziani (2023)	Tool development + case study	BIM-based leading indicator measurement
14	Lu, Gong, Tang, Sun & Li (2021)	Quantitative method development	BIM-integrated design-stage risk assessment
15	Tözer, Gürcanli, Çelik & Akboğa Kale (2023)	System development (Cyprus accident database, ICD-10)	BIM fall-hazard coding system
16	Akram, Thaheem, Khan, Nasir & Maqsoom (2022)	Systematic review + survey	BIM safety in developing countries
17	Man, Wen & So (2024)	Systematic review + meta-analysis	VR effectiveness in safety training
18	Sacks, Perlman & Barak (2013)	Experimental study (n = 66)	VR-based construction safety training
19	Delhi, Sankarlal & Thomas (2020)	Model development (YOLOv3 deep learning)	Computer-vision PPE compliance detection
20	Lyubykh, Turner, Hershcovis & Deng (2022)	Meta-analysis (194 samples, N = 104,364)	Leadership and workplace safety

Note: *Studies are numbered as they appear in the References list; the narrative discussion below groups them thematically rather than numerically.*

Berglund, Johansson, Johansson, Nygren, and Stenberg [4] took a related but distinct angle, exploring how "safety culture" specifically has been researched in the construction industry through searches of Scopus and Web of Science. After a structured screening process, their review examined models developed to operationalize safety culture, approaches to measuring it, and the role of management and leadership in shaping it. The authors found that while four articles proposed explicit models of safety culture, relatively few studies clearly distinguish safety culture from the related but narrower construct of safety climate, and they call for broader theoretical and methodological development in this area.

Sarvari, Edwards, Rillie, and Posillico [5] extended this discussion by comparing the Safety-I and Safety-II paradigms in construction. Using a scientometric analysis of 35 papers validated against the

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Web of Science database, and bibliometric mapping through HistCite and VOSviewer, the authors traced the historical progression of this research stream from its introduction (2011–2015) through solution-oriented studies (2015–2019) to more recent constructive proposals for integration (post-2019). They argued that Safety I, a reactive, hazard-control-oriented approach, and Safety II, which emphasizes learning from everyday successful adaptation and worker strengths, are often treated as competing paradigms but that construction organizations stand to benefit from strategies that combine both.

Safety Management Systems and Leading Indicators

Jazayeri and Dadi [6] reviewed the evolution of construction safety management systems (SMS) and methods of safety performance measurement, tracing developments since the U.S. Occupational Safety and Health Act of 1970. The review noted that despite significant regulatory and organizational investment in SMS, construction fatality rates have remained persistently high — citing Bureau of Labor Statistics data showing 856 construction fatalities in 2012 alone, representing 19 percent of all U.S. workplace fatalities that year — and argued that inconsistent performance-measurement practices continue to limit the effectiveness of formal SMS.

Golabchi, Abellanosa, Lefsrud, Pereira, and Mohamed [7] conducted a systematic literature review of safety leading indicators in construction following a three-stage PRISMA-based protocol. Their review traced how the definition of safety leading indicators has evolved over time, examined the transition from lagging to leading measurement approaches, and explored the relationship between leading indicators and both safety climate/culture and overall safety performance. The authors concluded that although interest in leading indicators has grown substantially, the field still lacks a structured, consensus-based framework that construction organizations can use to integrate these indicators systematically into safety management practice.

Newaz, Ershadi, Jefferies, Pillay, and Davis [8] performed a systematic review and bibliometric mapping of 180 studies published across 21 peer-reviewed journals between January 2010 and November 2021, using VOSviewer to analyze co-author citations and keyword co-occurrence. Their analysis identified seven trending research domains — safety systems, safety skills, accident causation, safety leadership and communication, safety behavior and attitude, safety climate and culture, and practices for improving safety performance — and highlighted a growing research interest in effective leadership styles, psychological interventions, and the application of advanced technologies to safety management.

Alkaissy, Arashpour, Ashuri, Bai, and Hosseini [9] reviewed two decades of quantitative safety risk-modeling research in construction, focusing on simulation- and optimization-based techniques and their interface with broader project performance modeling. The review found that risk-modeling methods have grown considerably more sophisticated over the study period and identified correlations between safety risk and other project performance metrics such as cost, quality, and productivity, while noting that model complexity has in some cases outpaced practical field validation.

Safety Leadership

Lyubykh, Turner, Hershcovis, and Deng [10] conducted a large-scale meta-analysis of the relationship between leadership and workplace safety, drawing on effect sizes from 194 samples totaling 104,364 participants across multiple industries, including construction. The study examined five categories of leadership behavior — change-oriented, relational-oriented, task-oriented, passive, and destructive — in relation to seven workplace safety variables, and tested contextual moderators such as industry risk level, workforce age, and whether leadership was measured as safety-specific or general. The authors found that leadership categories vary considerably in their relative importance for explaining safety outcomes, with safety-specific leadership behaviors generally showing stronger and more consistent associations than generalized leadership styles, particularly in higher-risk industry contexts such as construction.

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BIM-Enabled Safety Risk Management

Dadashi Haji, Behnam, Sebt, Ardeshir, and Katooziani [11] developed and tested a BIM-based safety leading indicator measurement tool, integrating a knowledge base of safety leading indicators extracted from expert input, documentation, and best practice with a construction project's BIM model. Their framework introduced the concept of an "effective radius" to capture how a leading indicator can influence safety risk beyond the immediate location of the associated activity, and a case study implementation demonstrated that the tool could track the time- and location-specific impact of leading indicators throughout a project's lifecycle.

Lu, Gong, Tang, Sun, and Li [12] proposed a quantitative, BIM-integrated method for construction safety risk assessment at the design stage, built around three indexes — likelihood, consequence, and exposure — whose sum-product across project activities yields an overall project safety risk score. Framed within the Construction Hazard Prevention through Design (CHPtD) philosophy, the study demonstrated how safety risk data can be embedded directly into BIM models so that architects and owners can evaluate the safety implications of design decisions before construction begins.

Tözer, Gürcanli, Çelik, and Akboğa Kale [13] developed a BIM-based coding system focused specifically on fall-from-height hazards, using a database of classified occupational accident records from Cyprus coded according to ICD-10 standards. Their system automatically warns designers when a design decision is likely to create a fall hazard and simultaneously proposes safer design alternatives, allowing hazards that would otherwise remain undetected until construction to be identified and mitigated during the design phase.

Akram, Thaheem, Khan, Nasir, and Maqsoom [14] examined the role of BIM in construction safety specifically within developing-country contexts, conducting a systematic literature review followed by an online questionnaire survey of construction management professionals from both developed and developing countries. Their study synthesized safety factors and BIM features into a set of BIM-based safety improvement strategies spanning the entire project lifecycle, and found that while professionals in developing countries generally recognize BIM's safety benefits, practical implementation is constrained by limited technical capacity and fragmented regulatory support relative to developed-country settings.

Wearable Sensing and IoT-Based Monitoring

Awolusi, Marks, and Hallowell [15] reviewed wearable technologies for personalized construction safety monitoring, cataloguing the range of devices available and assessing their performance characteristics for detecting and trending safety- and health-related data on site. The review presented a model for integrating multiple wearable sensors and systems to support multi-parameter safety performance monitoring, while noting that practical barriers — including device durability, measurement accuracy, and worker acceptance — continue to limit widespread field deployment.

Ahn, Lee, Sun, Jebelli, Yang, and Choi [16] reviewed the broader body of research on wearable sensing technology applications in construction safety and health, identifying five recurring use cases: preventing musculoskeletal disorders, preventing falls, assessing physical workload and fatigue, evaluating hazard-recognition ability, and monitoring workers' mental status. The authors highlighted several persistent technical and organizational challenges, including signal noise and artifacts in field measurements, the absence of standardized safety and health risk thresholds specific to construction, and workers' resistance to adopting wearable technology, and they called for future research on sensor fusion, business-case development, and integration of wearable data into risk assessment and compensability processes.

Fasoyinu and colleagues [17] conducted a more recent systematic review combining bibliometric and content analysis of, respectively, 107 and 92 studies on wearable sensing devices (WSDs) in construction published between 2010 and 2024. The review identified eight primary WSD application

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areas — including health and fatigue monitoring, hazard identification, activity recognition, location tracking, fall detection, environmental sensing, communication, and training — along with four key operational limitations and six adoption barriers, and proposed a conceptual multi-stakeholder framework to guide the strategic integration of wearable devices into construction safety systems going forward.

Virtual Reality for Safety Training

Sacks, Perlman, and Barak [18] conducted an early and influential experimental study testing whether safety training delivered in an immersive virtual reality (VR) construction site environment would be more effective than conventional training methods. Sixty-six subjects were tested on their safety knowledge before training, immediately after training, and again one month later, and the VR-trained group showed improved performance in identifying and assessing construction safety risks relative to those trained through conventional methods, supporting the feasibility and instructional value of VR-based safety training.

Man, Wen, and So [19] built on more than a decade of subsequent research with a systematic review and meta-analysis of VR applications in construction safety training and education (CSTE). Using standardized mean differences to compare VR training against traditional methods across behavior, skills, and experience-based outcome measures, the study found that VR was significantly more effective than traditional training overall, with effect-size advantages of 0.593, 0.432, and 0.777 for behavior, skills, and experience outcomes respectively, while also identifying training context and prior work experience as significant moderators of VR's effectiveness.

Computer Vision and AI for Automated Safety Compliance

Delhi, Sankarlal, and Thomas [20] developed one of the foundational computer-vision frameworks for real-time detection of personal protective equipment (PPE) compliance on construction sites, applying transfer learning to a convolutional neural network based on the YOLOv3 object-detection architecture. Motivated in part by India's comparatively high construction accident rate, the study demonstrated the feasibility of automatically sensing PPE compliance in real time and argued that such computer-vision techniques could be integrated directly into an organization's broader safety compliance workflow.

Taken together with more recent reviews of computer-vision-based construction monitoring, this stream of research shows detection systems evolving beyond simple PPE checks toward broader hazard recognition, worker-equipment proximity monitoring, and BIM-integrated safety-rule checking, even as questions remain about reliably translating high laboratory accuracy into low-false-alarm performance under variable real-world site conditions.

DISCUSSION: CROSS-CUTTING THEMES AND RESEARCH GAPS

Reading the twenty reviewed studies together reveals several recurring patterns.

- Definitional fragmentation. Multiple reviews independently note that core constructs — safety performance, safety climate, safety culture, and leading indicators — lack standardized definitions and measurement approaches, limiting comparability across studies and organizations [1–3, 7, 4].
- A shift from reactive to proactive safety management. Across management-systems, leading-indicator, and BIM-based design research, there is a clear trend toward identifying and mitigating hazards earlier in the project lifecycle rather than responding to incidents after they occur [2, 9, 8, 11, 12, 13].
- Convergence of human and technological research streams. Leadership and climate research increasingly intersects with technology-adoption studies, since the effectiveness of BIM, wearables, VR, and computer-vision tools appears to depend heavily on organizational safety culture and management commitment, and not on technical capability alone [14, 10].

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- Uneven diffusion across contexts. Several reviews highlight that developing-country and small-to-medium enterprise contexts lag behind in adopting digital safety technologies, due to cost, regulatory, and capacity constraints, raising equity concerns about who benefits from safety innovation [14].
- A gap between short-term efficacy and long-term outcomes. VR training and computer-vision detection studies frequently demonstrate strong short-term or laboratory results but rarely track sustained behavioral change or long-term injury-rate reduction on live projects [19, 18,20–19].

Taken together, these patterns suggest that future research would benefit from longitudinal, field-based studies that connect technological interventions to measurable safety outcomes over time, as well as from greater methodological standardization that would allow findings to be more reliably compared and aggregated across the fragmented construction safety literature.

Limitations of This Review

This review has its own methodological boundaries that should be weighed alongside its findings. First, the twenty included studies were selected narratively rather than through a fully systematic, protocol-driven search (e.g., pre-registered PRISMA screening with documented inclusion and exclusion criteria), so the sample, while weighted toward systematic reviews and meta-analyses, is not exhaustive and may under-represent smaller or non-English-language studies. Second, the reliance on already-aggregated reviews and meta-analyses means that primary empirical nuances within individual constituent studies are necessarily compressed, and any biases present in those source reviews (such as publication bias favoring statistically significant results) propagate into this synthesis. Third, the reviewed literature itself skews toward North American, European, and East Asian research contexts, which limits the extent to which the conclusions—particularly around technology diffusion—generalize to under-represented regions. Finally, because several of the underlying studies were published in 2024 and 2025, some findings reflect early-stage evidence that has not yet been replicated or subjected to long-term field validation. These limitations do not undermine the cross-cutting patterns identified above, but they do suggest that the patterns should be treated as a structured starting point for further systematic inquiry rather than a definitive account of the field.

CONCLUSION

This review has discussed twenty studies drawn from leading construction, safety, and engineering management journals to map the current state of construction safety research across seven interconnected themes: safety performance and its measurement, safety culture and climate, safety management systems and leading indicators, safety leadership, BIM-enabled risk management, wearable and IoT monitoring, VR training, and AI-based automated detection. The literature shows a field in active transition — moving from compliance-oriented, reactive safety management toward proactive, data-rich, and increasingly technology-mediated approaches. At the same time, persistent challenges around definitional consistency, uneven technology diffusion, and the translation of short-term gains into sustained safety outcomes remain unresolved. Addressing these gaps will likely require closer collaboration between behavioral and technical safety researchers, along with a stronger emphasis on rigorous, long-term field evaluation of the safety interventions and technologies reviewed here.

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