frontiers | Frontiers in Built Environment

TYPE Review
PUBLISHED 03 May 2024
DOI 10.3389/fbuil.2024.1414366

OPEN ACCESS

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RECEIVED 08 April 2024
ACCEPTED 23 April 2024
PUBLISHED 03 May 2024

CITATION
Baghdadi A (2024), Navigating occupational safety and health challenges in sustainable infrastructure projects: a comprehensive review.
Front. Built Environ. 10:1414366.
doi: 10.3389/fbuil.2024.1414366

Navigating occupational safety and health challenges in sustainable infrastructure projects: a comprehensive review

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Ensuring occupational safety and health (OSH) is paramount in infrastructure projects due to their inherently high-risk nature and the increased likelihood of accidents. Despite its importance, numerous obstacles impede the successful adoption of OSH measures in these settings. Addressing these challenges is key to not only implementing OSH protocols effectively but also to improving working conditions and managing other operational facets like quality and environmental concerns, ultimately resulting in better infrastructure developments. Adopting proactive OSH strategies is crucial for preventing significant accidents and fostering a safety culture within infrastructure projects. This review focuses on identifying the primary obstacles and barriers to effective OSH in infrastructure projects, laying the groundwork for improving safety performance in the sector. It highlights organizational and legislative issues as the foremost challenges due to their direct impact on safety culture, resource distribution, compliance, and accountability. Although factors related to environmental and safety practices are deemed less critical, they are nonetheless vital for comprehensive risk management and the promotion of a safe working environment. Tackling these issues is imperative for cultivating a strong safety culture and safeguarding the health of workers on infrastructure projects. It is also essential to acknowledge the distinct OSH challenges presented by different construction scenarios to devise customized safety measures and effectively reduce risks. This review emphasizes the necessity of recognizing the unique aspects of each construction project, addressing specific dangers, and meeting regulatory demands to achieve thorough safety management.

KEYWORDS

occupational health and safety, Osh, infrastructure projects, challenges, construction projects

1 Introduction

Infrastructure development is as a pivotal driver of national progress. Fostering economic growth across local, regional, and national landscapes (Willar et al., 2020). As emerging economies increasingly prioritise projects such as road construction, sewage facilities, water desalination and power plants, emphasising occupational safety and health (OSH) requirements has become a pressing need (Abu Aisheh et al., 2021). Unlike other construction projects, infrastructure projects uniquely interact with the public during construction, maintenance, and deconstruction, necessitating specialised attention to OSH considerations (Abu Aisheh et al., 2021). Workers engaged in infrastructure projects

encounter various threats within and outside the workplace, including falls, electrical hazards, and struck-by incidents. These challenges are different from those encountered in other construction forms (Gastauer et al., 2022). Factors such as steep terrain, toxic elements, water scarcity, high temperatures, and radiation present unique challenges in infrastructure projects, particularly those involving steep slopes after mining and construction (Gastauer et al., 2022).

Stakeholder analysis plays a critical role in infrastructure projects, enabling effective local strategies and sustainable development. Early public involvement is essential for project success (Wojewnik-Filipkowska et al., 2021). Unlike other construction projects, infrastructure projects, such as bridges, highways, airports, dams, and tunnels, typically involve larger scales and complexities. Consequently, they pose greater hazards and risks, requiring stringent safety measures (Balkhyour et al., 2019). Crucially, infrastructure projects often entail working in close proximity to public spaces and vital services, which means that public safety needs to be prioritised alongside worker safety. Aspects such as traffic management, utility protection and public communication require specialised attention (Balkhyour et al., 2019). Moreover, environmental challenges, including exposure to extreme weather conditions, high radiation levels and toxic elements, pose additional risks to workers' health and safety (Alaloul et al., 2020).

In regions marked by conflict or economic development challenges, such as Palestine, infrastructure projects face resource limitations, political instability and external controls that affect safety measures. For instance, the scarcity of financial resources and the limited availability of construction materials due to external controls such as the Israeli occupation impact infrastructure projects in Palestine Balkhyour et al., 2019; Eppenberger and Haupt, 2003). Furthermore, infrastructure construction sites are often perceived as unstructured and risky environments, characterised by challenges such as insufficient facilities, congested workspaces, and exposure to adverse weather conditions. These conditions diverge from those encountered in other construction projects, influencing safety practices and procedures (Eppenberger and Haupt, 2003).

Compliance with safety regulations and standards may vary between infrastructure projects and other forms of construction due to the unique risks and challenges associated with each type of project. Infrastructure projects may have specific regulatory requirements related to public safety, environmental protection, and project complexity (Campbell, 2008). Thus, customised approaches are essential to effectively address OSH challenges in infrastructure projects. Moreover, in regions such as Palestine, infrastructure projects encounter specific challenges such as financial resource scarcity and limited construction material availability due to external controls, necessitating long-term planning amidst ongoing obstacles (Meswani, 2008; Abu Aisheh et al., 2021). Road construction projects often lead to traffic diversions and detours, causing congestion and accidents, while underground utility issues such as gas lines and water pipes pose additional risks (Abu Aisheh et al., 2021).

In comparison, other construction forms may face different OSH challenges, such as poor safety awareness among leaders, inadequate worker training and ineffective safety regulation implementation (Kheni and Afatsawu, 2022; Kunodzia et al., 2024). Overall, infrastructure projects, encompassing structures such as bridges, highways, airports, dams, and tunnels, demand rigorous safety measures to ensure worker wellbeing and project success (Sánchez et al., 2017). Effective risk management strategies are vital for identifying uncertainties early and implementing effective mitigation strategies (Ravschan and Zikriyoev, 2019).

OSH has emerged as a significant concern in human resource management due to the prevalence of construction accidents and their implications for workers, companies, and societies (Sánchez, Peláez, and Alís, 2017Addressing OSH concerns is crucial for preserving worker health, saving costs and adding value to infrastructure projects (Gonzalez-Delgado et al., 2015). Achieving zero workplace accidents is a challenging but essential goal, with OSH contributing to production efficiency in the construction industry (Chellappa et al., 2021). Overcoming challenges in OSH management, such as budget limitations and technical expertise shortages, is crucial for effective implementation (Enshassi, 2003).

While previous research has primarily focused on construction projects, this study concentrates on infrastructure projects, aiming to identify serious OSH adoption challenges affecting project performance. Section 1 introduces OSH concerns in the infrastructure sector, emphasising the unique characteristics of infrastructure projects and their significant implications for OSH challenges. Section 2 outlines the research strategies and literature analysis methods employed in this work, providing a structured approach to com-prehending OSH challenges within infrastructure projects through the synthesis of relevant scholarly work. Section 3 presents the review's findings regarding the identified OSH challenges in infrastructure projects, offering insights into the specific hazards and risks prevalent in construction and development activities in this sector. Section 4 provides case studies and performs a comparative analysis between OSH challenges in infrastructure projects and those in other construction contexts, elucidating the distinct complexities of ensuring safety within infrastructure projects. Section 5 summarises the conclusions drawn from the review and provides actionable recommendations for addressing OSH challenges in infrastructure projects, aiming to enhance safety practices in the sector. Finally, Section 6 discusses the inherent limitations of the review process and suggests potential avenues for future research, acknowledging constraints and proposing areas for further exploration and inquiry within the field of OSH in infrastructure projects.

2 Research methodology

The review methodology consisted of four main stages aimed at comprehensively identifying and categorising OSH challenges in infrastructure projects:

2.1 Literature search strategy

- A systematic literature search was conducted across major scholarly databases, including Scopus, ScienceDirect, Google Scholar and Web of Science, which are renowned for their comprehensive coverage (Chadegani et al., 2013).

- Relevant search terms related to OSH challenges in infrastructure projects, such as "OSH," "infrastructure projects," "challenges," "barriers" and "construction sector," were carefully selected and combined using Boolean operators (AND, OR, NOT) to optimise the search results.
- The search strategy was meticulously documented, specifying search strings, date restrictions (1995–2024) and any additional filters applied to ensure transparency and reproducibility.

2.2 Inclusion and exclusion criteria

- Clear inclusion criteria were established to select relevant and high-quality articles, consistent with typical investigation procedures (Moher et al., 2015). These criteria included:

1. Publication between 1995 and 2024 to capture recent developments in the field.
2. Explicit mention or analysis of OSH barriers and challenges in infrastructure projects.
3. Online availability of full-text articles for accessibility.
4. English language publication for comprehension and accessibility.

- Similarly, exclusion criteria were defined to eliminate irrelevant or low-quality articles that lack a focus on OSH challenges in infrastructure projects or published in languages other than English.

2.3 Screening process

- A two-stage screening process was employed to identify relevant articles. Initially, the titles and abstracts of the retrieved records were screened to assess potential relevance to the research question.
- Subsequently, full-text articles were reviewed to confirm alignment with the inclusion criteria and to extract the relevant data.
- Any discrepancies or uncertainties during screening were resolved through a team discussion, with decisions documented for transparency and consistency.

2.4 Data extraction and analysis

- Systematic data extraction captured pertinent information from the selected articles, including OSH challenges, methodologies, key findings, and references.
- Thematic analysis served as the primary approach to identifying common themes, patterns, and trends across the literature, facilitating synthesis and interpretation.
- The data analysis process was iterative, with findings reviewed and discussed among the research team to ensure accuracy, validity, and reliability. Following these methodological stages, 76 papers initially met the study's criteria, which were then refined to 54 publications through secondary screening and alignment with the research scope. This methodology provided a robust framework for comprehensively examining OSH challenges in infrastructure projects and informing the development of effective mitigation strategies. The depicted research methodology in Figure 1 illustrates the systematic approach employed in this study.

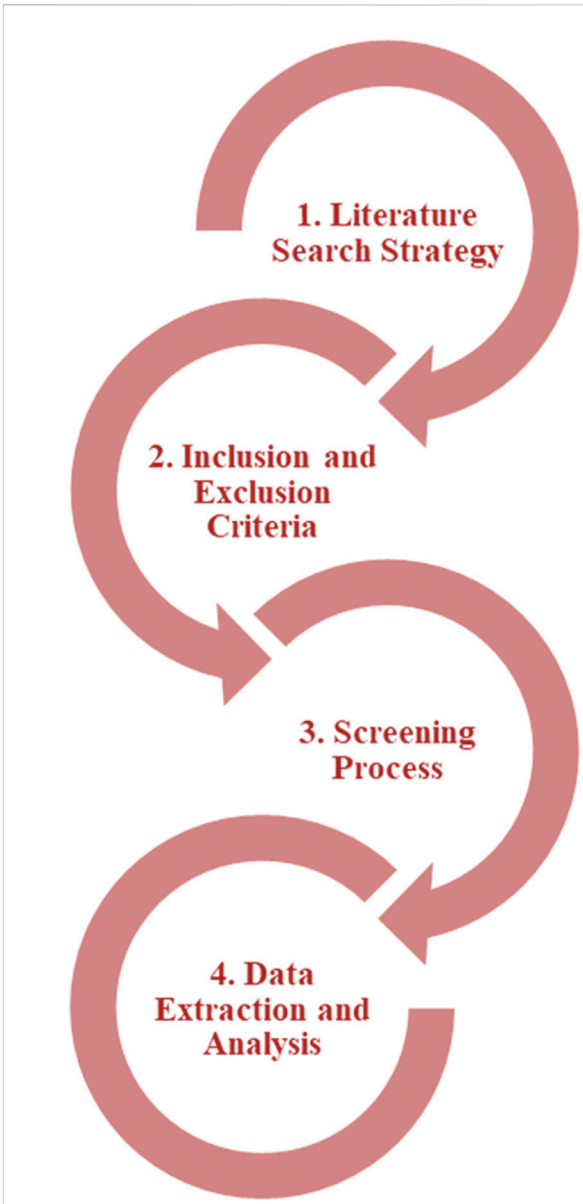

FIGURE 1
Research methodology.

3 Findings and discussion

Infrastructure projects play a crucial role in improving societal well-being by facilitating access to essential systems, services, and utilities necessary for economic activities. However, the nature of these projects presents significant challenges and threats that can result in serious injuries to personnel and contractors, thereby necessitating effective management to prevent and mitigate such risks (Prochazkova and Prochazka, 2014). Unlike many other industries where project staff may not need to be present on-site

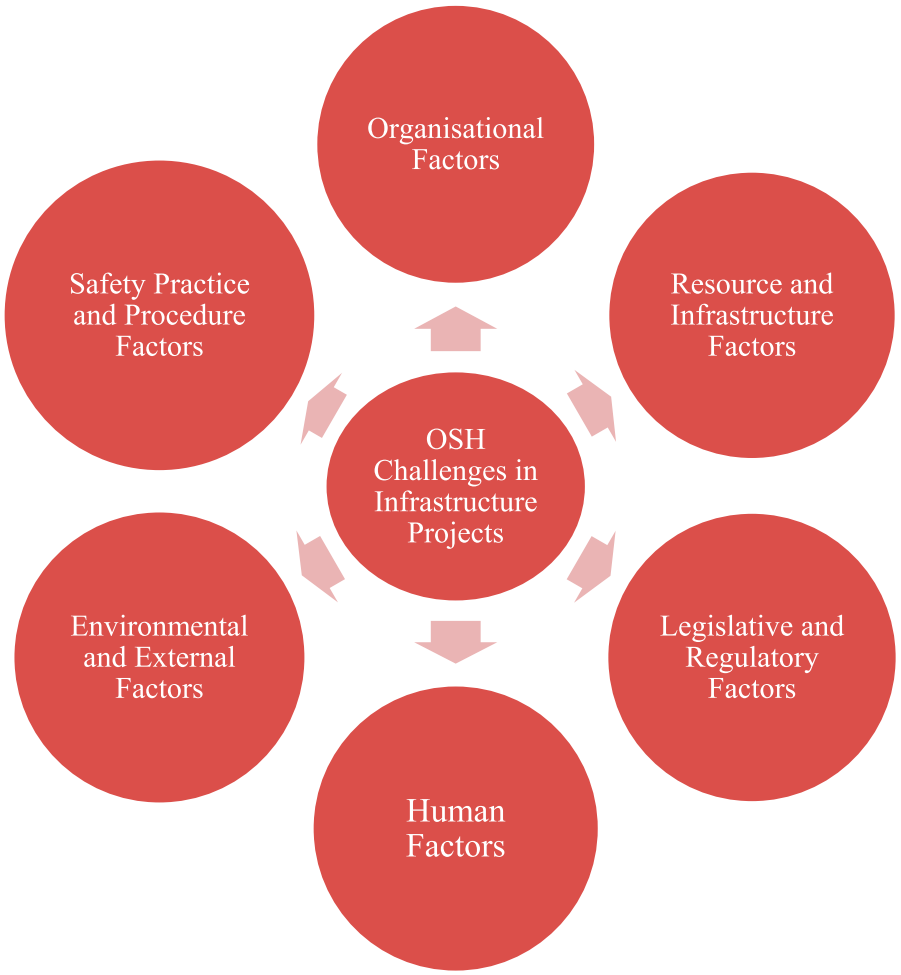

FIGURE 2
Main categories of the identified OSH challenges in infrastructure projects.

at all times (Alaloul et al., 2020), all workers and technical engineers involved in infrastructure projects are required to work on-site, either to carry out operations or ensure project completion according to specifications (Balkhyour, Ahmad and Rehan, 2019). Therefore, the ability to manage unforeseen circumstances is imperative.

Construction and infrastructure projects encounter similar risks. In contrast, infrastructure projects often face additional challenges and safety issues that are uncontrollable, such as those related to OSH concerns, which is related to third-party public safety (Campbell, 2008). Infrastructure construction sites are perceived as inherently risky environments characterised by unstructured conditions, inadequate facilities, congested workspaces, and exposure to adverse weather conditions Eppenberger and Haupt, 2003). Therefore, ensuring the safety of workers and the general public is paramount in such projects.

Challenges to OSH in infrastructure projects are generally intertwined with construction challenges (Campbell, 2008), which is why prioritising infrastructure OSH is imperative for stakeholders, including owners, consultants, contractors, governments, and project participants (Reid, 2009). Continuously improving OSH conditions is essential for all countries, with an emphasis on enhancing the risk assessment process and the effectiveness of risk elimination or reduction decisions (Cagno et al., 2001).

Various factors contribute to the heightened risks and vulnerabilities of OSH in infrastructure projects compared to other types of construction projects. Such factors include construction methods, use of heavy equipment, workers' casual attitudes towards safety, inadequate leadership, and limited client and project management involvement in OSH (Laryea, 2010). Furthermore, accidents affect not only the individuals involved, but also the project parameters, leading to delays and loss of productivity (Chileshe and Dzisi, 2012; Saad, 2016) emphasised that poor safety performance results in increased overall OSH expenses. This study focused on identifying the barriers and challenges to OSH in infrastructure projects. Contextual fac-tors, which are often viewed as spin-offs of barriers, encompass variables that are indirectly related to OSH interventions but significantly influence their success (Stolk et al., 2012; Micheli et al., 2018). Evaluating OSH in infrastructure projects becomes challenging if these barriers are not addressed (Abu Aisheh et al., 2021).

Worksite incidents often occur due to failure to recognise or address inherently dangerous conditions, negligence, or disregard for safety protocols (Zerguine et al., 2016). Inadequate personal

protective equipment (PPE), lack of safety training, absence of well-structured safety management systems and insufficient supervision also contribute to safety hazards in infrastructure projects (Hamid et al., 2008; Teo et al., 2008; Priyadarshani et al., 2013; Nawi et al., 2016).

Workers' negligence, inability to follow job processes, high-level work, unsafe working conditions, poor site management, lack of skill and attitude towards safety all contribute to safety challenges in infrastructure projects (Ammad et al., 2020). Accidents are also attributed to a lack of safety awareness, educational training, company insurance and practical guidance, as well as unregulated activity and insufficient equipment (Enshassi et al., 2008).

A lack of safety training and policies are significant barriers to safety implementation in infrastructure projects (Saad, 2016). Safety training is vital for accident prevention and reduction (Yiu et al., 2018). Insufficient safety awareness and understanding among workers lead to unsafe behaviours and practices (Chileshe and Dzisi, 2012; Sobral and Soares, 2019). Thus, effective safety communication between managers and workers is crucial for safety management (Hanafi, 2018). Communication difficulties, including linguistic, religious, and cultural barriers, may hinder safety efforts on worksites (Mouleeswaran, 2014). Management's inconsistent OSH behaviour, inadequate information and communication, and prioritisation of production over safety are the main barriers to safety implementation (Garnica and Barriga, 2018). The four key challenges to OSH implementation are an uncomfortable work environment, lack of safety awareness, absence of safety management programmes and industry norms discouraging safety programmes (Buniya et al., 2021). Meanwhile, factors such as poor project preparation, financial constraints, inadequate data, lack of emergency plans, hazardous conditions and overall project constraints further exacerbate the safety challenges in infrastructure projects, especially in developing countries (Nawaz et al., 2020)

Risky work environments, limited equipment accessibility, social isolation and individual obligations during the workday are significant concerns that affect safety performance (Pamidimukkala and Kermanshachi, 2021). Tight project schedules add pressure and stress, contributing to health and safety hazards and reduced productivity (Kartam, Flood and Koushki, 2000). Perceived OSH challenges include costs, lack of management commitment, inadequate safety culture, resource shortages, lack of enforcement, training deficiencies and lack of understanding of development (Dugolli, 2021). Poor data management makes estimating risk impact and taking corrective measures difficult (Khan, 2013; Revathi K et al., 2017). Alcohol consumption at work increases the risk of injury for drinkers and others, underscoring the importance of safety awareness and education (Meliá and Becerril, 2009; Arezes and Bizarro, 2011; Manjula and De Silva, 2014). Safety knowledge is crucial for promoting safety practices and behaviours (Manjula and De Silva, 2014).

A lack of safety regulations, procedures, standards, and effective communication of safety standards hinder safety programmes (Aksorn and Hadikusumo, 2008). Company culture plays a significant role in employee safety; a lack of commitment to safety and failure to follow safety regulations contribute to deficiencies in safety (Zhang and Gao, 2012). Workers' failure to use PPE correctly is attributed to ignorance, negligence, apathy, and excessive trust, thereby underscoring the importance of safety awareness and training (Tan and Razak, 2014). Insufficient safety regulations, procedures, and standards, coupled with ineffective communication, further hinder safety efforts (Aksorn and Hadikusumo, 2008; Mahmoudi et al., 2014).

Table 1 presents a comprehensive compilation of the OSH challenges encountered in infrastructure projects, classified into distinct categories: Organisational factors; resource and infrastructure factors; legislative and regulatory factors; human factors; environmental and external factors; safety practices and procedures. Within each category, specific barriers identified from the literature review are delineated, along with corresponding references. This systematic categorisation facilitated a structured comprehension of the multifaceted challenges that are inherently present in ensuring OSH compliance within infrastructure projects.

In infrastructure projects, OSH challenges are intricate and encompass various factors that significantly influence safety outcomes and project success. Understanding these challenges from organisational dynamics to regulatory frameworks and external factors is crucial. This discussion aimed to dissect different categories and factors of OSH challenges, emphasising those with the most impact and their implications for project stakeholders. Doing so enabled us to deepen our understanding of OSH management in infrastructure projects and identify areas for targeted interventions to improve safety outcomes and project performance.

- Most significant category and factors:
- Organisational factors: Our findings highlight the critical role of organisational factors, such as management commitment, resource allocation, safety culture and effective safety management practices, in ensuring worker wellbeing and project success (Nawaz et al., 2020; Al-Mhdawi et al., 2024). Strong commitment from top management is essential for fostering a safety-first culture and ensuring adequate resource provision for safe work practices (Nawaz et al., 2020; Al-Mhdawi et al., 2024). Conversely, a weak safety culture and lack of worker engagement present significant barriers to effective safety management (Nawaz et al., 2020; Al-Mhdawi et al., 2024). Implementing robust safety management systems, including planning, training, and monitoring, is vital for mitigating health and safety risks (Nawaz et al., 2020; Al-Mhdawi et al., 2024). Failures in safety management practices contribute to unsafe work conditions and undermine safety efforts (Nawaz et al., 2020; Al-Mhdawi et al., 2024), and inadequate planning and communication among stakeholders can further exacerbate safety challenges Nawaz et al., 2020).
- Legislative and regulatory factors: Adhering to OSH regulations is crucial for maintaining a safe work environment and upholding ethical standards in infrastructure projects (Nordengen and Roux, 2013). Non-compliance can lead to severe repercussions, underscoring the need for a robust regulatory framework and a culture of safety compliance in the industry Nordengen and Roux, 2013). Effective legislation, enforcement and awareness of safety requirements are essential for promoting safe work practices and ensuring stakeholders' accountability

TABLE 1 List of the OSH challenges in infrastructure projects.

Categories	Identified challenges from the literature review	References
Organisational Factors	Limited resources	Kogi (2002); Goh and Chua (2013), Yiu et al. (2018)
	Tight project schedule	Kogi, 2002; Goh and Chua (2013), Ju and Rowlinson (2014)
	Insufficient OSH commitment	Goh and Chua (2013), Yiu et al. (2018)
	Putting OSH as a lower concern	Kogi (2002), Stephen and Hunt (2002), Yiu et al. (2018)
	Senior management's unawareness of safety issues	Kogi, 2002; Fang et al. (2006), Ghahramani (2017), Yiu et al. (2018)
	Lack of finance	Mashwama et al. (2018), Murugasamy et al. (2020)
	Exploitation and corruption	Khan (2013)
	Weak commitment	Mohamed et al. (2009), Walters (2010), Priyadarshani et al. (2013), Nawi et al. (2016), Zulkifle and Hanafi (2017), Mashwama et al. (2018), Yiu et al. (2018)
	Lack of safety promotion	Mouleeswaran (2014)
	Lack of safety management systems	Mouleeswaran (2014), Mashwama, Aigbavboa and Thwala (2018)
	Insufficient supervision	Teo et al. (2008), Awwad et al. (2016)
	Poor safety awareness among project managers	Hamid et al. (2008), Mahfuth et al. (2019), Mahfuth et al. (2019)
	Insufficient safety briefings/toolbox meetings	Cheah (2007), Priyadarshani et al. (2013), Nawi et al. (2016), Maano and Lindiwe (2017), Revathi K et al. (2017), Mahfuth et al. (2018)
Resource and Infrastructure Factors	Scarcity of competent labour	Yiu, Sze and Chan (2018)
	Shortage of appropriate machines and equipment	Toole, 2002; Hamid et al. (2008), Meliá and Becerril (2009), Kadiri et al. (2014), Durdyev et al. (2017), Oke et al. (2017), Mashwama et al. (2018)
	Lack of inspection	Hamid et al. (2008), Charehzehi and Ahankoob (2012), Khan, 2013; Oke et al. (2017)
	Deficient designs	Lubega et al. (2000), Baghdadi and Kishk (2015), Baghdadi (2017), Baghdadi and Kishk (2017), Baghdadi and Almathamei (2023)
	Inadequate materials	Lubega, Kiggundu and Tindiwensi (2000), Alnunu and Maliha (2015)
	Inappropriate construction techniques	Lubega, Kiggundu and Tindiwensi (2000)
	Lack of labour participation, personal risk assessment and work pressure	Mashwama, Aigbavboa and Thwala (2018)
	High costs, the cost of raw materials and telecommunications	Zahoor et al. (2016); Murugasamy et al. (2020)
Legislative and Regulatory Factors	Insufficient OSH rules and regulations	Priyadarshani et al. (2013); Kadiri et al.(2014); Agbede et al. (2016); Awwad et al. (2016); Cooney (2016); Li et al. (2018)
	Inadequate legislation	Chiocha et al. (2011); Khan (2013); Agbede et al. (2016); Awwad et al. (2016); Buniya et al. (2021)
	Insufficient attention from leaders towards OSH	Kogi (2002); Fang et al. (2006); Bhole (2016); Yiu et al. (2018)
	Lack of workers' compensation insurance	Durdyev et al. (2017); Mashwama et al. (2018)
	Inadequate technical directing	Hamid et al. (2008); Alnunu and Maliha (2015); Saeed (2017)
	Inadequate awareness of safety and health regulations	Lubega et al. (2000); Maano and Lindiwe (2017); Mahfuth et al. (2018)
Human Factors	Insufficient training	Kartam et al. (2000)
	Assuming that OSH is only the responsibility of safety personnel	Stephen and Hunt (2002); Yiu et al. (2018)
	Poor communications between management and employees	Teo et al. (2008); Kheni et al. (2010); Khosravi et al, (2014); Mouleeswaran (2014); Saad (2016); Garnica and Barriga (2018)
	Lack of experience	Choudhry and Fang (2008); Manjula and De Silva (2014); Alnunu and Maliha (2015); Vitharana et al. (2015)
	Low education level	Dester and Blockley (1995); Manjula and De Silva (2014)

(Continued on following page)

TABLE 1 (*Continued*) List of the OSH challenges in infrastructure projects.

Categories	Identified challenges from the literature review	References
	Workers under the influence of drugs and alcohol	Zerguine et al. (2016); Manjula and De Silva (2014); Meliá and Becerril (2009); Murugasamy et al. (2020); Cooney (2016); Dester and Blockley (1995)
	Lack of safety knowledge	Choudhry and Fang (2008); Charehzehi and Ahankoob (2012); Manjula and De Silva (2014); Okoye et al. (2016)
	Lack of accident reports or formal safety statistics	Cheah (2007); Zekri (2013); Durdyev et al. (2017); Li et al. (2018); Mahfuth et al. (2018)
	Insufficiently educated labour	Hamid et al. (2008); Kheni et al. (2010); Mashwama et al. (2018)
	Lack of awareness of the necessary training	Maano and Lindiwe (2017)
Environmental and External Factors	Harsh weather conditions	Mullen (2004); Cheah (2007)
	Working for productive incentives	Sawacha et al. (1999); Langford et al. (2000); Andi (2008); Vitharana et al. (2015); Nawi et al. (2016)
Safety Practices and Procedures Factors	Inapplicable risk assessment	Nawi et al. (2016); Ghahramani (2017)
	Neglecting report incidents/accidents	Awwad et al. (2016); Nawi et al. (2016); Ghahramani (2017)
	Lack of safety knowledge	Choudhry and Fang (2008); Charehzehi and Ahankoob (2012); Manjula and De Silva (2014); Okoye et al. (2016)
	Low awareness of the importance of wearing PPE	Dester and Blockley (1995); Enshassi et al. (2007); Diugwu et al. (2012); Tan and Razak (2014); Revathi et al. (2017); Mahfuth et al. (2018)
	Lack of an OSH signage board	Nawi et al. (2016)
	Absence of first aid	Mullen (2004); Hamid et al. (2008); Alnunu and Maliha. (2015); Awwad et al. (2016); Maano and Lindiwe (2017); Ishak et al. (2022)

Moreover, Figure 2 provides a graphical representation of the primary categories of the identified OSH challenges prevalent in infrastructure projects for enhanced clarity and understanding.

(Nordengen and Roux, 2013). Compliance with OSH regulations is indispensable for meeting legal obligations, minimising le-gal liabilities and fostering a safety culture within infrastructure projects (Nordengen and Roux, 2013).

- Least significant category and factors:

- Environmental and external factors: Environmental and external factors are important, yet their direct impact on safety outcomes in infrastructure projects is perceived as less significant than that of organisational and legislative factors (McDonnell and Chung, 2002; Nekhoroshkov and Nekhoroshkov, 2018; Abolelmagd et al., 2023). However, proactive risk management remains crucial for addressing challenges and ensure project success (McDonnell and Chung, 2002; Nekhoroshkov and Nekhoroshkov, 2018; Abolelmagd et al., 2023). While environmental factors such as adverse weather conditions and regulatory changes can introduce complexities and risks, they are often beyond the direct control of project stakeholders (McDonnell and Chung, 2002; Nekhoroshkov and Nekhoroshkov, 2018; Abolelmagd et al., 2023). Effective risk management strategies and contingency planning can help mitigate their impact on safety and overall project performance (McDonnell and Chung, 2002; Nekhoroshkov and Nekhoroshkov, 2018; Abolelmagd et al., 2023).
- Safety practice and procedure factors: Safety practices and procedures are vital for creating a safe work environment. However, their influence on safety outcomes is considered relatively less significant than that of organisational and legislative factors (Nawaz et al., 2020; Bolsherotov, 2021; Al-Mhdawi et al., 2024). The effectiveness of safety practices depends on the support and compliance established at higher organisational and regulatory levels (Nawaz et al., 2020; Bolsherotov, 2021; Al-Mhdawi et al., 2024). Without robust organisational support and adherence to regulatory requirements, safety protocols may not be adequately implemented or enforced, limiting their direct impact on safety outcomes (Nawaz et al., 2020; Al-Mhdawi et al., 2024). Safety practices and procedures represent the implementation tier of safety management systems, and their efficacy is contingent upon support from organisational and regulatory levels (Nawaz et al., 2020; Al-Mhdawi et al., 2024).

4 Case studies and comparative analysis

Infrastructure projects and other construction ventures face distinct OSH challenges due to differences in scale, complexity, duration and impact on public safety and the environment. Recognising these variations is crucial for implementing effective safety management practices that address the specific hazards and regulatory requirements associated with each project type (Baniassadi et al., 2018; Greiman and Sclar, 2019; Indrayana and Suraji, 2022). Four case studies are represented, to illustrate the significant differences in OSH challenges between infrastructure projects and other forms of construction.

4.1 Infrastructure projects

4.1.1 Big Dig tunnel project (Boston, Massachusetts, USA)

- OSH challenges: The extensive scale and complexity of the Big Dig project in Boston introduced significant safety challenges, with workers encountering risks associated with confined spaces, underground utility handling and coordination with multiple stakeholders. Notably, the threat of tunnel collapses posed a considerable risk, exemplified by incidents such as the 2006 ceiling panel collapse, resulting in a motorist fatality (Albee, 1991).
- Key differences: Infrastructure projects such as the Big Dig involve specialised construction techniques and intricate underground work, such as tunnelling and bridge construction, necessitating tailored safety measures and equipment (Albee, 1991; Welsh, 1999).

4.1.2 Channel Tunnel (Eurotunnel)

- OSH challenges: The construction of the Channel Tunnel between the UK and France presented unique safety challenges due to its underwater nature. Workers navigated the underwater conditions, managed compressed air environments and prevented flooding during the construction process (Welsh, 1999).
- Key differences: Underwater or subsurface construction projects such as the Channel Tunnel pose distinct hazards related to water pressure and diving operations, requiring specialised expertise and equipment (Anner et al., 2013; Gueorguiev, 2019; Li et al., 2021).

4.2 Construction projects

4.2.1 *Rana* Plaza building collapse (Dhaka, Bangladesh)

- OSH challenges: The *Rana* Plaza disaster highlighted common safety issues in various construction contexts, such as inadequate building codes, poor structural integrity and unsafe working conditions. Workers, particularly in garment factories, faced risks such as overcrowding, absence of fire exits and structural deficiencies (Hossain, 2019; Trebilcock, 2020; Grier et al., 2023; Rehman et al., 2023).
- Key differences: Infrastructure projects focus on challenges related to scale and complexity, whereas other construction forms prioritise different safety aspects, such as fire safety and building integrity, necessitating tailored safety measures (Rudnik, 2018; Chen et al., 2022).

4.2.2 Grenfell Tower fire (London, UK)

- OSH challenges: The Grenfell Tower fire exposed systemic failures in fire safety, building regulations and construction practices. Issues such as inadequate fire safety pro-visions and confusing building regulations contributed to the tragic outcome (Mitchener, 2018; Chen et al., 2019; Ewen, 2023).
- Key differences: Residential construction projects such as Grenfell Tower prioritise fire safety and evacuation procedures, while infrastructure projects may emphasise hazards such as structural stability and environmental impact (Baniassadi et al., 2018; Indrayana and Suraji, 2022).

4.3 Comparative analysis

- Scale and complexity: Infrastructure projects typically involve larger scales and complexities due to their extensive nature, encompassing structures such as bridges, highways, airports and tunnels. Thus, managing safety across vast areas and intricate structures presents unique challenges (Masrom et al., 2015; Ayat et al., 2023). In contrast, other construction projects vary in size and complexity, with more standardised processes and less extensive spatial requirements (Dardiri et al., 2017).
- Workforce skills and training: Infrastructure projects demand a highly specialised workforce with expertise in various engineering disciplines, requiring training in specific safety protocols. Other construction projects may have a more generalised workforce with training focused on standard construction safety practices (Misra and Mohanty, 2021; Ahmed, 2023).
- Duration and timeline: Infrastructure projects typically have longer durations, which is why the possibility of accidents may increase over time. Other construction projects may vary in duration, affecting the intensity and duration of the OSH challenges faced by workers (Jones, Caudle and Pappworth, 1996).
- Regulatory compliance: Infrastructure projects are subject to complex regulations due to their significant impact on public safety and the environment. Compliance with OSH regulations, environmental regulations and industry standards adds complexity to safety management (Dimitrova et al., 2014; Mwelu et al., 2018).
- Public safety concerns: Infrastructure projects prioritise public safety because they have a direct impact on public wellbeing, involving hazards such as working near live traffic. Other construction projects may entail fewer public safety risks (Chi et al., 2016).
- Environmental impact: Infrastructure projects have significant environmental implications, requiring compliance with environmental regulations. While all construction projects must consider environmental impact, the scale and scope of these projects may vary (Alamgir et al., 2018; Saldaña-Márquez et al., 2019). Understanding these differences is essential for implementing tailored safety measures that address the unique challenges in each type of construction project.

5 Conclusion and recommendations

Infrastructure projects are indispensable for societal advancement, but strict adherence to OSH regulations to safeguard both individuals and property is necessary for such projects to be executed successfully. These projects, which are characterised by complexity and hazards, can give rise to hazardous environments and adverse environmental impacts if safety measures are not prioritised (Gámez-García et al., 2019). Inadequate OSH practices contribute significantly to the rate of injuries, fatalities, and property damage in construction projects, particularly in infrastructure projects. Infrastructure projects have long been associated with risks and incidents, resulting in project delays, escalated costs, diminished productivity, and negative reputational consequences (Sathvik et al., 2023). Hence, ensuring OSH compliance is essential to avoid accidents. Identifying impediments to OSH in the infrastructure sector is critical so that

governments, organisations and policymakers can devise and implement effective interventions gradually to ameliorate these barriers and enhance OSH performance. This research identified major hurdles that need to be addressed to improve OSH performance in the infrastructure sector. The findings of this review can serve as a basis for further exploration of the identified challenges. This study is significant because it elucidates the OSH challenges and barriers in infrastructure projects, provides insights to improve OSH and educates professionals in the field. Addressing infrastructure challenges is imperative because they affect not only project deliverables, but also the safety of the involved personnel. In addition, the findings contribute to infrastructure safety by offering theoretical insights and a comprehensive understanding of stakeholder challenges during infrastructure development.

Organisational and legislative factors are the most significant categories and factors influencing OSH in infrastructure projects. Their impact on safety culture, resource allocation, compliance and accountability highlight their significance in ensuring the wellbeing of workers and the success of projects. Addressing organisational and legislative factors through proactive measures and robust safety management practices is essential for promoting a safe work environment, minimising risks, and achieving positive outcomes in infrastructure projects. These include:

- Design and implement safety protocols specifically tailored to address the distinct risks and complexities inherent in infrastructure projects, with factors such as project scale, environmental considerations and resource limitations taken into consideration.
- It is crucial to prioritize the early detection, evaluation, and reduction of risks at every phase of infrastructure projects. This proactive approach ensures that potential dangers to both workers and the environment are minimized effectively. By addressing risks before they escalate, we can safeguard the health and safety of personnel and protect the natural surroundings throughout the project's duration.
- Advocate for the establishment and enforcement of robust regulatory frameworks that effectively uphold safety standards and ensure compliance with OSH regulations in infrastructure development endeavours.
- It is essential to foster cooperation between different stakeholders involved in infrastructure projects, such as government bodies, contractors, engineers, and safety experts. This collaboration should aim to facilitate the exchange of best practices, insights gained from past experiences, and innovative approaches. By sharing this valuable information, all parties can work together more effectively to tackle occupational safety and health (OSH) challenges that arise during infrastructure projects.
- Dedicate sufficient resources to ongoing research with the specific goal of improving occupational safety and health (OSH) practices, technologies, and methodologies. This research should be specially designed to meet the distinct needs of infrastructure projects. By investing in such targeted research, we can develop and refine strategies and tools that are directly applicable to the challenges faced in these complex environments. This commitment to innovation will help ensure that OSH measures keep pace with the evolving demands of infrastructure development and continue to protect workers effectively.
- Offer specialised training programmes and educational initiatives to equip workers with the skills, knowledge and awareness required to identify and mitigate OSH risks effectively.
- Cultivate a culture of safety across all organisational levels, emphasising the importance of OSH practices, fostering open communication and empowering workers to actively engage in safety initiatives.
- Establish robust mechanisms for monitoring and evaluating the effectiveness of implemented safety measures, identifying areas for improvement, and ensuring the continuous enhancement of OSH performance in infrastructure projects.
- Involve local communities in the planning and execution of infrastructure projects to address safety concerns, environmental impacts, and community wellbeing, thereby fostering transparency and trust.
- Embrace innovative technologies such as drones, sensors, and virtual reality simulations to enhance the safety monitoring, risk assessment and decision-making processes in infrastructure projects.

6 Limitations

This study has several limitations that are inherently present during the literature review process, including potential selection, publication, language, research design and temporal biases. These limitations can be addressed if future research into the OSH of infrastructure projects focuses on conducting comparative analyses with other construction forms, exploring regional disparities, conducting longitudinal studies to assess intervention effectiveness, integrating technological innovations, engaging stakeholders, examining psychosocial factors, evaluating community health impacts, and analysing OSH policies. Addressing these research areas can result in a more comprehensive understanding of the OSH challenges in infrastructure projects, informing evidence-based strategies for enhancing worker safety, project sustainability and community wellbeing.

Author contributions

AB: Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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