

Robotic Technologies for Hazardous Construction Tasks: Implications for Occupational Health and Safety

Omojokun Gabriel Aju¹ and Kgabo Mokgohloa²

^{1&2}Graduate School of Business Leadership, University of South Africa, South Africa

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Abstract

This study examines the potential roles of robotic technologies in executing hazardous construction tasks and advancing occupational health and safety (OHS). Drawing on a comprehensive analysis of accident trends, risk profiles, and limitations of conventional safety management using structured literature review methodology, the study synthesizes current applications of robotics in work at height, demolition, excavation, confined spaces, and emergency response. It evaluates the integration of robotics with digital construction systems (BIM, IoT, and AI) and analyses levels of automation and human–robot interaction. The findings highlight significant potential for risk reduction, ergonomic improvement, and accident prevention, while also identifying emergent safety, psychological, and regulatory challenges associated with collaborative robotics. By examining drivers, barriers, and global adoption patterns, the study advances a socio-technical perspective on safe automation and proposes policy, industry, and research pathways to support responsible and sustainable deployment of robotics in hazardous construction environments.

Keywords: Construction Robotics, Occupational Health and Safety, Hazardous Work, Automation, Human–Robot Interaction.

1. Introduction

The construction industry remains one of the world's most hazardous sectors, it consistently reports high rates of occupational injuries, illnesses, and fatalities due to its inherently complex, dynamic, and physically demanding work environments (Liang & Cheng, 2023). The traditional “Focus Four” hazards: falls, struck-by incidents, caught-in/between accidents, and electrocutions continue to dominate injury statistics, thereby imposing significant emotional, medical, and economic burdens on workers and their families (Harris et al., 2023). Beyond acute accidents, prolonged exposure to noise, dust, repetitive movements, heavy lifting, and ergonomic strain contributes to chronic health conditions among craft workers. Occupational health and safety (OHS) therefore remain a persistent concern for researchers, policymakers, employers, and industry practitioners. Although safety regulations, protective equipment, and risk-control procedures have advanced, serious injuries remain prevalent, strengthening the case for technological interventions capable of reducing workers' exposure to hazards at their source and throughout the project lifecycle (Earnest et al., 2026).

Within this context, robotic technologies and automation are emerging as transformative tools for addressing hazardous construction tasks that have historically placed human workers at unacceptable risk. Robotics spans a spectrum from autonomous inspection

robots and unmanned aerial vehicles (UAVs) to collaborative robots (“cobots”) and wearable assistive systems such as exoskeletons, each designed to replace or augment human participation in dangerous work processes. Recent empirical and conceptual studies highlight how mobile robots can autonomously navigate complex jobsite environments to perform safety inspections, while exoskeletons and cobots can reduce physical strain and musculoskeletal disorders, which are key contributors to chronic disability (Urrea & Kern, 2025). However, introducing robotic systems into unstructured and continuously changing construction environments may also generate proximity hazards, human–robot interaction risks, operational uncertainty, and concerns about algorithmic reliability (Niehaus et al., 2025). Robotics must therefore be examined not merely as a technical solution, but as an intervention that can simultaneously mitigate existing hazards and create new categories of occupational risk.

Socio-Technical Systems Theory provides the principal theoretical lens for examining this duality. The theory conceptualises workplace performance and safety as outcomes of interactions between social and technical subsystems rather than as products of technology alone. From this perspective, the deployment of robotics represents more than the substitution of machinery for human labour. It reconfigures the interdependent relationships among workers, robotic technologies, organisational procedures, task structures, managerial

¹ Corresponding Author

Email address: ajuog@unisa.ac.za; 2mokgok@unisa.ac.za

practices, and safety cultures (Ang, Sankaran & Liu, 2025). This theoretical framing is especially important because existing studies have predominantly emphasised the technical capabilities, operational efficiency, and productivity benefits of robotics, while paying comparatively limited attention to how robotic adoption transforms risk exposure and human–work system relationships (Lin et al., 2025; Bahadori-Jahromi et al., 2025). Although robotic systems may reduce direct exposure to demolition, excavation, inspection, material handling, and work-at-height hazards, they may also create operational complexity, coordination failures, system dependencies, communication difficulties, and unintended vulnerabilities. The central issue is therefore not simply whether robotics improves construction safety, but under what organisational, technological, and behavioural conditions such improvements are achieved.

High Reliability Theory complements this central lens by directing attention to the organisational capabilities required to manage technologically complex operations in hazardous environments. From this perspective, superior safety performance depends not only on sophisticated robotic systems, but also on organisational resilience, continuous learning, operational redundancy, sensitivity to emerging hazards, and proactive risk management (Lin et al., 2025). The theory therefore provides a basis for assessing whether robotic integration strengthens the reliability of construction operations or produces emergent risks that undermine established safety controls. Human Factors Theory further extends the analysis by foregrounding the cognitive, ergonomic, and psychosocial dimensions of human–robot collaboration. Although robotics can reduce physical strain, fatigue, and workers' exposure to hazardous environments, it may also affect operator workload, situational awareness, trust in automation, decision-making, and human–machine coordination (Giallanza et al., 2024). Together, these perspectives demonstrate that effective robotic integration requires attention to technical reliability, organisational preparedness, and the physical and cognitive capacities of workers.

Accordingly, important questions remain regarding how robotic systems redistribute occupational risks, how human–robot collaboration affects workers' ergonomic and psychosocial wellbeing, and how system design, regulation, training, and safety-management practices should evolve to ensure that technological innovation strengthens rather than compromises worker safety. Addressing these questions requires an interdisciplinary synthesis of robotics, construction management, safety science, organisational studies, and human factors research. Anchored principally in Socio-Technical Systems Theory and supported by High Reliability Theory and Human Factors Theory, this review examines robotics

as both a hazard-mitigation mechanism and a possible source of emerging risk. This theoretically integrated approach provides a basis for explaining why similar robotic technologies may produce different OHS outcomes across construction contexts and advances a more holistic understanding of worker safety and wellbeing within Construction 4.0.

2. Research Methodology

This study adopts a structured literature review design to examine the role of robotic technologies in mitigating hazardous construction tasks and advancing occupational health and safety (OHS) outcomes. The exploratory approach is appropriate given the interdisciplinary and evolving nature of robotics integration within construction environments, where empirical evidence remains fragmented across engineering, construction management, ergonomics, and safety science domains. The review aimed to map existing knowledge, identify dominant research themes, and uncover gaps related to robotic deployment in high-risk operations such as demolition, excavation, confined-space work, height-related tasks, and exposure to toxic or extreme conditions.

A structured search strategy was implemented across major academic databases, including Scopus and Web of Science with targeted searches in leading construction automation and safety journals. Keywords and Boolean combinations include terms such as “construction robotics,” “hazardous tasks,” “occupational health and safety,” “automation in construction,” “robot-assisted demolition,” and “remote operation systems.” Peer-reviewed journal articles, conference proceedings, and authoritative industry reports published in English within the last seven (7) years were considered to capture recent technological advancements.

Studies were screened based on predefined inclusion criteria focusing on relevance to hazardous task substitution, risk reduction, worker exposure mitigation, and documented safety outcomes. The initial search process identified 538 records. Following relevance screening, 104 studies were subjected to eligibility assessment. Duplicate records, studies with limited relevance, and inaccessible publications were subsequently eliminated using The Evidence Review Accelerator (TERA) tool, resulting in a refined dataset comprising studies that met the predefined inclusion criteria and ensured the rigour and reliability of the review process. A total number of 41 publications were analysed and included in the study, comprising 36 journal articles, 2 conference proceedings, and 3 book chapters.

The selected literature was subjected to thematic synthesis and qualitative content analysis to identify patterns in technological application, safety

performance, implementation drivers and barriers, and regulatory implications. Findings were categorized into occupational health and safety challenges in construction; robotic applications for hazardous construction tasks; implications for occupational health and safety; drivers and barriers to adoption of safety-oriented construction robotic; and comparative perspectives and global experiences. This analytical process enabled the development of recommendations for the adoption of robotic technologies for hazardous construction tasks for policy, industry, and practice in form of regulatory frameworks for safe deployment of construction robots, industry guidelines and best practices, and workforce training and safety culture transformation. Methodological rigour was systematically evaluated using the Critical Appraisal Skills Programme (CASP) Qualitative Checklist. The appraisal results informed both study inclusion decisions and the evidential weighting applied during synthesis, thereby enhancing the credibility, methodological robustness, and interpretive integrity of the review findings.

3. Findings

3.1. Occupational Health and Safety Challenges in Construction

The construction industry remains one of the most hazardous sectors globally due to the dynamic, complexity, and task-intensive nature of its operations. Its core activities, including work at heights, excavation, heavy equipment operation, demolition, and hazardous material handling expose workers to elevated risks of falls, struck-by incidents, electrocutions, ergonomic strain, and chemical hazards. These exposures are often simultaneous and compounding; for instance, lifting heavy materials at elevation increases both musculoskeletal and fall risks. Although task-based exposure characterization is widely adopted to inform preventive controls, the intermittent and heterogeneous configuration of construction work complicates conventional hazard profiling and limits the effectiveness of traditional exposure assessment tools (Olimat et al., 2025).

Longitudinal safety research continues to report disproportionately high injury and fatality rates in construction compared with other industrial sectors. Falls, caught-in/between incidents, and struck-by events consistently dominate accident statistics, reflecting the inherently physical and high-risk character of construction tasks (Adebowale & Agumba, 2024). Despite progressive regulatory developments since the 1970s, accident prevalence remains significant, underscoring structural vulnerabilities in safety governance (Olimat et al., 2025). Empirical studies further identify inadequate safety training, insufficient personal protective equipment (PPE), and entrenched risk-taking cultures as predictors of

elevated accident rates within firms (Hassan et al., 2025).

While regulatory compliance, hazard identification, and risk assessment frameworks have yielded incremental improvements, they remain constrained by static evaluation models that inadequately address rapidly evolving site conditions, transient labour structures, and multi-contractor complexity. Implementation barriers, including limited safety resources, weak managerial commitment, fragmented communication, high labour turnover, and constrained worker participation continue to undermine proactive risk control (Rantsatsi, 2025). Increasing production pressures and compressed project timelines further exacerbate these weaknesses. Consequently, emerging scholarship advocates a transition toward transformative safety paradigms integrating robotics, automation, real-time data analytics, and dynamic risk modelling, alongside strengthened safety culture and participatory governance mechanisms to achieve sustainable reductions in occupational injuries and fatalities (Olimat et al., 2025).

3.2. Robotic Applications for Hazardous Construction Tasks

Robotic technologies are increasingly deployed to mitigate high-risk work at height, a leading cause of fatalities in construction. Tasks such as façade inspection, exterior finishing, and maintenance traditionally require workers on scaffolds or elevated platforms. Unmanned aerial vehicles (UAVs), wall-climbing robots, and aerial manipulators are enabling visual inspection, structural mapping, and light maintenance without human exposure to fall hazards. The advanced sensing technologies and deep-learning detection systems are also allowing real-time monitoring of fall risks, enhancing hazard identification and situational awareness (Urrea & Kern, 2025; Sahoo et al., 2025). While autonomous navigation, adhesion mechanics, and aerial manipulation are further supporting precision operations like drilling and anchor setting, thereby substantially reducing fall-risk exposure.

In demolition, excavation, and material handling, robotics reduces human exposure to structural collapse, debris, and hazardous materials. Remote-controlled demolition machines with hydraulic breakers, saws, or shears allow operators to perform tasks safely from a distance, lowering traumatic injury risks (Liu et al., 2024). Also, the autonomous heavy equipment platforms enable remote or automated execution of repetitive excavation and earthmoving tasks, minimizing operator exposure to unstable ground and mobile equipment hazards (Liu & Kim, 2025). Additionally, automated guided vehicles (AGVs) and robotic lifting systems are being used to transport heavy materials across uneven or congested sites, improving ergonomics and protecting workers from

musculoskeletal and struck-by injuries (Liu et al., 2024).

Furthermore, robotics is also being used in confined spaces and toxic environments where human entry is highly hazardous. Specialized tethered crawlers, vine-like robots, and ATEX-certified inspection systems can navigate narrow or contaminated spaces, perform inspections, and collect sensor data without human presence which reduces the risks of asphyxiation, poisoning, or entrapment (Qu, 2026). These systems provide rich situational awareness while ensuring compliance with occupational health standards, enabling safer operations in environments traditionally prohibitive for personnel.

Finally, robotic inspection, monitoring, and emergency response systems also enhance both routine and crisis safety management. UAVs and autonomous mobile robots equipped with LiDAR and cameras can conduct frequent, high-resolution inspections and safety audits, improving defect detection and quality assurance while reducing exposure to hazardous conditions (Halder & Afsari, 2023). In emergencies, teleoperated reconnaissance robots can detect hazards such as gas leaks or fire hotspots, and assess post-collapse conditions without risking additional personnel, thereby enhancing situational awareness and enabling timely, life-saving interventions (Naik et al., 2025).

3.3. Drivers and Barriers to Adoption of Safety-Oriented Construction Robotics

The adoption of safety-oriented construction robotics is primarily propelled by rapid technological advancements and demonstrable performance gains in precision, productivity, and occupational safety. Autonomous inspection drones, collaborative robots (cobots), and robotic systems for hazardous material handling reduce human exposure to high-risk environments while improving task consistency and operational efficiency. Emerging capabilities in autonomous navigation, human-robot collaboration, and sustainability-oriented automation further enhance their applicability in repetitive and dangerous construction activities (Xu et al., 2025). Evidence from systematic reviews indicates that integration with digital platforms such as Building Information Modelling strengthens the productivity-safety nexus, reinforcing the economic and operational rationale for deployment amid labour shortages and demographic transitions (Lin et al., 2025).

Notwithstanding these technological drivers, organizational and workforce barriers significantly constrain widespread uptake. Industry fragmentation, tight margins, and entrenched work practices discourage capital-intensive investments in robotics, particularly among small and medium-sized enterprises (Akinradewo et al., 2024). Persistent skills gaps, limited access to specialized training, and low

awareness of robotic capabilities undermine readiness for implementation and contribute to workforce resistance (Obi et al., 2025). Sociotechnical analyses further demonstrate that leadership vision, change management strategies, and proactive workforce development are decisive mediating factors; firms with innovation-oriented cultures are more likely to realize safety and productivity gains, whereas conservative organizational climates inhibit adoption (Ang et al., 2024).

Externally, regulatory, ethical, and liability uncertainties introduce additional complexity into adoption decisions. The deployment of robots in dynamic, human-shared construction environments generates novel safety risks that existing occupational health and safety frameworks only partially address, particularly in relation to autonomous decision-making and emergent hazards (Earnest et al., 2026). Ambiguities in standards, certification pathways, insurance coverage, and incident liability contribute to cautious implementation strategies, especially where collaborative robots operate in close proximity to workers (Vecellio Segate & Daly, 2024). Ethical concerns regarding workforce displacement, equitable access to robotic technologies, and trust in autonomous systems further shape stakeholder perceptions, underscoring the need to balance technological innovation with social responsibility and worker well-being (Callari et al., 2024).

3.4. Comparative Perspectives and Global Experiences

In developed construction markets, robotics adoption has accelerated over the past decade in regions such as the United States, Europe, Japan, South Korea, and China, driven by labour shortages, productivity pressures, and heightened safety expectations. Research aligned with Construction 4.0 paradigms highlights autonomous navigation, sensor fusion, and human-robot collaboration as core innovations (Xu et al., 2025). Applications including autonomous earthmoving, prefabrication systems, inspection drones, semi-autonomous manipulators, and exoskeletons have demonstrably reduced worker exposure to repetitive and hazardous tasks (Earnest et al., 2026; Hilmi et al., 2024). Despite these advances, adoption remains uneven, particularly among small- and medium-sized firms, due to high capital costs, perceived technical risks, and regulatory complexity (Ting & Kong, 2025).

However, the emerging and developing economies face structural barriers such as limited capital, digital infrastructure constraints, and lower workforce technological readiness, which slow robotics integration compared to advanced markets (Ibrahim et al., 2026). Nevertheless, even incremental adoption can provide significant occupational health benefits, particularly for high-risk tasks like demolition,

confined-space inspection, and structural monitoring. Case studies indicate that aligning robotics deployment with smart city initiatives and modular prefabrication strategies can overcome resource limitations, offering safer, more efficient solutions while supporting local labour market constraints (Alazmi et al., 2025). More importantly, strategic investments in vocational training, education, and public-private partnerships are critical to developing sustainable digital competencies for robotics adoption.

The global impacts on occupational safety standards are profound. While robotics reduces exposure to traditional construction hazards, it also introduces novel risk profiles that require careful management (Earnest et al., 2026). International standards, including International Standard Organization (ISO) frameworks, are beginning to address industrial robotics safety, but construction-specific guidance lags due to project variability. Bridging this gap will require globally harmonized occupational safety guidelines integrating hazard analysis, prevention-through-design principles, and human-centred risk assessment. Finally, collaboration among regulators, industry stakeholders, and researchers will be essential to ensure that robotics enhances worker safety without introducing unintended vulnerabilities.

3.5. Implications for Occupational Health and Safety

The integration of robotic technologies into hazardous construction tasks presents substantial implications for occupational health and safety (OHS), particularly in relation to risk reduction and accident prevention. Autonomous mobile robots, robotic demolition systems, and inspection drones increasingly assume high-risk operations associated with falls, struck-by incidents, confined spaces, and toxic exposures, thereby limiting direct human exposure to hazardous environments. Industry evidence indicates that robotic deployment can reduce repetitive hazardous work by up to 72% and eliminate certain high-risk exposure scenarios altogether (Emani, 2026). In addition, AI-enabled robotic systems equipped with advanced perception and adaptive motion planning dynamically respond to changing site conditions, mitigating collision risks and unsafe configurations (Shah & Mishra, 2024). These capabilities reinforce prevention-through-design principles and strengthen the hierarchy-of-controls framework central to contemporary OHS practice.

In addition to accident mitigation, robotics contributes to improved ergonomic outcomes by addressing the high prevalence of musculoskeletal disorders (MSDs) in construction. Wearable exoskeletons and collaborative robotic platforms redistribute biomechanical loads, reduce repetitive strain, and promote safer working postures, thereby decreasing cumulative fatigue and physical stress (Niehaus et al.,

2025). Such applications align with ergonomic role-allocation models, wherein robots assume physically demanding tasks while workers engage in supervisory or lower-risk functions (Merlo et al., 2024). However, ergonomic benefits depend on appropriate system calibration, anthropometric alignment, and task compatibility; poorly configured systems may introduce new forms of discomfort or strain. Effective integration therefore necessitates rigorous ergonomic assessment and adaptive design strategies to ensure sustained reductions in MSD incidence.

Notwithstanding these physical safety gains, robotic integration introduces psychological, cognitive, and systemic risks that require careful governance. Human-robot collaboration (HRC) environments can heighten mental workload, vigilance demands, and stress levels, with empirical studies reporting increased emotional strain during cobot-assisted construction tasks (Wang, 2025). Broader safety reviews also identify cognitive distraction, trust miscalibration, and reduced situational awareness as emerging psychosocial risk factors in HRC settings (Lin et al., 2025).

Furthermore, mechanical malfunctions, software failures, cybersecurity vulnerabilities, and the absence of construction-specific collaborative safety standards present additional hazards (Earnest et al., 2026; Liu et al., 2025; Urrea & Kern, 2025). These evolving risk landscapes underscore the necessity for systemic, human-centred OHS frameworks that incorporate tailored risk assessment, regulatory development, and standardisation to ensure that robotic adoption enhances, rather than compromises worker health and safety outcomes. Table 1 presents a concise synthesis of the relationships among major construction hazards, corresponding robotic applications, and their implications for occupational health and safety.

4. Discussion

Robotics adoption in developed construction markets, including the United States, Europe, Japan, South Korea, and China has accelerated over the past decade, propelled by labour shortages, productivity imperatives, and stringent safety expectations. Recent bibliometric evidence indicates a marked expansion in robotics research aligned with Construction 4.0 paradigms, emphasizing autonomous navigation, sensor integration, and human-robot collaboration (Xu et al., 2025). The review shows that autonomous earthmoving systems, inspection drones, prefabrication robots, and exoskeleton technologies can reduce worker exposure to hazardous and repetitive tasks, particularly in trenching, grading, and heavy lifting operations (Hilmi et al., 2024; Earnest et al., 2026). Nevertheless, adoption remains uneven, as high capital costs, technical uncertainty, and regulatory complexity continue to constrain small and medium-sized

Table 1: Summary mapping of construction hazards, robotic applications, and OHS implications

Major Construction Hazard	Robotic Applications	Key OHS Implications	Supporting Literature
Falls and work at height	UAVs, wall-climbing robots, and aerial manipulators	Reduce worker exposure to scaffolds, roofs, and elevated structures; require reliable navigation and fail-safe controls	Urrea and Kern (2025); Sahoo et al. (2025)
Demolition, excavation, and mobile-equipment hazards	Remote-controlled demolition robots and autonomous heavy equipment	Limit exposure to structural collapse, debris, unstable ground, and equipment collisions; introduce risks from system or sensor failure	Liu et al. (2024); Liu and Kim (2025)
Heavy lifting and repetitive work	AGVs, robotic lifting systems, cobots, and exoskeletons	Reduce musculoskeletal strain, fatigue, and struck-by risks; poor calibration may create new ergonomic hazards	Niehaus et al. (2025); Merlo et al. (2024)
Confined, toxic, and contaminated environments	Tethered crawlers, vine robots, ATEX-certified systems, and sensor-equipped robots	Minimise exposure to asphyxiation, poisoning, entrapment, and hazardous substances; depend on accurate sensing and communication	Qu (2026); Naik et al. (2025)
Inspection, monitoring, and emergency response	UAVs, LiDAR-equipped mobile robots, and teleoperated reconnaissance systems	Improve hazard detection, situational awareness, and emergency assessment; require human oversight, cybersecurity, and clear accountability	Halder and Afsari (2023); Earnest et al. (2026)

enterprises (Ting & Kong, 2025). In developing and emerging economies, robotics integration is moderated by structural constraints such as limited capital access, inadequate digital infrastructure, and workforce skill gaps (Ibrahim et al., 2026). Despite these barriers, robotics presents substantial occupational health benefits in high-risk activities including demolition, confined-space inspection, and structural monitoring. Evidence from policy-aligned Construction 4.0 initiatives demonstrates that integration can be catalysed when robotics deployment is embedded within broader smart city and infrastructure modernization strategies (Alazmi et al., 2025). Additionally, modular automation and off-site prefabrication offer context-sensitive entry points, particularly where controlled production environments mitigate site-level uncertainties.

Globally, the expansion of construction robotics carries significant implications for occupational safety governance. While automation reduces exposure to traditional hazards, it simultaneously introduces new risk profiles requiring adaptive regulatory responses (Earnest et al., 2026). Although, organizations such as the International Standard Organization (ISO) have advanced robotics safety standards in industrial domains, construction-specific frameworks remain underdeveloped due to the sector's variability and project-based complexity. There is therefore a pressing need for harmonized international guidelines that integrate prevention-through-design principles, job hazard analysis, and human-centred risk assessment to ensure that robotics adoption enhances, rather than

compromises, worker safety across diverse economic contexts.

5. Recommendation for Policy, Industry, and Practice

The safe integration of robotic technologies into hazardous construction tasks requires an adaptive and forward-looking regulatory architecture. Policymakers should embed robotics within existing occupational health and safety legislation while addressing emergent risks associated with human-robot interaction, algorithmic governance, cybersecurity, and liability allocation. Harmonized international standards, performance-based regulatory instruments, and safety-by-design procurement frameworks are essential to ensure certification integrity, risk assessment rigour, and data governance compliance. Regulatory coherence, coupled with incentive-driven public procurement, can accelerate responsible diffusion while safeguarding worker welfare.

At the industry and organizational levels, regulatory principles must be operationalized through standardized safety protocols, continuous risk monitoring, and clearly defined accountability structures across technology providers, contractors, and site managers. Firms should implement pre-deployment validation, digital twin simulations, and real-time safety analytics to mitigate high-risk exposures, while industry consortia should facilitate benchmarking and knowledge sharing. Concurrently, workforce transformation is imperative: training programmes must extend beyond technical operation to

encompass systems literacy, ethical awareness, and human-machine collaboration competencies. By aligning regulatory innovation, industrial governance, and safety culture transformation, stakeholders can ensure that robotics functions as a protective augmentation mechanism that substantively advances occupational health and safety outcomes within the construction sector.

6. Conclusion

This study critically examined the role of robotic technologies in mitigating hazardous construction tasks and enhancing occupational health and safety (OHS) outcomes. The findings indicate that robotics, particularly in high-risk operations such as demolition, confined-space inspection, heavy lifting, and exposure-intensive activities substantially reduces direct worker exposure to physical, chemical, and ergonomic hazards. Evidence across applications demonstrates measurable improvements in injury prevention, exposure control, task precision, and operational reliability. Nonetheless, persistent barriers remain, including high capital costs, integration complexities, workforce skill deficits, and regulatory uncertainty. Overall, the results reposition robotics not merely as a productivity instrument but as a transformative safety

intervention capable of fundamentally redistributing risk within construction systems.

Future research should prioritize longitudinal, multisite investigations to quantify long-term occupational health impacts across diverse construction contexts, while refining risk assessment frameworks that address emergent hazards within human-robot ecosystems. By situating robotics within a prevention-through-design paradigm, this study advances OHS scholarship through an integrated lens that links technological adoption, workforce transformation, regulatory evolution, and organizational safety culture. It highlights the imperative for proactive policy development, targeted capacity building, and ethically grounded human-robot collaboration models to ensure that technological innovation strengthens, rather than compromises the foundational objectives of worker protection and sustainable construction practice.

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