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Enhancing Construction Safety and Health through IoT and Wearable Devices: A Systematic Review

Darwis Baso[1*]

[1]*Environmental Engineering Department, Universitas Muslim Indonesia, Makassar, Indonesia*
** Corresponding author: darwis.baso@umi.ac.id*

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Abstract: The construction industry faces some of the highest occupational safety and health (OSH) risks, driven by hazardous behaviors, unsafe conditions, and limited adoption of technology and training. This study employs a systematic literature review (SLR) of recent publications to evaluate the trends, benefits, and challenges of applying Internet of Things (IoT) and wearable devices in construction OSH management. The findings indicate that technologies such as smart helmets, sensor vests, and biometric wristbands enable real-time monitoring, early risk detection, and predictive safety management, reducing reliance on traditional inspection methods. Furthermore, the integration of IoT with Artificial Intelligence (AI), Big Data Analytics, Building Information Modeling (BIM), and Industry 5.0 principles enhances predictive capacity, infrastructure resilience, efficiency, and sustainability of construction projects. Despite these benefits, barriers including data privacy concerns, high implementation costs, interoperability issues, and shortages of skilled personnel remain, especially in developing countries such as Indonesia. Overall, IoT and wearable technologies demonstrate significant potential to transform OSH practices in the construction sector by improving safety, productivity, and sustainability. However, their broader adoption requires comprehensive strategies, including worker training, strong data protection policies, regulatory support, and participatory approaches to ensure effective and sustainable implementation.

Keywords: Construction industry; Internet of Things; Occupational safety and health; Project sustainability; Real-time monitoring; Wearable devices

1. Introduction

The construction industry is recognized as one of the sectors with the highest risk to occupational safety and health [1]. The persistently high accident rate in this sector of which approximately 80-90% are attributed to risky behaviors, hazardous working conditions, or inadequate equipment highlights the serious challenges in implementing effective occupational health and safety (OHS) practices [2]. The increasing number of incidents caused by construction-related hazards further underscores the urgent need for more systematic hazard analysis methods and the development of effective preventive measures [3]. Moreover, the selection and operation of construction equipment in relation to OHS remain constrained by contractors' internal factors, particularly the lack of operator training to achieve optimal productivity and the limited adoption of alternative technologies. Consequently, fossil fuel consumption continues to dominate practices in the field [4].

Recent advances in digital technologies, particularly the Internet of Things (IoT) and wearable devices, provide significant opportunities for real-time monitoring and worker protection. Devices such as smart helmets, sensor vests, and biometric wristbands can capture vital signs, worker location, stress levels, body temperature, and potential hazards [5,6]. These data enable early risk detection, proactive interventions, and predictive safety management, which ultimately enhance both productivity and efficiency. Wireless sensor networks (WSN) further support real-time monitoring, fault detection, and automated protection systems [7]. By reducing dependence on manual inspections, which are often slow, subjective, and error-prone, wearable devices play a crucial role in advancing safety innovation in construction [8].

Beyond worker protection, IoT applications also enhance structural resilience. IoT-based structural health monitoring combined with deep learning analytics, such as Long Short-Term Memory (LSTM) models, has shown high accuracy in tracking humidity, temperature, pressure, and vibration, outperforming manual inspection methods [9]. The integration of edge computing further reduces latency, increases data reliability, and enables predictive decision-making, thus strengthening infrastructure maintenance and resilience [10].

Environmental risks such as air pollution and noise are critical concerns in OHS management, where IoT-based monitoring enables automated control and risk reduction for workers and surrounding communities [11]. Wearable IoT devices that track vital signs, worker location, and interactions with heavy machinery enhance accident prevention and accelerate emergency response [12]. Integrating these data streams with predictive analytics supports early hazard detection and long-term exposure management, contributing to safer and more sustainable construction practices

A paradigm shift in worker health monitoring is evident in the use of real-time wearable devices that track heart rate, body temperature, and exposure to hazards. Continuous monitoring enables timely identification and mitigation of risks, fostering safer workplaces. Beyond individual protection, this technology strengthens organizational safety culture by providing data-driven insights for proactive decision-making and policy development. It also promotes cross-disciplinary collaboration between engineers, health professionals, and safety managers, thereby advancing innovation in OHS systems. Overall, wearable technologies hold significant potential to transform construction safety management by integrating preventive, responsive, and predictive approaches into a unified framework [13].

Despite its potential, the adoption of IoT technologies faces several barriers. Concerns over privacy, data security, and limited worker involvement in technology design hinder wider acceptance [14]. Technical challenges, such as high costs, system integration, device interoperability, and the need for trained human resources, also remain significant constraints [15]. Moreover, most existing studies focus on developed countries, while contexts in developing regions, including Indonesia and Southeast Asia, remain underexplored.

The integration of IoT with Artificial Intelligence (AI), Big Data Analytics, and Building Information Modeling (BIM) enhances efficiency, safety, and sustainability in construction projects [12]. This convergence enables real-time monitoring, predictive risk analysis, and optimized resource management throughout the project lifecycle. Furthermore, it supports sustainable practices by improving energy efficiency, reducing waste, and facilitating lifecycle assessment. Overall, such integration represents a key advancement toward smarter and more resilient construction.

Given this context, the present study aims to evaluate the trends, benefits, and challenges of IoT and wearable devices in the construction industry through a systematic literature review. It also seeks to identify research gaps related to worker participation, trust-building strategies, implementation in developing countries, and integration with intelligent technologies. The findings are expected to provide a foundation for more effective, safe, and sustainable IoT implementation strategies, ultimately improving worker safety, health, productivity, and the overall sustainability of construction projects.

2. Literature Review

2.1 Occupational Health and Safety (OHS) in the Construction Industry

Occupational Safety and Health (OSH) is a central issue in the construction industry, which is recognized as high-risk due to labor-intensive tasks, heavy equipment usage, and complex working conditions. Risk control in piling operations within construction projects remains limited and requires the implementation of technical and administrative controls, personal protective equipment (PPE), training, and technological support such as Virtual Reality (VR) and the Internet of Things (IoT) to achieve zero-accident targets [16]. The main factors hindering OSH implementation include the lack of standards and protocols, weak law enforcement, and low commitment from both contractors and workers [17].

Current OSH policies in the construction sector still emphasize administrative controls and PPE usage, which should be strengthened through worker consultation, risk assessment, training programs, and project planning that considers specific site conditions [18]. Limited OSH budgets also affect the effectiveness of safety systems, making appropriate fund allocation crucial for enhancing worker safety and project performance [19]. Corporate management efforts play a more significant role than workers in ensuring OSH, contrary to Heinrich's Domino Theory, highlighting the need for management to prioritize worker health and safety over training cost considerations.

The effectiveness of OSH training for construction workers is influenced by perceived behavioral control, attitudes, and subjective norms, suggesting that training strategies should be tailored to worker types to improve outcomes [20]. Therefore, a comprehensive and innovative approach is necessary to reduce accident rates and enhance worker well-being.

2.2 Development of the Internet of Things (IoT) in Construction

Wearable devices represent an innovative extension of IoT technology for worker safety. Tools such as smart helmets, sensor-equipped vests, and biometric wristbands are capable of recording vital worker data, including heart rate, body temperature, and fatigue levels [6,15]. These devices have proven effective in reducing reliance on manual inspections and enabling proactive measures before risks escalate into accidents [8]. Wearable devices have the potential to transform worker health monitoring systems into a new paradigm grounded in real-time data [13].

Digitalization has become a transformative force in the construction industry, with the Internet of Things (IoT) emerging as one of its most influential innovations. IoT refers to the interconnection of devices through sensors, wireless networks, and cloud platforms that facilitate real-time data collection, communication, and analysis [7]. In construction, IoT technologies have been applied in diverse areas, including worker tracking, hazard detection, equipment monitoring, structural health assessment, and environmental quality control.

IoT adoption is not merely a technological upgrade but a necessity for the construction industry. By enabling efficient resource utilization, enhancing equipment performance, and streamlining safety management, IoT significantly improves overall project performance [21]. Similarly, emphasized the role of IoT in predictive safety management. By processing real-time data, IoT systems can identify patterns that suggest emerging hazards, thereby supporting proactive decision-making and minimizing potential losses.

The success of IoT adoption, however, depends on various factors.Technological readiness is the most influential determinant, followed by external factors such as regulatory support and client expectations, as well as organizational readiness in terms of leadership and culture. Interestingly, individual-level factors such as personal attitudes toward technology adoption were found to have a comparatively smaller effect [22]. These insights suggest that IoT adoption in construction is primarily driven by systemic and organizational conditions rather than individual user preferences.

2.3 Application of Wearable Devices for OHS

Among the most prominent applications of IoT in construction safety is the use of wearable devices equipped with sensors to monitor physiological and environmental data [6,15]. Examples include smart helmets, sensor vests, and biometric wristbands that track impacts, posture, fatigue, and vital signs. These devices enable real-time monitoring and early intervention, reducing accidents and work-related illnesses. When integrated with IoT platforms, wearable data also support risk analysis and strengthen compliance with OHS standards.

IoT and AI-based wearable devices have significant potential to enhance occupational health and safety (OHS), but their effectiveness largely depends on user training, survey design, and integration with workplace safety systems [23]. Wearable sensors support OHS management by monitoring worker exposure, although their success is influenced by work context, data quality, privacy concerns, and user acceptance [24]. Studies indicate that wearables reduce reliance on traditional manual inspections, which are often time-consuming, subjective, and prone to human error. These devices provide accurate, objective, and timely data, enabling proactive interventions before risks escalate into accidents. Technologies have the potential to transform construction health monitoring into a new paradigm based on real-time, data-driven approaches [8,13].

Furthermore, integrating wearables with connected worker platforms enhances safety, health, and productivity through real-time physical and mental monitoring, predictive analytics, and decision-support tools for timely interventions [25]. This paradigm shift not only improves safety outcomes but also contributes to greater efficiency and productivity on construction sites.

2.4 Challenges in Implementing IoT and Wearable Devices

Despite their numerous benefits, the implementation of IoT and wearable devices faces several significant challenges. One of the primary concerns is data privacy and security. Workers may be reluctant to use wearable devices due to fears of constant surveillance or misuse of personal health data [26]. Low trust in data management systems can hinder the implementation of this technology. This highlights the importance of building worker trust through transparent policies, ethical data handling, and inclusive technology design to ensure successful implementation [13].

Cost is another major barrier. The initial investment required for IoT infrastructure including sensors, communication networks, and data management systems can be substantial, particularly for small and medium sized enterprises [15]. In addition, interoperability issues between different devices and platforms complicate system integration. Without standard protocols, organizations often struggle to create a cohesive and reliable IoT ecosystem. The successful implementation of sensor technologies also demands adequate education and training for users [27].

Human resource limitations further hinder adoption. IoT implementation requires specialized skills, ranging from system installation and data analysis to cybersecurity, which are often scarce in developing countries [22]. This challenge is exacerbated by the fact that most research and practical implementations remain concentrated in developed countries. Consequently, empirical evidence regarding the adaptation of IoT and wearable devices in the socio-economic, regulatory, and cultural contexts of developing countries including Indonesia and Southeast Asia remains limited. This underscores the need for research and adoption strategies that account for local conditions, infrastructure, human resource capacity, and regulations on data privacy and security to ensure effective and sustainable implementation of IoT and wearable devices [28].

2.5 Integration of IoT with Intelligent Technologies

The integration of the Internet of Things (IoT) with smart technologies such as Artificial Intelligence (AI), Big Data Analytics, and Building Information Modeling (BIM) increasingly strengthens the role of IoT in construction management. This collaboration enhances risk prediction capabilities, operational efficiency, and project sustainability [10,12]. For example, IoT-based structural health monitoring systems combined with Long Short-Term Memory (LSTM) deep learning models demonstrate high accuracy in monitoring humidity, temperature, pressure, and vibration [9].

IoT integration not only improves worker safety but also serves as a foundation for digital transformation in the construction industry. The implementation of Industry 5.0 principles, combining IoT, Machine Learning (ML), Digital Twins, and Big Data, enables more efficient, resilient, and human-centered predictive maintenance and condition monitoring [29]. Furthermore, IoT has become a transformational force in the digital era by connecting diverse devices and systems. However, its implementation faces challenges in data integration and interoperability, including device heterogeneity, security, scalability, and the need for standards and regulations, which can be addressed through advanced technological strategies [30].

The integration of IoT with AI provides significant benefits across various sectors, including healthcare, industry, smart cities, agriculture, smart homes, and transportation, by enhancing operational efficiency, supporting data-driven decision-making, and creating interconnected intelligent environments [31]. Consequently, this integration positions IoT not merely as a tool for worker safety but as a key driver of comprehensive digital transformation in the construction industry. Overall, the convergence of IoT with intelligent technologies transforms it from a standalone tool into a fundamental component of digital transformation in construction. This transformation is expected to redefine safety management, improve project execution, and promote sustainability at the industry-wide level.

3. Research Method

3.1 Research Design

This study adopts a Systematic Literature Review (SLR) approach to comprehensively analyze the role of the Internet of Things (IoT) in enhancing Health, Safety, and Environment (HSE) performance within construction projects. The SLR method was chosen due to its ability to provide a transparent, replicable, and unbiased synthesis of existing knowledge. The review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [32], which ensure methodological rigor and minimize selection bias.

3.2 Search Strategy

The literature search was conducted between [month–year] across major academic databases including Scopus, Web of Science, ScienceDirect, IEEE Xplore, SpringerLink, and Taylor & Francis Online. Keywords were developed based on Boolean logic to capture a wide range of relevant studies, such as:

1. ("IoT" OR "Internet of Things" OR "sensor networks" OR "wearable devices") AND
2. ("construction industry" OR "construction projects" OR "built environment") AND
3. ("safety" OR "health" OR "HSE" OR "OSH" OR "occupational safety and health") AND
4. ("performance" OR "monitoring" OR "management" OR "risk reduction")

Additionally, backward and forward snowballing techniques were applied to identify supplementary studies from the reference lists of included articles.

3.3 Inclusion and Exclusion Criteria

To ensure relevance and quality, the following inclusion criteria were applied:

1. Published in peer-reviewed journals or conference proceedings between 2022 and 2025.

2. Written in English.
3. Focused on the integration or application of IoT in improving HSE outcomes within construction projects.
4. Empirical research, case studies, experimental studies, or systematic reviews that provide data-driven evidence.

The exclusion criteria were:
1. Non-academic sources (blogs, news articles, white papers).
2. Studies unrelated to construction or HSE (e.g., IoT in healthcare or agriculture).
3. Publications without accessible full text.
4. Duplicate records across databases.

3.4 Study Selection

The study selection process involved four stages following PRISMA:
1. Identification (All records were imported into a reference management software Mendeley/Zotero and duplicates were removed).
2. Screening (Titles and abstracts were screened to exclude irrelevant studies).
3. Eligibility (Full texts were reviewed based on inclusion/exclusion criteria).
4. Inclusion (Final studies that met all criteria were included in the review).

A PRISMA flow diagram is provided to illustrate the screening process and final number of included studies.

3.5 Data Extraction

A standardized data extraction form was used to collect the following information from each study:
1. Bibliographic details (author, year, journal)
2. Type of IoT technology (sensors, wearable devices, UAVs, RFID, etc.)
3. Application area (safety monitoring, hazard detection, worker health tracking, environmental monitoring, etc.)
4. Methodology employed (case study, simulation, field experiment, survey, etc.)
5. Key findings regarding HSE outcomes (reduction of accidents, improved monitoring, enhanced compliance, sustainability, etc.)
6. Integration with other technologies (BIM, AI, Big Data, Digital Twin).

3.6 Quality Assessment

To ensure reliability, each included study was subjected to a quality assessment using a modified Critical Appraisal Skills Programme (CASP) checklist. The criteria included clarity of objectives, methodological rigor, validity of findings, and relevance to HSE in construction. Only studies scoring above a defined threshold (≥ 70%) were included in the synthesis.

3.7 Data Analysis

Data were synthesized using thematic analysis to identify recurring themes, challenges, and emerging trends. Studies were grouped into thematic categories:
1. IoT applications for real-time safety monitoring.
2. Wearable and sensor-based health management.
3. IoT-enabled environmental monitoring and sustainability.
4. Integration of IoT with BIM, AI, and Big Data for predictive safety and operational optimization.

The synthesis was both descriptive (mapping trends, technologies, and contexts) and analytical (evaluating strengths, weaknesses, and gaps).

3.8 PRISMA Flow Diagram

The overall selection process is illustrated in the PRISMA Flow Diagram in Fig.1, which demonstrates the flow of information through identification, screening, eligibility, and inclusion stages.

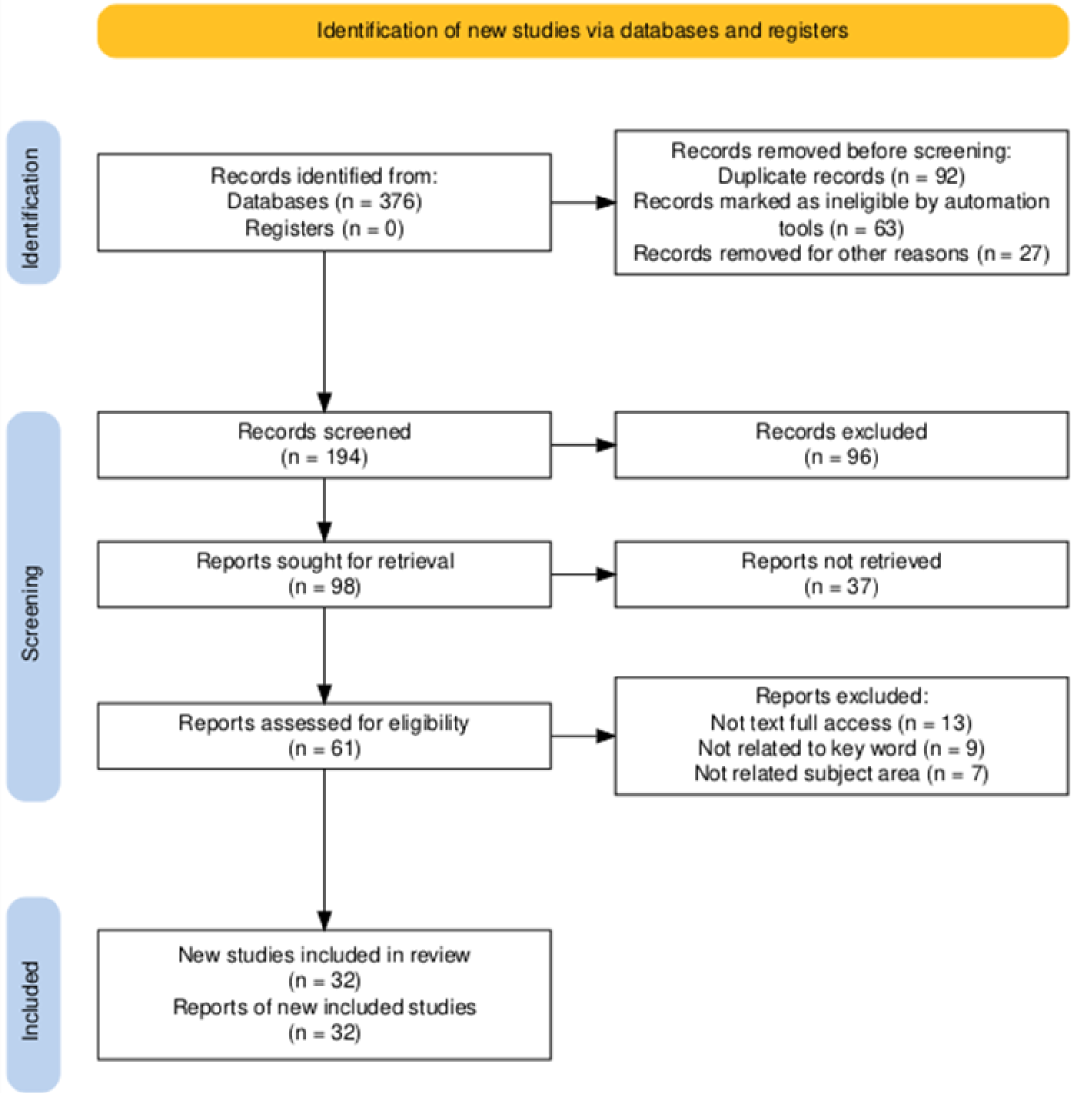

Fig. 1. Systematic Review and Meta-Analysis Flow Diagram

4. Results and Discussion

4.1. Descriptive Analysis of Study Data

A total of 32 articles that met the inclusion criteria were synthesized qualitatively. Descriptive analysis was conducted to identify publication characteristics, including year of publication, source journals, geographical context, and methodological approaches. The results regarding the most productive journals from 2020 to 2025 are presented in Fig. 2.

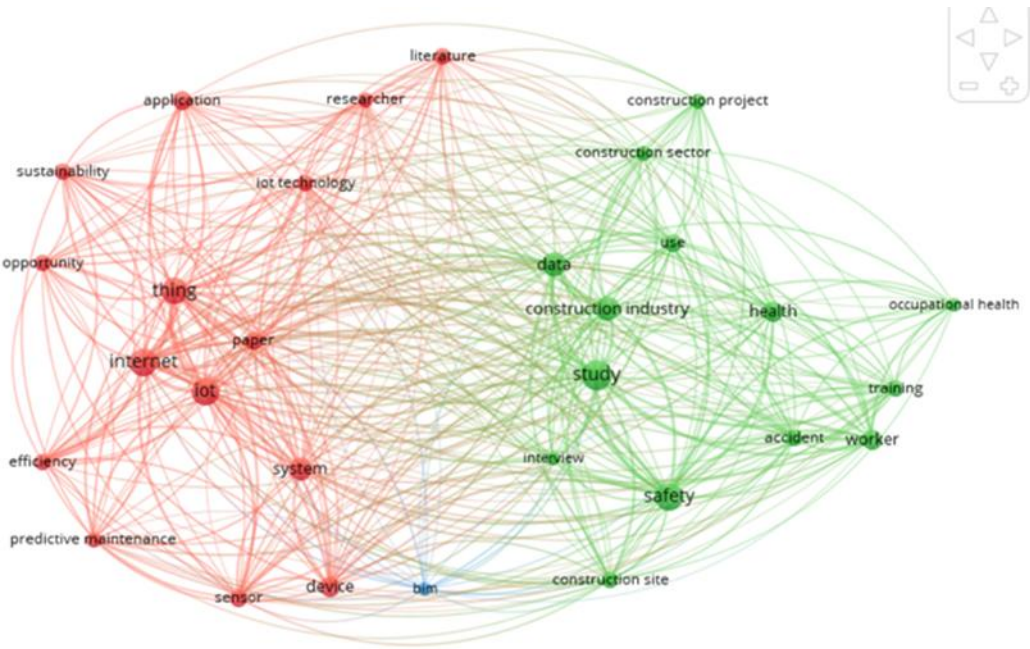

Fig. 2. Network Visualization Most Productive Journals from 2020 to 2025

The network visualization in Fig. 2, reveals three main interconnected clusters within the related body of literature. The red cluster focuses on issues concerning the Internet of Things (IoT) and wearable devices, which encompass the use of sensors, smart equipment, and real-time monitoring technologies to enhance worker safety. The green cluster emphasizes construction safety and health, representing the growing scholarly attention on accident prevention, workplace condition monitoring, and the implementation of safety management systems. Meanwhile, the blue cluster highlights technology integration, particularly the convergence of IoT with Building Information Modeling (BIM), Artificial Intelligence (AI), and big data, which presents significant opportunities for optimizing risk management and improving data-driven decision-making in construction.

Table 1. Literature Mapping by Thematic Category

Thematic Category	Literature	Main Focus
Occupational Safety & Health (OSH) in Construction	[1], [17], [18], [19], [20]	Migrant workers' safety; OSH implementation factors; impacts of hot climates; OSH project costs; training transfer effectiveness
IoT & Wearable Technologies for OSH	[2], [3], [5], [9], [13], [15], [21], [22], [23], [24], [25]	IoT for construction safety; accident trends; wearable privacy; construction monitoring; real-time wearable systems; workers' perception; technology adoption
Pollution & Environmental Monitoring with IoT	[6], [12], [28]	Air pollution and noise monitoring; smart waste management
Green & Sustainable Construction	[4], [8], [29]	Green construction evaluation; Construction 4.0 for safety; predictive maintenance (Industry 4.0–5.0)
Integration of IoT, AI, Big Data & Digital Technologies	[7], [10], [11], [14], [26], [27], [30], [31], [33]	Wireless sensor networks; IoT for food and crop monitoring; AI–IoT integration; big data applications; IoT interoperability; smart city systems

In Table 2, overall, the thematic mapping illustrates the multidimensional character of research in this field, spanning worker-level health and safety, organizational practices, environmental sustainability, and digital innovation.

4.2. Trends in IoT and Wearable Devices Implementation in Construction

The literature review indicates that the adoption of the Internet of Things (IoT) and wearable devices in the construction industry has increased significantly over the past five years. These technologies are employed to monitor worker conditions, detect hazards, manage equipment, and track structural health in real time [24,33]. Wearable devices, such as smart helmets, sensor vests, and biometric wristbands, can record workers' vital signs, location, stress levels, body temperature, and exposure to hazards, enabling early risk identification and preventive interventions [6,13,15].

Furthermore, the deployment of wireless sensor networks (WSNs) supports real-time monitoring, anomaly detection, and automated protection systems, thereby reducing reliance on slow and error-prone manual inspections [8]. IoT is also utilized to monitor air quality and noise levels, mitigating environmental risks for workers and surrounding communities [11,12]. These trends reflect a paradigm shift from reactive safety management to predictive approaches, where real-time data enables preventive measures before serious incidents occur.

4.3. Benefits of IoT and Wearable Devices Implementation

The implementation of IoT and wearable devices provides multidimensional benefits, particularly in enhancing worker safety, health, and productivity. First, wearable devices enable real-time monitoring of workers' health conditions, allowing the early detection of fatigue, heat stress, or cardiovascular issues, thereby facilitating timely preventive actions [25]. Second, this technology improves situational awareness and risk management through location tracking in hazardous zones, which can trigger automatic alerts [29].

Furthermore, the integration of wearables with intelligent systems supports continuous physical and mental monitoring of workers while enabling risk prediction for faster and more accurate interventions [25]. Ultimately, wearable devices have the potential to transform occupational health monitoring in construction, fostering innovation, strengthening cross-disciplinary collaboration, and creating a safer, healthier, and more efficient work environment [13].

4.4. Implementation Challenges

Despite their significant benefits, the adoption of IoT and wearable devices faces several major challenges. Data privacy and security issues are critical concerns; workers may be reluctant to use these devices due to fears of constant surveillance or misuse of personal data [26]. Additionally, high initial costs for IoT infrastructure, limited interoperability among devices, and insufficient training represent significant barriers, especially for small and medium-sized enterprises [15,27].

The scarcity of human resources with specialized skills such as system installation, data analysis, and cybersecurity, also limits adoption, particularly in developing countries like Indonesia and the broader Southeast Asian region [22,28]. Moreover, most research and implementations remain concentrated in developed countries, leaving limited empirical evidence on technology adaptation in local developing contexts. These challenges underscore the need for adoption strategies that consider local conditions, regulations, workforce capacity, and data security.

4.5. Integration with Intelligent Technologies

The integration of IoT with Artificial Intelligence (AI), Big Data Analytics, and Building Information Modeling (BIM) further strengthens IoT's role in construction management [10,12]. This combination enhances risk prediction, operational efficiency, and project sustainability. The application of Industry 5.0 principles merging IoT, Machine Learning, Digital Twins, and Big Data enables more efficient, resilient, and human-centric predictive maintenance [29].

The integration of the Internet of Things (IoT) with advanced technologies represents not only an emerging trend in construction safety but also delivers tangible benefits such as real-time monitoring, early risk detection, and enhanced operational efficiency [30,31]. In fig. 5, widespread adoption remains constrained by challenges, including data privacy concerns, high implementation costs, and limited skilled workforce. At this point, integration with Artificial Intelligence (AI), Big Data Analytics, Building Information Modeling (BIM), and Industry 5.0 principles becomes critical, as it bridges trends, benefits, and challenges within a comprehensive framework of digital transformation. Consequently, IoT evolves beyond a worker monitoring tool to serve as a primary driver of digital transformation in the construction industry. This shift reflects a paradigm change from reactive approaches toward predictive, data-driven, and intelligent system–based safety management, thereby strengthening safety performance, productivity, and overall project sustainability.

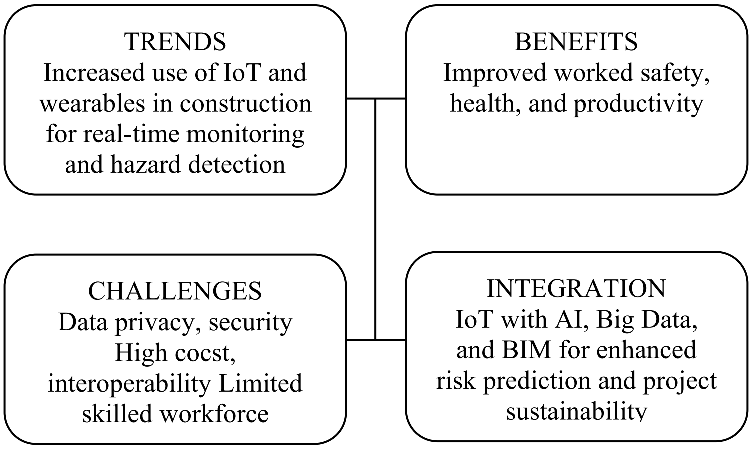

Fig. 3. Interrelationship of Trends, Benefits, Challenges, and Integration

These findings highlight that recent research is increasingly centered on the adoption of integrated digital technologies to enhance occupational health and safety in the construction sector. Nevertheless, practical applications remain limited, calling for further research to explore effectiveness, implementation challenges, and opportunities for the integration of IoT, BIM, AI, and big data in fostering safer and more sustainable construction practices.

4.6. Research Gaps and Implications

The review identifies several research gaps. First, worker involvement in the design and implementation of IoT technologies remains limited, affecting trust and technology acceptance. Second, most studies focus on developed countries, while adaptation in developing countries, particularly Indonesia, has been minimally explored. Third, integrating IoT with intelligent technologies requires further research on interoperability, standards, and regulations to ensure more effective and sustainable implementation.

These findings carry practical and policy implications. Implementing IoT and wearable devices should be accompanied by worker training strategies, data protection policies, and participatory approaches to enhance adoption rates. Governments and project developers can promote technology adoption through regulations, incentives, and cross-sector collaboration, thereby ensuring the safety, health, productivity, and sustainability of construction projects.

5. Conclusion

The construction industry faces high occupational safety and health (OSH) risks, primarily due to hazardous behaviors, unsafe conditions, and limited technology and training. Recent developments highlight the growing adoption of Internet of Things (IoT) and wearable devices, which enable real-time monitoring, early risk detection, and predictive safety management. These technologies significantly improve workplace safety, resilience, and operational efficiency while reducing reliance on traditional, error-prone inspection methods.

The integration of IoT with Artificial Intelligence (AI), Big Data Analytics, Building Information Modeling (BIM), and Industry 5.0 principles further enhances predictive capabilities and project sustainability. However, challenges such as data privacy, high infrastructure costs, interoperability issues, and limited skilled personnel remain barriers to wider adoption, particularly in developing countries like Indonesia. Therefore, comprehensive strategies including worker training, strong data protection policies, regulatory support, and participatory approaches are essential. With proper implementation, IoT and wearable technologies have the potential to transform OSH management, improve productivity, and strengthen both sustainability and efficiency in construction projects.

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