
Exoskeletons in Construction Industry: A Systematic Literature Review

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Abstract: This systematic literature review examines the potential benefits and challenges of implementing exoskeletons in the construction industry, focusing on their impact on efficiency, occupational safety, and employee acceptance. Drawing on 15 peer-reviewed journal articles published between 2016 and 2024, the review provides a comprehensive analysis of how exoskeletons can improve workplace safety and productivity. The findings reveal that exoskeletons offer significant benefits, such as reducing muscle fatigue, improving physical support, and lowering injury risks. However, challenges include limited user acceptance, high costs, and potential ergonomic drawbacks during extended use. The review highlights the importance of balancing technical advancements with employee needs and operational feasibility. These insights

provide valuable guidance for stakeholders in the construction industry seeking to implement exoskeleton technologies effectively, addressing both opportunities and concerns for sustainable adoption. This paper additionally adopts an innovation management perspective, conceptualizing exoskeleton adoption as a human-centric process innovation shaped by socio-technical alignment, worker meaning-making, and organizational implementation conditions.

Keywords: Exoskeletons; Robotic Suit; Construction; Ergonomics; Wearable Assistive Devices; Humane Machine Interaction; Blue Collar Workers; Human Strength Enhancement

1 Introduction

Construction firms face a compounded innovation management challenge: simultaneously improving productivity, reducing occupational injuries, and maintaining workforce sustainability in an industry known for conservatism and slow implementation of new production technologies (Xue et al., 2014). When comparing a typical construction site from a few years ago to one today, it becomes apparent that the fundamental processes and structures have not significantly changed (Stoyanova, 2020) and productivity improvements have lacked behind compared to other industries. Productivity is primarily influenced by typical challenges on construction such as time performance, administrative problems and costs (Alhomidan, 2013), which are further affected by among others through labor, equipment, technology and materials (Rathnayake & Middleton, 2023). This highlights that optimizing worker productivity can directly impact overall project productivity. However, productivity in the construction industry is often constrained by challenging working conditions and limited by human physical capability. Workers frequently face physically demanding tasks, such as heavy lifting, repetitive movements, and prolonged periods of strenuous labor. These factors can lead to physical strain, fatigue, and injuries, further limiting their efficiency and overall output (Abdelhamid & Everett, 2002). What was once considered as a defining characteristic and hallmark of this industry, has developed into an emerging field of activity. The construction industry has failed in keeping up with the rapidly developing digital innovations (Han et al., 2024; Lindhard et al., 2025), such as the promising technology "Exoskeletons", which are providing relief to employees in other highly physically demanding industries (Demirkesen & Tezel, 2022). Exoskeletons, wearable devices designed to support joints and muscles, appear to offer a human-centric technological response by redistributing load and reducing strain. However, adoption in construction is not simply a technical choice; it is an organizational and socio-technical change process that must be managed across fragmented project ecosystems, with workers, supervisors, safety systems,

subcontractors, and clients shaping implementation conditions (Xue et al., 2014). Moreover, exoskeleton use directly alters day-to-day routines, task execution, and perceptions of dignity, autonomy, and fairness, making employee acceptance a first-order adoption determinant rather than a secondary "implementation issue." We therefore treat exoskeleton introduction as human-centric process innovation in a low-digitalization, project-based industry where implementation success depends on culture, collaboration, champions/leadership, and diffusion mechanisms (Xue et al., 2014), and where workers' interpretations of "why" the technology is introduced shape uptake (Öberg & Verganti, 2014).

The high physical workload on the workforce in this sector in addition to aging demographics, and the growing prevalence of workplace injuries and long-term health issues, such as musculoskeletal disorders, describe the alarming situation in the sector despite technological and ergonomical advancements (Du et al., 2024; Nnaji et al., 2023; Abdelhamid & Everett, 2002). Other industries, except construction such as logistics, automotive, and the healthcare sector, are already utilizing exoskeletons, providing a wide insight into the challenges and potentials associated with their implementation (Gan et al., 2024; Hill et al., 2017; Danko & Straka, 2022).

Therefore, this paper aims to address the research question: *"What potentials and challenges arise from the use of exoskeletons in the construction industry regarding efficiency, occupational safety, and employee acceptance?"*

Exploring this question offers valuable guidance for stakeholders in the construction industry, addressing both opportunities and concerns, and aims to provide a comprehensive understanding of the implications for the sustainable adoption of exoskeletons.

2 Theoretical Background

Existing research indicates that exoskeletons can reduce physical workload, particularly in overhead or static tasks, and may contribute to injury prevention by lowering muscle activation and perceived exertion. Yet construction-specific evidence remains patchy: studies often focus on narrow tasks, short trial durations, or controlled settings, limiting transferability to dynamic, space-constrained construction sites with variable sequences of movements and environmental disturbances. The field evidence underscores this gap: Lindhard et al. (2025) report that when bricklayers tested a passive shoulder exoskeleton under real conditions, two primary limitations emerged: (1) the device was not designed around bricklaying tasks and (2) it supported primarily a single upward motion and could counteract downward motions, thereby limiting necessary movements

and reducing work pace and quality. This illustrates that "benefits" reported in laboratories can be offset by workflow disruption and reduced craft control on site.

Exoskeletons can generally be described as "wearable devices that provide external support to the body's joints and muscles" (Botti & Melloni, 2024), typically worn on the complete torso, arms, or legs and constructed from lightweight materials such as carbon, aluminum, or other composites. Their primary objective is to offer additional mechanical support, thereby reducing physical fatigue, minimizing muscle activity, loads and strains to prevent related injuries, also referred to as Musculoskeletal Disorders (MSDs) or Work-Related Musculoskeletal Disorders (WMSDs) (Zhu et al., 2021; Mahmud et al., 2022; Musso et al., 2024; De Looze et al., 2015).

Musculoskeletal disorders are a cross-industry problem often associated with long periods of absence (Badura et al., 2018; Meyer et al., 2022). In 2021, 21.5% of work incapacity days in Germany were attributable to WMSDs, with the construction industry showing the highest share at 25%, closely followed by manufacturing at 24% (Meyer et al., 2022). As the number of days of absence increases, the amount of lost production also rises (Bauer et al., 2016), which is why measures to reduce MSDs are an important labor policy tool. According to Boschman et al. (2012), typical MSD-increasing activities include "lifting and carrying", "working in an upper body position", and "working at and above head height", as well as kneeling, stooping, repetitive arm-hand movements, and working with vibrating hand tools. To minimize the occurrence of MSDs during these tasks, the introduction of exoskeletons can provide a potential solution.

A distinction can be made between active and passive exoskeletons. Passive exoskeletons operate without electrical power sources and rely on mechanical principles such as springs or dampers, offering lightness, low cost, and independence from external energy sources, though they are less beneficial for speed movements compared to active exoskeletons (Danko & Straka, 2022; Botti & Melloni, 2024; De Looze et al., 2015). Active exoskeletons rely on electrical, hydraulic, or other assistive actuators that deliver additional energy to the user's movements, enabling fast and forceful movements, but come with higher maintenance requirements and investment costs, and are therefore primarily used in sectors such as aerospace and healthcare (De Looze et al., 2015; Danko & Straka, 2022). The literature also mentions hybrid exoskeletons, combining the lightness of passive with the actuators of active systems (Danko & Straka, 2022; Botti & Melloni, 2024). Exoskeletons are further classified into lower body, upper body, or full-body devices (De Looze et al., 2015; Danko & Straka, 2022).

Exoskeletons have gained significance across industries with physically demanding tasks. In automotive, they support employees in overhead work and

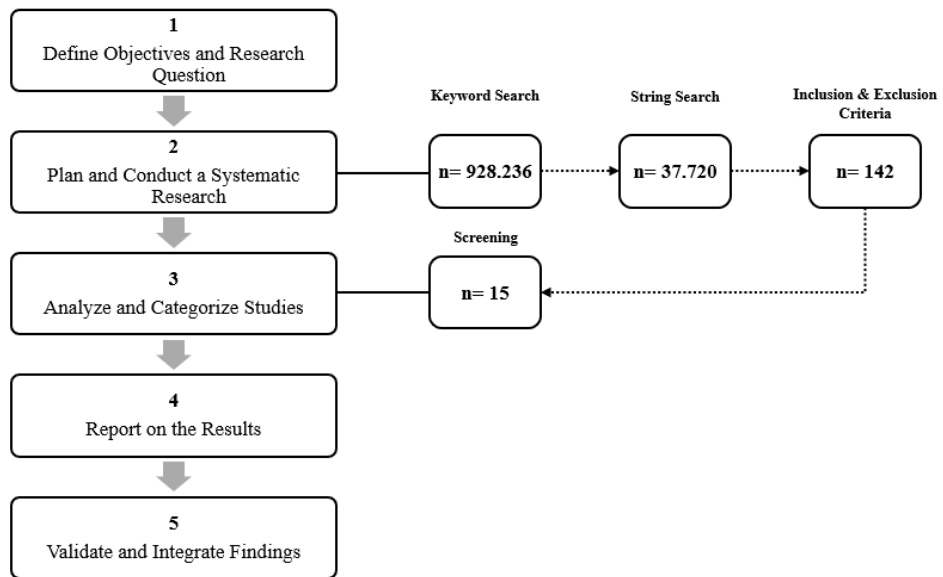
repetitive tasks, leading to improvements in ergonomic conditions and fatigue reduction (Spada et al., 2017; Iranzo et al., 2020; Gan et al., 2024). In logistics, they facilitate lifting processes, though long-term adoption is often hindered by unfamiliarity with the devices (Danko & Straka, 2022; Mitterlehner et al., 2023; Howard et al., 2020). In healthcare, exoskeletons reduce spinal strain during patient repositioning and assist patients in regaining lost motor functions in rehabilitation (Hill et al., 2017; Flor-Unda et al., 2023). Although exoskeleton application is more advanced in these industries than in construction, the literature suggests similar potentials exist for adoption in the latter.

From an innovation management perspective, Öberg and Verganti (2014) argue that organizations may succeed by redefining the purpose and interpretation of a technology: for exoskeletons in construction, meaning could shift from "speed-up/control" to "care, inclusion, and capability preservation," affecting acceptance and legitimacy. Magliocca et al. (2025) highlight a shift from technology as a tool to technology shaping daily routines, emphasizing human-centric strategies to address information asymmetry, cognitive distance, and technostress. De Spiegelaere et al. (2012) show that job content insecurity can be particularly detrimental for blue-collar employees, highly relevant because wearable technologies may be interpreted as changing job content, evaluation, or control. Coelho (2025) demonstrates that participatory, work-centered design approaches can improve operational performance and knowledge sharing during process innovation implementation. Taken together, construction exoskeleton adoption is best explained as a socio-technical innovation process, not merely a device-effect relationship.

3 Research Method

The research design for this study follows the methodology of a Systematic Literature Review (SLR) in five steps as outlined by Wieringa (2014). Each step builds upon the previous one, creating a cohesive framework for the investigation (Figure 1).

Figure 1 SLR Process adapted from Wieringa (2014)



The initial phase involves identifying the study's aim and research question: *"What potentials and challenges arise from the use of exoskeletons in the construction industry regarding efficiency, occupational safety, and employee acceptance?"* The second step entailed planning and carrying out a systematic literature search using the Web of Science (WoS) database, which enables advanced search functions through logical operators and offers filtering tools and bibliometric analyses that deliver essential insights for the review process. Specific keywords were chosen based on the PICO framework, including "exoskeletons," "construction," and "ergonomics," illustrated in Table 1. Logical operators (e.g., AND, OR) were applied to create precise string combinations. Inclusion criteria limited results to English-language publications from 2016 to 2024 addressing industrial usage only.

The original pool of 928,236 articles was reduced to 142 studies after applying exclusion criteria to filter out duplicates, non-industrial research, and inaccessible papers. The third step involved screening and selecting relevant studies through

abstract reviews and thematic relevance checks, narrowing results to 15 peer-reviewed articles directly aligned with the research question. The selection criteria focused on ensuring that the studies provided meaningful insights into efficiency, occupational safety, and employee acceptance within the context of exoskeleton use in construction. The fourth step synthesized findings using a concept matrix based on the framework of Webster & Watson (2002) (Table 7), aggregating and categorizing results into three key themes: efficiency, occupational safety, and employee acceptance. This thematic categorization allowed for a comprehensive examination of the key opportunities and challenges associated with the adoption of exoskeletons in the construction industry. The final step validated results by cross-checking the data extraction process to ensure consistency with the research objectives and practical applicability for construction industry stakeholders.

By following this structured approach, the study delivers valid and meaningful results, contributing valuable insights to the discussion on exoskeleton use in construction.

Data Sources

The search was conducted using the electronic databases Web of Science (WoS) as it is a leading platform providing access to a wide range of scientific literature and key publications across various fields of study. This database enables advanced search functions through logical operators tailored to the requirements of the systematic review presented in this research. Additionally, it offers filtering tools and bibliometric analyses that deliver essential insights to support the systematic review process.

Search and Selection Strategy

To identify relevant papers aligned with our research question, it is essential to define specific keywords that are applied in WoS using logical operators. This ensures a targeted and systematic search strategy.

Following the approach of Considine et al., this study used the PICO framework to derive relevant keywords related to our research question, considering the areas of *Population*, *Intervention*, *Comparison*, and *Outcomes* (Considine et al. (2017)). However, as this study focuses exclusively on exoskeletons and does not include comparison groups, the *Comparison* component was not taken into account.

Taking this method and our research question into consideration, the following keywords were defined: “*Exoskeletons*”, “*Robotic Suit*”, “*Construction*”, “*Ergonomics*”, “*Wearable Assistive Devices*”, “*Humane Machine Interaction*”, “*Blue Collar Workers*” and “*Human Strength Enhancement*”.

The individual search for these keywords in WoS yields the following total number of published papers.

Table 1 Keywords based on PICO Model

PICO Model	Keywords	Results in WoS
Population	<i>Construction</i>	874.016
	<i>Blue Collar Workers</i>	1.657
Intervention	<i>Exoskeletons</i>	10.477
	<i>Robotic Suit</i>	1.261
	<i>Wearable Assistive Devices</i>	977
Comparison	-	-
Outcomes	<i>Ergonomics</i>	22.685
	<i>Humane Machine Interaction</i>	18.159
	<i>Human Strength Enhancement</i>	4
TOTAL		928.236

As this pool was too large, various keyword combinations referred to as strings were conducted using logical operators to reduce results and identify relevant papers. Only papers published in English between 2016 and 2024 related to industrial usage were considered; papers not fully available or duplicated across strings were excluded. Since the number of published papers on exoskeletons in the construction industry is relatively limited, less stringent exclusion criteria were applied to ensure a broader selection. Thematic relevance was subsequently identified through manual abstract screening to determine suitability based on relevance to the construction industry context (Table 2).

Quality Assessment of Selected Studies

To ensure methodological rigor and replicability, a structured quality assessment was applied to all 15 articles prior to their inclusion in the synthesis. Each study was evaluated against four criteria: (1) clarity and explicitness of the research design and data collection method; (2) specificity to construction or a comparable physically demanding industrial context; (3) relevance of measured outcomes to at least one of the three core themes (efficiency, occupational safety, employee acceptance); and (4) transparency of results and conclusions. Studies were retained only if they satisfied a minimum of three out of four criteria, and all 15 final articles met this threshold. Publication in a peer-reviewed journal, verifiable through the Web of Science classification, served as a baseline quality indicator. This procedure aligns with established quality appraisal practices for systematic reviews (Wieringa, 2014; Considine et al., 2017). Papers that discussed exoskeletons only in passing, were purely theoretical without empirical grounding, or focused exclusively on rehabilitation or medical applications were excluded during abstract screening, which accounts for the step from 142 to 15 studies.

Table 2 Applied String Search and Selection Strategy

<i>String</i>	<i>Results without Inclusion & Exclusion Criteria</i>	<i>Results with Inclusion & Exclusion Criteria</i>	<i>Results after Industry & Abstract Screening</i>
<i>(Exoskeleton OR Robotic Suit OR Wearable Assistive Devices) AND (Blue-Collar workers)</i>	<i>11.634</i>	<i>14</i>	<i>3</i>
<i>(Exoskeleton OR Robotic Suit OR Wearable Assistive Devices) AND (Construction)</i>	<i>11.634</i>	<i>127</i>	<i>8</i>
<i>(Exoskeleton OR Robotic Suit OR Wearable Assistive Devices) AND (Human Machine Interaction OR Human Strength Enhancement)</i>	<i>14.446</i>	<i>0</i>	<i>3</i>
<i>(Construction) AND (Ergonomics) AND (Blue- Collar workers)</i>	<i>6</i>	<i>1</i>	<i>1</i>
<i>TOTAL</i>	<i>37.720</i>	<i>142</i>	<i>15</i>

4 Analysis of Papers

This section presents a detailed examination of the 15 papers analyzed, published between 2016 and 2024. The presentation of study characteristics such as countries of origin, publication years, leading authors, and research methods is essential for transparency and reproducibility of the review, and to identify patterns and research gaps crucial for future investigations.

Countries and Publication Years

In order to assess the research focus of the exoskeleton papers analyzed, the countries in which each study was conducted and the corresponding publication years were examined. As shown in Table 3, a total of 10 countries contributed to the research, reflecting geographical diversity but a somewhat limited scope. The USA leads with 5 publications spread across 2016, 2019, 2020, 2021, and 2023, highlighting its continued and active role in driving research in this area. Countries such as Germany, Canada, Italy, Switzerland, Bulgaria, the UK, the Netherlands, and China have contributed one study each, showing a more sporadic commitment to the topic. Interestingly, Denmark stands out with 2 publications in 2021 and 2023, indicating a growing research interest in recent years. The total number of studies is 15, with a significant increase in publication activity in the years after

2020. This upward trend may reflect the growing interest and investment in exoskeleton technology, particularly in response to advances in robotics, healthcare, and industrial applications.

Table 3 Countries and Publication years

Countries	2016	2019	2020	2021	2022	2023	2024	Total
Germany							1	1
Canada							1	1
Italy							1	1
Denmark						1	1	2
USA		1		1	1	1	1	5
Switzerland				1				1
Bulgaria			1					1
England		1						1
Netherlands	1							1
China							1	1
TOTAL								15

Journals

A total of 15 papers were published across 13 different journals, highlighting a diverse dissemination of research within the field. Notably, the journal "Applied Sciences-Basel" stands out with the highest number of publications (3 papers), demonstrating its role as a significant platform for exoskeleton research. This is followed by "Automation in Construction" with 2 papers, indicating the importance of exoskeleton technology within the construction sector. The remaining journals, including "Applied Ergonomics", "Ergonomics", "Safety Science", and "IEEE Transactions on Robotics", each contributed 1 paper. These journals span fields such as ergonomics, robotics, construction, safety, and engineering, reflecting the interdisciplinary nature of exoskeleton research. It is evident that research on exoskeletons is not confined to a single discipline but spans multiple scientific areas, and the variety of journals suggests a growing interest in the topic across diverse research communities.

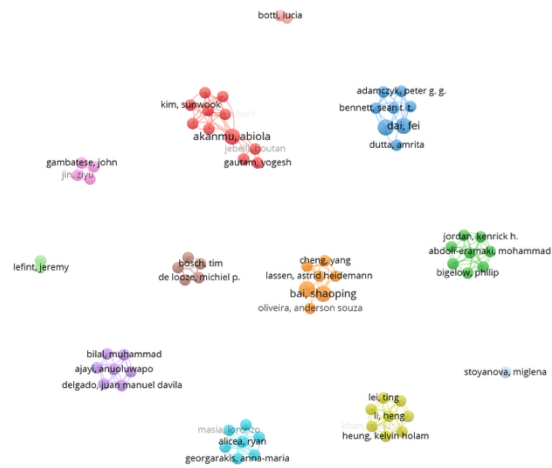
Table 4 Journals

<i>Journals</i>	<i>No. of Papers</i>
APPLIED ERGONOMICS	1
APPLIED SCIENCES-BASEL	3
AUTOMATION IN CONSTRUCTION	2
CONSTRUCTION INNOVATION-ENGLAND	1
ERGONOMICS	1
IEEE TRANSACTIONS ON ROBOTICS	1
IIEE TRANSACTIONS ON OCCUPATIONAL ERGONOMICS & HUMAN FACTORS	1
JOURNAL OF BUILDING ENGINEERING	1
JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT	1
SAFETY SCIENCE	1
SENSORS	1
TEM JOURNAL-TECHNOLOGY EDUCATION MANAGEMENT INFORMATICS	1
TOTAL	15

Co-Authorships

The analysis of the co-author network provides important insights into research on exoskeletons in the construction industry. The field is characterized by several closely networked research groups that work together intensively. Prominent clusters around "Akanmu, Abiola" and "Kim, Sunwook", as well as "Bai, Shaoping" and "Adameczyk, Peter G. G.", are examples of well-established research teams advancing the topic with different focal points. These groups form the backbone of the current literature and contribute significantly to the development of the research field. Independent researchers such as "Lefint, Jeremy" and "Botti, Lucia" complement the field with their individual perspectives and specific approaches. A notable feature of the network is the limited connections between clusters, indicating little cross-team collaboration to date. This holds potential for greater networking and knowledge integration, as stronger bridges between clusters could help bring fragmented knowledge together and further advance the understanding of exoskeleton applications in construction.

Figure 2 CO-Authorships: VOSviewer



Data Collection

As shown in Table 5, literature reviews were the most frequently employed data collection method, appearing in 5 studies. Experiments were the second most utilized method, used in 4 studies, highlighting their importance in gathering empirical evidence. Interviews, including semi-structured interviews, were employed in a total of 4 studies (2 each), demonstrating the value of qualitative data collection. Questionnaires and electronic searches were each used in 1 study. Two of the 15 papers used a combination of experiments and interviews. Overall, the findings indicate a diverse range of data collection methods, with a notable emphasis on systematic literature reviews and experimental approaches.

Table 5 Data Collection Method

<i>S/ N</i>	<i>Data Collection Method</i>	<i>Count</i>
1	Electronic Search	1
2	Experiment	4
3	Interviews	2
4	Literature Review	5
5	Qualitative Study	2
6	Questionnaire	1
7	Semi-structured Interviews	2

Research Areas

As shown in Table 6, Engineering is the most prominent research area, comprising 10 of the 15 articles. Chemistry follows with 4 articles, while Building Technology, Construction, Materials Science, and Physics each account for 3. Smaller contributions are seen in Computer Science, Ergonomics, Industrial, Management Science, Operations Research, and Robotics, with 1 article each. Psychology contributes 2 articles, reflecting a minor but notable focus on behavioral aspects. In total, 36 research areas are mentioned among the 15 articles, highlighting a strong emphasis on engineering and technical disciplines, with limited attention to niche and behavioral fields.

Table 6 Research areas

Research Area	Number of mentions in the articles
<i>Applied</i>	1
<i>Building Technology</i>	3
<i>Chemistry</i>	4
<i>Computer Science</i>	1
<i>Construction</i>	3
<i>Engineering</i>	10
<i>Ergonomics</i>	1
<i>Industrial</i>	1
<i>Instruments & Instrumentation</i>	1
<i>Management Science</i>	1
<i>Materials Science</i>	3
<i>Operations Research</i>	1
<i>Physics</i>	3
<i>Psychology</i>	2
<i>Robotics</i>	1
TOTAL	36

5 Findings

Exoskeletons offer promising potential, particularly in improving productivity, reducing physical strain and the risk of injury. Nevertheless, there are concerns about occupational safety, integration and the perception of long-term applicability.

With the help of a Concept Matrix based on Webster & Watson (2002), the identified potentials and challenges related to the use of exoskeletons in the construction industry can be analyzed in relation to the 15 papers reviewed. In the concept matrix below (Table 7), three significant themes and nine concepts concerning the potentials and challenges of exoskeletons in the construction industry were found: *Efficiency - Task Performance, Fatigue Reduction, Energy Consumption; Occupational Safety - Injury Prevention, Task Safety, Integration with PPE (Personal protective equipment); Employee Acceptance - Comfort, Trust and Value; Type of exoskeletons - Active, Passive.*

The “x” symbol indicates in which paper(s) the mentioned element can be found.

Table 7 Concept Matrix

<i>Paper</i>	<i>Efficiency</i>		<i>Occupational Safety</i>				<i>Employee Acceptance</i>			<i>Type of exoskeletons</i>	
	<i>Task Performance</i>	<i>Fatigue Reduction</i>	<i>Energy Consumption</i>	<i>Injury Prevention</i>	<i>Task Safety</i>	<i>Integration with PPE</i>	<i>Comfort</i>	<i>Trust</i>	<i>Value</i>	<i>Active</i>	<i>Passive</i>
<i>(Du et al., 2024)</i>	X	X		X	X	X	X		X		X
<i>(Lefint and Moniz, 2024)</i>	X	X		X	X	X	X		X	X	X
<i>(Botti and Melloni, 2024)</i>	X	X	X	X	X	X	X		X	X	X
<i>(Lindhard et al., 2025)</i>	X	X	X	X	X	X	X		X	X	X
<i>(Nnaji et al., 2023)</i>	X	X		X	X	X	X		X	X	X
<i>(Mahmud et al., 2022)</i>	X	X		X	X		X	X	X	X	X
<i>(Xiloyannis et al., 2021)</i>	X	X	X	X	X	X	X		X		X
<i>(Zhu et al., 2021).</i>	X	X		X	X			X		X	X
<i>(Stoyanova, 2020)</i>				X	X						
<i>(Delgado et al., 2019)</i>	X			X	X	X		X		X	X
<i>(Kim et al., 2019)</i>	X			X	X	X		X		X	X
<i>(de Looze et al., 2015)</i>	X	X		X	X					X	X
<i>(Musso et al., 2024)</i>		X		X	X						X
<i>(Ojha et al., 2024)</i>		X	X	X	X					X	X
<i>(Lei et al. 2024)</i>		X	X	X	X		X			X	
Total	11	12	5	15	15	8	8	4	7	11	13

Efficiency

Exoskeletons can reduce fatigue in the construction industry by reducing physical strain and increasing productivity. Du et al. (2024) emphasize that they support work performance, especially in repetitive tasks, while Lefint & Moniz (2024) emphasize the long-term ergonomic benefits. However, success depends heavily on adaptation to specific tasks, as poorly adapted exoskeletons can restrict

freedom of movement or put strain on other areas of the body. Users also report discomfort during prolonged use. Targeted further development is necessary to exploit the full potential.

Exoskeletons also enhance task performance by increasing stability and reducing musculoskeletal strain. Delgado et al. (2019) reported improved efficiency in repetitive tasks, such as drywall installation. However, challenges remain, as Lefint & Moniz (2024) highlighted limited mobility and difficulty in adapting exoskeletons to diverse construction tasks, particularly those involving tight spaces or dynamic movements. Lindhard et al. (2025) noted that exoskeletons could obstruct productivity due to design flaws, such as restricted hip rotation.

Regarding energy consumption, active exoskeletons demonstrate potential for reducing metabolic cost and fatigue, but their effectiveness is limited by current technology and design constraints. Botti & Melloni (2024) observed reduced metabolic consumption with active exoskeletons, suggesting potential for lessening fatigue during extended work periods. Xiloyannis et al. (2021) also emphasized the ability of soft robotic suits to reduce the metabolic cost of movement, contributing to improved biomechanical efficiency. However, many devices rely on external power sources, which limits their efficiency and portability in dynamic construction environments.

Occupational Safety

Exoskeletons offer significant potential for improving occupational safety in the construction industry by reducing the risk of injuries, enhancing task safety, and potentially integrating with personal protective equipment (PPE).

Studies consistently highlight their role in mitigating MSDs by reducing strain on critical body parts like the back and shoulders. Nnaji et al. (2023) emphasized the role of exoskeletons in redistributing physical load and providing ergonomic support, thereby minimizing MSD risks. Despite these benefits, improper use or mechanical failures can introduce new hazards, such as joint hyperextension or falls due to shifted center of gravity (de Looze et al., 2015; Kim et al., 2019).

Improved task safety is another key benefit of exoskeletons. By reducing physical strain, these devices enhance workers' perceptions of safety, as noted by Du et al. (2024). However, challenges remain in ensuring their safe integration into complex construction environments. Nnaji et al. (2023) also pointed out environmental factors like dust, heat, or slippery surfaces that can increase risks when using exoskeletons on construction sites.

Effective integration of exoskeletons with existing PPE remains a crucial challenge for ensuring worker safety. Delgado et al. (2019) emphasized the need

for compatibility with safety harnesses and helmets to avoid operational inefficiencies. On the other hand, Lefint & Moniz (2024) reported that exoskeletons often fail to accommodate layered safety gear, limiting their adoption in complex environments.

Employee Acceptance

Employee acceptance of exoskeletons in the construction industry is influenced by factors like comfort, trust, and perceived value, with findings revealing both potential benefits and persistent challenges.

Comfort significantly influences workers' acceptance of exoskeletons. Xiloyannis et al. (2021) highlighted the advantages of lightweight and flexible designs in enhancing wearability. However, discomfort from rigid materials or poor fit can lead to rejection by users (Botti & Melloni, 2024; Mahmud et al., 2022). Proper customization and ergonomic adjustments are critical to addressing this challenge.

Building trust in exoskeleton technology is essential for widespread adoption. Construction workers expressed confidence in devices that demonstrated reliability and reduced physical strain (Mahmud et al., 2022). Nevertheless, cultural barriers and fears of equipment failure undermine trust, particularly among older or less technologically inclined workers (Nnaji et al., 2023).

Construction workers generally perceive exoskeletons as valuable for specific tasks, such as overhead installations or heavy lifting. Du et al. (2024) found that workers appreciated the reduced effort required for these activities. However, perceptions of limited utility for general tasks and high initial costs pose significant barriers to acceptance (Kim et al., 2019; Lei et al., 2024). To increase employee acceptance of exoskeletons, it is essential to select the appropriate exoskeleton tailored to the specific tasks within the construction sector.

The studies analyzed in this paper consistently note that both active and passive exoskeletons have potential benefits in the construction industry. For instance, active exoskeletons may be more effective for dynamic tasks, such as walking, lifting, and carrying, because they can provide assistance throughout the entire range of motion. Conversely, passive exoskeletons may be more effective for static tasks, such as holding a tool or maintaining a posture (Ojha et al., 2024; Kim et al., 2019).

Active exoskeletons tend to be heavier and more complex than passive exoskeletons and they consistently require a power source, which can limit their portability. Passive exoskeletons are generally lighter, simpler, and less expensive than active exoskeletons. They are also more portable because they do not require a power source (Lei et al. 2024).

6. Discussion & Conclusion

Synthesizing the 15-study evidence base through innovation management theory suggests that exoskeleton adoption in construction is best modeled as human-centric process innovation under project fragmentation (Xue et al., 2014). Efficiency and safety outcomes are not intrinsic device properties; they are emergent outcomes of socio-technical alignment: task variability, site constraints, PPE systems, supervisory routines, and worker meaning-making. This aligns with Xue et al. (2014), who emphasize that construction innovation outcomes depend on antecedents such as collaboration and culture and on effective implementation and diffusion processes. It also aligns with Öberg and Verganti's (2014) "innovation of meaning," implying that successful adoption depends on crafting a convincing "why" for wearable assistance (e.g., inclusion and sustainability of work) rather than merely proving biomechanical effects.

This review is distinguished from prior work by its explicit innovation management framing. Existing reviews focus primarily on biomechanical and ergonomic outcomes: De Looze et al. (2015) surveyed ergonomic effects across manufacturing sectors, and Zhu et al. (2021) examined exoskeletons for manual material handling without theorizing adoption dynamics. Botti and Melloni (2024) broaden the scope to occupational acceptance but do not situate findings within innovation management theory or address implementation conditions in project-based industries. None of the existing reviews integrates organizational implementation conditions, worker meaning-making, socio-technical alignment, or diffusion mechanisms as analytical categories. The present review fills this gap. Magliocca et al. (2025) warn that technology can create technostress; thus, implementation should include knowledge management and human-centric governance to reduce cognitive distance. De Spiegelaere et al. (2012) suggest implementation strategies should increase autonomy and learning opportunities while avoiding signals that increase job content insecurity for blue-collar workers. Integrating the reviewed evidence and theoretical perspectives, this study proposes a three-layer conceptual framework. The first layer, Device-Task Fit, captures whether the exoskeleton type (active vs. passive) is matched to the biomechanical demands of the specific construction task; poor fit directly undermines efficiency and triggers rejection regardless of technical quality (Lindhard et al., 2025; Du et al., 2024). The second layer, Socio-Technical Alignment, captures organizational and site-level conditions mediating whether device-task fit translates into actual performance improvements: PPE compatibility, supervisory support, site logistics, workforce diversity, and safety culture (Nnaji et al., 2023; Mahmud et al., 2022; Xue et al., 2014). The third layer, Worker Meaning and Legitimacy, captures whether workers collectively accept the "why" of exoskeleton introduction as care, capability preservation, or

inclusion, rather than perceiving it as surveillance, deskilling, or speed-up pressure (Öberg & Verganti, 2014; De Spiegelaere et al., 2012). The three layers are interdependent: technical fit is necessary but insufficient without socio-technical alignment, and both are undermined without legitimate meaning. This framework provides a diagnostic and design tool for innovation managers planning exoskeleton implementation in construction.

For innovation managers, the evidence suggests a shift from "device rollout" to portfolio experimentation and co-design: select task niches with high fit (e.g., sustained overhead work), run field pilots measuring workflow disruption and PPE compatibility, actively manage meaning and legitimacy (Öberg & Verganti, 2014), and build learning infrastructures to prevent technostress (Magliocca et al., 2025). Future research should test diffusion mechanisms across projects, compare lab vs. field performance systematically, and evaluate whether participatory ergonomics approaches improve adoption in construction (Coelho, 2025; Lindhard et al., 2025).

Limitations

Many studies take place under laboratory conditions, limiting transferability to the complex and dynamic conditions of construction sites. The focus is often on specific tasks without covering the variety of construction activities, and methodological differences make it difficult to develop standardized recommendations. Important aspects such as cost-benefit analyses, regulatory requirements, and the inclusion of diverse worker groups are underrepresented. Practical long-term studies, interdisciplinary approaches, and realistic field tests are needed to capture the actual benefits and challenges of exoskeletons in construction.

Practical Implications

Exoskeletons have the potential to lastingly improve working conditions in construction by minimizing the strain of strenuous physical labor, repetitive motions, and inconvenient postures, thereby reducing absenteeism and protecting workers' long-term health. In practical terms, they are employed for tasks such as lifting, drilling, welding, and overhead work. Based on the findings, passive exoskeletons are, due to their lighter weight, absence of a required power source, and effectiveness for static tasks, easier to apply in construction. Understanding which type aligns with users' comfort levels and work requirements is crucial for successful deployment. In conclusion, exoskeletons hold considerable potential that could be fully exploited through further research and hands-on testing in real working environments.

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