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DIGITAL-ENABLED OFF-SITE CONSTRUCTION FOR DISASTER-RESILIENT BUILT ENVIRONMENTS: A SYSTEMATIC REVIEW AND CONCEPTUAL FRAMEWORK

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Abstract: The increasing frequency and intensity of climate-related disasters present significant challenges for the resilience of the built environment. Conventional construction practices often struggle to respond effectively to these challenges due to their resource-intensive nature, lengthy project timelines, and limited adaptability. Off-site construction (OSC), including modular and prefabricated systems, has emerged as a promising approach for improving construction efficiency, reducing waste, and accelerating infrastructure delivery. At the same time, digital technologies such as Building Information Modelling (BIM), digital twins, and Internet of Things (IoT) systems are transforming the planning, design, and management of built assets. Despite growing interest in these developments, research addressing the intersection of digitalisation, off-site construction, and disaster resilience remains fragmented. This study presents a systematic review of literature examining how digital technologies can enhance the resilience and sustainability of off-site construction systems. The review synthesises existing knowledge on disaster resilience in the built environment and identifies emerging opportunities for integrating digital technologies with OSC practices. The findings reveal that although resilience has been widely discussed in policy and academic discourse, practical implementation within construction delivery remains limited due to institutional, technical, and knowledge barriers. The paper proposes an integrated conceptual framework linking digital technologies, off-site construction, and resilient infrastructure development. The study contributes to ongoing discussions on sustainable and resilient construction by highlighting pathways for integrating digital innovation with modern construction methods to support disaster-resilient built environments.

Keywords: Off-site construction; disaster resilience; digital construction; built environment; sustainable construction

1 INTRODUCTION

The increasing frequency and intensity of climate-related hazards, including floods, storms, and extreme weather events, have significantly heightened the vulnerability of the built environment. These events disrupt infrastructure systems, damage housing, and undermine socio-economic stability, thereby reinforcing the need for resilient infrastructure capable of withstanding and recovering from disaster impacts. Contemporary perspectives define resilience as the capacity of built systems to absorb disturbances, maintain functionality, and adapt to evolving risks (Hassler and Kohler 2014). This broader understanding reflects a shift from traditional hazard mitigation approaches towards more holistic and adaptive resilience strategies. Despite growing recognition of resilience in both academic and policy discourse, its practical integration into construction processes remains limited. Studies have identified persistent gaps between disaster risk reduction policies and their implementation within infrastructure delivery, often due to fragmented governance structures, limited institutional capacity, and inadequate stakeholder coordination (Palliyaguru, Amaratunga, and Haigh 2010; Malalgoda, Amaratunga, and Haigh 2014). Furthermore, built environment professionals play a critical role in shaping resilience outcomes through decisions made across planning, design, and construction stages, yet these roles are not always effectively aligned with resilience objectives (Haigh and Amaratunga 2010).

In response to these challenges, off-site construction (OSC), including modular and prefabricated systems, has emerged as a promising approach for improving construction efficiency and adaptability. OSC involves the production of building components in controlled factory environments, enabling enhanced quality control, reduced material waste, and accelerated project delivery. These characteristics make OSC particularly relevant in disaster-prone contexts, where rapid reconstruction and reliable infrastructure performance are essential. However, despite its advantages, the adoption of OSC remains constrained by factors such as regulatory limitations, supply chain challenges, and resistance to innovation within the construction industry.

At the same time, digital technologies are increasingly transforming construction practices. Tools such as Building Information Modelling (BIM), digital twins, and Internet of Things (IoT) systems facilitate improved collaboration, enhanced design accuracy, and real-time monitoring of infrastructure performance. These technologies enable data-driven decision-making and provide opportunities for integrating resilience considerations across the asset lifecycle. For example, digital models can support hazard simulation and performance analysis, while sensor-based systems enable continuous monitoring of structural and environmental conditions. Although resilience, off-site construction, and digitalisation have each received growing scholarly attention, research addressing their intersection remains fragmented. Existing studies often examine these domains independently, limiting the development of integrated approaches capable of supporting resilient infrastructure delivery. This fragmentation restricts the ability of industry stakeholders to fully leverage the combined potential of digital technologies and innovative construction methods. This study therefore aims to address this gap by conducting a systematic review of literature to examine how digital technologies can enhance off-site construction systems for disaster-resilient built environments. The paper further proposes an integrated conceptual framework linking digitalisation, OSC practices, and resilience objectives to support sustainable infrastructure development.

2 RESEARCH METHODOLOGY

This study adopts a systematic literature review (SLR) approach to synthesise existing knowledge at the intersection of disaster resilience, off-site construction (OSC), and digital technologies in the built environment. Systematic reviews are widely recognised as a rigorous and transparent method for identifying, evaluating, and integrating findings from existing studies, thereby enhancing the reliability and reproducibility of research outcomes (Tranfield, Denyer, and Smart 2003; Kitchenham and Charters 2007). This approach is particularly suitable for this study, given the fragmented nature of research across the three domains of interest.

The review process was guided by established systematic review principles, including the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which provides structured procedures for literature identification, screening, and selection (Moher et al. 2009).

Although originally developed in the health sciences, PRISMA has been increasingly applied in built environment research to improve methodological transparency and reduce selection bias. In this study, the framework informed a structured and replicable review process, ensuring that relevant literature was systematically identified and evaluated. A comprehensive search of academic literature was conducted using major scholarly databases, including Scopus, Web of Science, and Google Scholar. The search strategy employed a combination of keywords and Boolean operators to capture studies related to disaster resilience, off-site construction, and digital technologies. Key search terms included combinations of “disaster resilience”, “built environment”, “off-site construction”, “modular construction”, “prefabrication”, “digital construction”, “Building Information Modelling (BIM)”, “digital twins”, and “Internet of Things (IoT)”. The search focused on peer-reviewed journal articles, conference papers, and relevant reports published primarily within the last two decades to reflect contemporary developments in construction practices and resilience research.

To ensure the relevance and quality of the selected studies, explicit inclusion and exclusion criteria were applied during the screening process. Studies were included if they addressed disaster resilience within the built environment, examined off-site or modular construction systems, or explored the application of digital technologies in construction. Conversely, studies were excluded if they were not directly related to the built environment, lacked clear methodological or theoretical contributions, or were not available in English. Following the initial search, duplicate records were removed, and titles and abstracts were screened to assess their relevance to the research objectives. Full-text articles were subsequently reviewed to confirm their eligibility for inclusion in the final analysis, consistent with systematic review procedures (Moher et al. 2009). Figure 1 presents the PRISMA-based literature identification, screening, eligibility assessment, and final study selection process adopted in this study.

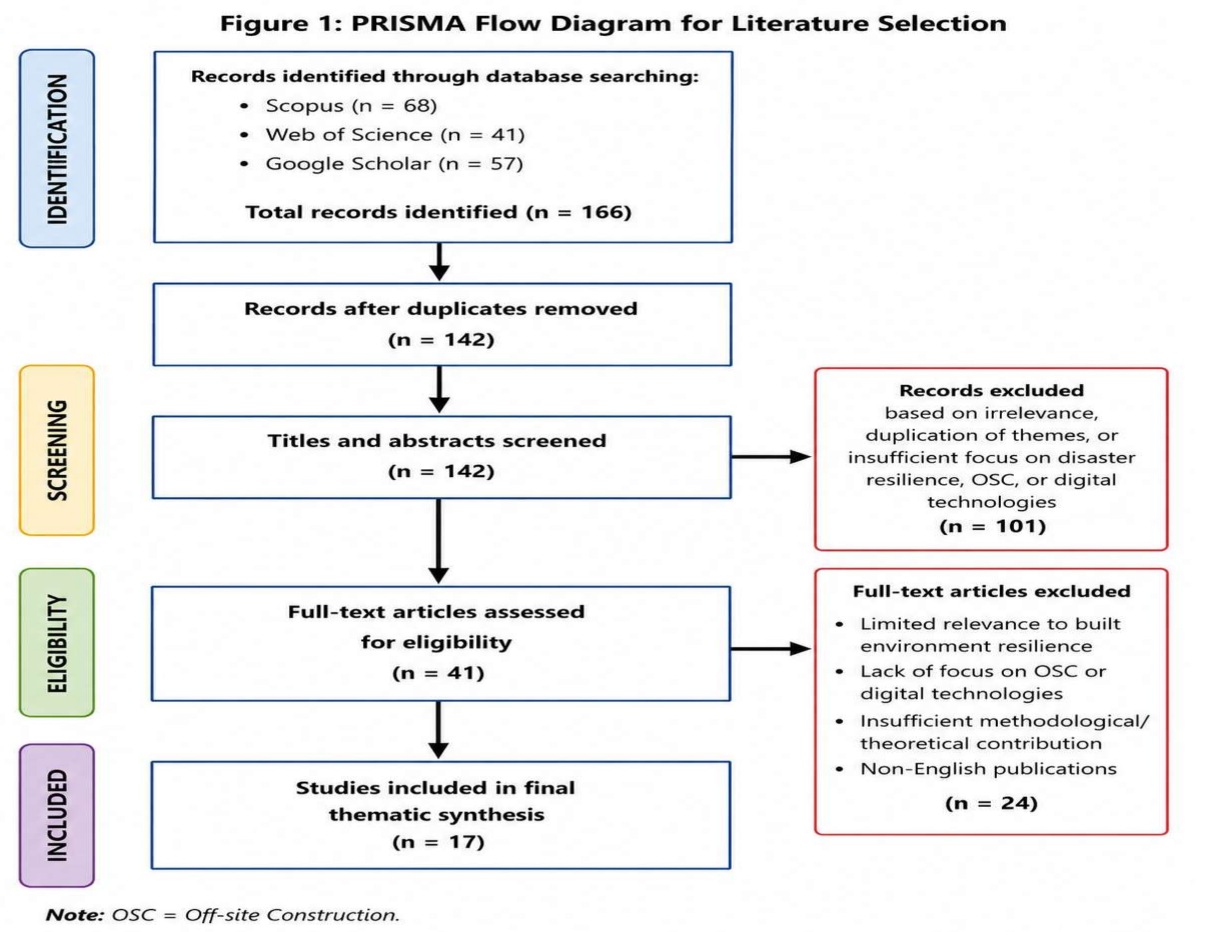

Figure 1: PRISMA Flow Diagram for Literature Selection

The selected studies were analysed using a thematic synthesis approach, which enables the identification and interpretation of recurring patterns and relationships across the literature (Braun and Clarke 2006). The thematic synthesis process enabled the categorisation of recurring themes and informed the development of the proposed conceptual framework linking digital technologies, off-site construction, and disaster resilience. The analysis focused on key thematic areas, including disaster resilience in the built environment, off-site construction and infrastructure delivery, and digital technologies in construction. Through this process, the study identified critical challenges, emerging opportunities, and areas of convergence across these domains. The synthesis further enabled the identification of significant research gaps, particularly regarding the limited integration of digital technologies and off-site construction in resilience-oriented infrastructure development. The findings from the systematic review informed the development of an integrated conceptual framework linking digital technologies, OSC practices, and disaster resilience objectives. This framework provides a structured basis for understanding how digital-enabled construction approaches can enhance the resilience and sustainability of the built environment.

3 DISASTER RESILIENCE IN THE BUILT ENVIRONMENT

The concept of disaster resilience in the built environment has evolved significantly over the past two decades, shifting from a narrow focus on structural resistance towards a broader and more dynamic understanding of system performance. Contemporary perspectives conceptualise resilience as the capacity of buildings and infrastructure systems to absorb disturbances, maintain functionality, and adapt to changing conditions over time (Hassler and Kohler 2014). This evolution reflects increasing recognition that resilience extends beyond physical robustness to include social, institutional, and economic dimensions that influence how communities respond to and recover from disaster events. Despite its growing prominence, disaster resilience remains a contested and multifaceted concept with no universally accepted definition. Different disciplines interpret resilience in varying ways, ranging from short-term recovery and hazard mitigation to long-term adaptation and transformation processes (Shamout, Boarin, and Mannakkara 2020). This lack of conceptual clarity presents challenges for implementation within the built environment, as stakeholders often operate with differing assumptions regarding resilience objectives and priorities. Consequently, translating resilience theory into practical construction strategies remains complex and inconsistent.

The role of built environment professionals in shaping resilience outcomes is widely acknowledged. Decisions made during planning, design, construction, and asset management stages significantly influence the vulnerability and adaptive capacity of infrastructure systems. Haigh and Amaratunga (2010) emphasise that professionals such as engineers, architects, and planners play a central role in integrating disaster risk reduction into development processes. However, in practice, these roles are often constrained by institutional limitations, fragmented governance structures, and competing project priorities. A persistent challenge identified in the literature is the gap between resilience-oriented policies and their implementation within construction and reconstruction processes. Studies highlight that while disaster risk reduction frameworks are frequently incorporated into national and international policies, their translation into operational practices remains limited (Palliyaguru, Amaratunga, and Haigh 2010). This disconnect is further exacerbated by weak coordination among stakeholders, inadequate regulatory enforcement, and insufficient technical capacity at the local level (Malalgoda, Amaratunga, and Haigh 2014). As a result, reconstruction efforts following disasters often replicate pre-existing vulnerabilities rather than addressing underlying risk factors.

Recent research has emphasised the importance of adopting holistic approaches that move beyond hazard mitigation to address systemic vulnerabilities within the built environment. Palliyaguru, Amaratunga, and Baldry (2014) argue that effective disaster risk reduction requires integrating vulnerability reduction strategies into planning and reconstruction processes. Similarly, Perera, Adeniyi, and Babatunde (2017) highlight the role of community capacity-building and local knowledge in enhancing resilience outcomes. These perspectives underscore the need for inclusive and context-sensitive approaches that consider both technical and socio-institutional dimensions of resilience. While these studies provide valuable insights into resilience theory and policy, limited attention has been paid to the role of construction delivery methods and enabling technologies in operationalising resilience objectives. Much of the existing literature focuses on high-level frameworks and governance challenges, with comparatively little emphasis on how innovations in construction practices can directly support resilient infrastructure development. This gap highlights the need to explore alternative construction approaches, such as off-site construction, alongside emerging digital technologies that can enhance the planning, delivery, and performance of resilient built assets. Resilience research focuses more on policy/governance, but less on construction delivery implementation, which creates the need for OSC and digital integration.

4. OFF-SITE CONSTRUCTION AND RESILIENT INFRASTRUCTURE DELIVERY

Off-site construction (OSC), encompassing modular, prefabricated, and industrialised building systems, has gained increasing attention as a technically advanced approach for improving construction efficiency and infrastructure performance. Unlike traditional on-site construction, OSC involves the manufacture of building components in controlled factory environments, followed by transportation and assembly on-site. This shift from site-based to factory-based production introduces greater precision, standardisation, and quality control, which are critical for achieving consistent structural performance and reducing construction variability. From a technical perspective, OSC enables improved dimensional accuracy and tighter tolerances due to controlled manufacturing conditions. Factory production minimises exposure to environmental uncertainties such as weather disruptions, which often compromise construction quality in conventional practices. As a result, prefabricated components typically exhibit enhanced structural integrity and reduced defect rates. These characteristics are particularly relevant in disaster-prone environments, where structural reliability and performance under extreme loading conditions are essential. A key technical advantage of OSC lies in its capacity for design standardisation and repeatability. Modular systems are often based on standardised units that can be replicated across projects, allowing for the integration of resilient design features such as reinforced structural connections, improved load paths, and enhanced material specifications. This standardisation supports the incorporation of hazard-resistant design principles, including resistance to wind loads, seismic forces, and flooding impacts. Furthermore, prefabricated systems can be engineered to comply with higher performance standards, thereby improving the overall resilience of infrastructure systems.

OSC also contributes to accelerated construction timelines, which is a critical factor in post-disaster recovery contexts. The parallel execution of off-site manufacturing and on-site preparation significantly reduces project duration compared to sequential traditional construction processes. Rapid deployment capabilities enable faster restoration of housing and infrastructure, thereby reducing the socio-economic impacts of disaster events. Additionally, modular construction systems allow for scalability, enabling the efficient delivery of large volumes of housing units in response to emergency needs. From a sustainability perspective, OSC offers notable improvements in material efficiency and waste reduction. Factory-based production facilitates better material optimisation, reducing excess usage and construction waste. This contributes to lower environmental impacts and aligns with broader sustainability objectives in the construction sector. Moreover, improved logistics and reduced on-site activities lead to lower emissions and reduced disruption to surrounding communities. Despite these advantages, the adoption of OSC remains constrained by several technical and institutional challenges. One major limitation is the complexity of design coordination, particularly in projects involving high levels of customisation. While standardisation enhances efficiency, it can also limit design flexibility if not carefully managed. Additionally, transportation and logistics constraints may affect the feasibility of large modular components, particularly in regions with inadequate infrastructure. Structural connections between prefabricated elements also require careful engineering to ensure robustness under dynamic loading conditions, including those induced by extreme events.

Furthermore, the integration of OSC into existing construction practices requires significant changes in procurement strategies, supply chain coordination, and regulatory frameworks. Traditional construction systems are often not fully aligned with the requirements of industrialised production, creating barriers to widespread adoption. These challenges highlight the need for enabling technologies that can improve design coordination, enhance information flow, and support lifecycle performance monitoring. In this context, digital technologies present significant opportunities for enhancing the technical and operational effectiveness of OSC systems. The integration of digital tools with off-site construction processes can improve precision in design, optimise production workflows, and enable real-time monitoring of structural performance. However, despite these potential benefits, the combined application of digital technologies and OSC for disaster-resilient infrastructure remains underexplored in existing research. OSC improves efficiency and standardisation, but lacks sufficient digital integration for resilience optimisation.

4. DIGITAL TECHNOLOGIES IN CONSTRUCTION

Digital transformation is increasingly redefining construction practices through the integration of advanced technologies associated with the Fourth Industrial Revolution (Industry 4.0). These technologies including Building Information Modelling (BIM), digital twins (DT), Internet of Things (IoT), artificial intelligence (AI), and big data analytics—enable the development of intelligent, interconnected, and data-driven construction systems. Industry 4.0 is characterised by the convergence of digital, physical, and communication technologies that support automation, real-time data exchange, and enhanced decision-making across infrastructure systems. Within the construction sector, BIM has emerged as a foundational digital technology that facilitates the creation of integrated digital representations of built assets. BIM enhances collaboration among project stakeholders by enabling shared information environments for design, planning, and execution. It supports improved coordination, reduces design conflicts, and enhances construction accuracy. Importantly, BIM has been identified as a critical enabler of modular and prefabricated construction, as it facilitates virtual modelling, fabrication planning, and integration of building components within off-site construction systems.

Beyond BIM, digital twin technology represents a significant advancement in digital construction by enabling the continuous interaction between physical assets and their virtual counterparts. Digital twins are defined as dynamic digital replicas that integrate real-time data to simulate, monitor, and optimise the performance of infrastructure systems throughout their lifecycle. The concept enables improved asset management, predictive analysis, and proactive decision-making by linking physical systems with digital models. These capabilities extend beyond static modelling by allowing real-time feedback and adaptive system optimisation. From a technical standpoint, digital twins provide advanced functionalities such as real-time monitoring, predictive maintenance, and performance optimisation. These capabilities are particularly relevant for enhancing resilience in the built environment, as they enable early detection of system failures and support data-driven risk management strategies. Studies have shown that digital twin technologies can improve operational efficiency, enhance monitoring and prediction capabilities, and support lifecycle optimisation of infrastructure systems, thereby contributing to improved performance and sustainability outcomes.

The integration of IoT technologies further strengthens digital construction systems by enabling continuous data collection from physical assets through embedded sensors. These sensors capture critical data related to structural performance, environmental conditions, and asset usage, which can be analysed to support predictive analytics and real-time decision-making. The combination of IoT with BIM and digital twins enables the creation of cyber-physical systems that enhance situational awareness and improve infrastructure management. Such integration is central to Industry 4.0, where interconnected systems facilitate intelligent and automated construction processes. Despite the significant potential of digital technologies, their adoption within the construction industry particularly in developing economies remains limited. Empirical studies have identified several barriers to adoption, including lack of technical expertise, resistance to change, inadequate infrastructure, and uncertainty regarding the benefits of digital transformation. Similarly, challenges such as high implementation costs, lack of standardisation, interoperability issues, and limited collaboration among stakeholders continue to hinder the effective implementation of BIM and related technologies in construction. Furthermore, while digital technologies have demonstrated substantial benefits in improving project delivery, lifecycle management, and sustainability, their integration with off-site construction systems remains insufficiently explored. Existing research tends to focus on individual technologies rather than examining their combined application within construction delivery processes. This limits the ability to fully leverage digital innovation for enhancing construction standardisation, quality control, and resilience outcomes. Consequently, there is a need for integrated approaches that combine digital technologies with off-site construction methods to unlock their full potential. The convergence of BIM, digital twins, and IoT systems with OSC processes can enhance design precision, optimise production workflows, and enable continuous monitoring of infrastructure performance. Such integration provides a pathway for improving both the efficiency and resilience of the built environment. Digital tools are mostly studied independently, while integration with OSC for resilience remains underexplored.

5. RESEARCH GAPS AND CONCEPTUAL FRAMEWORK

The review of literature across disaster resilience, off-site construction (OSC), and digital technologies reveals significant fragmentation in existing research. While resilience has been widely explored within the built environment, much of the literature remains conceptual, with limited emphasis on practical implementation within construction delivery processes. Studies have consistently highlighted the disconnect between resilience policies and their operationalisation in infrastructure development, often due to governance fragmentation, institutional limitations, and inadequate coordination among stakeholders (Palliyaguru, Amaratunga, and Haigh 2010; Malalgoda, Amaratunga, and Haigh 2014). This indicates that, despite advances in resilience theory, its translation into actionable construction practices remains insufficient. Similarly, research on off-site construction has predominantly focused on productivity, sustainability, and efficiency improvements, with comparatively limited attention given to its role in enhancing disaster resilience. Although OSC offers technical advantages such as improved quality control, standardisation, and rapid deployment capabilities, its integration within resilience-oriented infrastructure frameworks remains underexplored. Existing studies emphasise the benefits of modular construction in improving project delivery and reducing waste, yet there is a lack of systematic investigation into how these capabilities can be strategically leveraged to support disaster-resilient built environments (Awodele, Mewomo, and Eze 2023).

In parallel, the growing body of literature on digital technologies in construction has largely concentrated on improving design coordination, project management, and lifecycle efficiency. Technologies such as BIM, digital twins, and IoT systems have demonstrated significant potential in enabling data-driven decision-making, real-time monitoring, and predictive maintenance (Awodele et al. 2025). However, these studies often examine digital technologies in isolation, without adequately addressing their integration with construction delivery methods such as OSC. Furthermore, barriers such as high implementation costs, lack of technical expertise, resistance to change, and inadequate infrastructure continue to limit the adoption of digital technologies, particularly in developing economies (Awodele et al. 2024). A critical gap therefore exists at the intersection of these three domains. Current research rarely provides integrated frameworks that connect digital technologies, off-site construction, and disaster resilience within a unified analytical structure. This lack of integration restricts the ability of industry stakeholders to fully exploit the combined potential of digital innovation and modern construction methods for enhancing infrastructure resilience. Consequently, there is a need for a holistic framework that bridges these domains and provides a structured approach to resilient infrastructure development. The development of the conceptual framework was informed by recurring themes identified through the thematic synthesis of the reviewed literature. Specifically, the resilience literature highlighted the need for adaptive and sustainable infrastructure systems, while studies on off-site construction emphasised standardisation, rapid deployment, and improved quality control. In parallel, the digital construction literature demonstrated the enabling role of technologies such as BIM, digital twins, and IoT in supporting real-time monitoring, lifecycle optimisation, and data-driven decision-making. The convergence of these themes informed the structure and relationships represented within the proposed framework. In response to these gaps, this study proposes an integrated conceptual framework that positions digital technologies as key enablers of resilient off-site construction systems. The framework conceptualises digital tools such as BIM, digital twins, and IoT as facilitating enhanced design integration, real-time performance monitoring, and data-driven decision-making across the construction lifecycle. These capabilities support the optimisation of OSC processes, including standardisation, quality control, and rapid deployment of modular systems. Within the framework, the integration of digital technologies with OSC is expected to lead to improved construction efficiency, enhanced structural performance, and increased adaptability of infrastructure systems to disaster risks. By enabling continuous monitoring and predictive analysis, digital technologies also support proactive risk management and lifecycle optimisation, thereby strengthening long-term resilience outcomes. Ultimately, the interaction between digitalisation and OSC contributes to the development of sustainable and disaster-resilient built environments. This framework provides a conceptual foundation for understanding how the convergence of digital technologies and innovative construction methods can address existing limitations in resilience implementation. It also offers practical implications for policymakers, industry practitioners, and researchers by highlighting pathways for integrating digital innovation into construction processes to enhance infrastructure resilience. Figure 2 illustrates the conceptual framework developed in this study, showing the sequential relationship between digital technologies, off-site construction systems, and the development of sustainable and disaster-resilient built environments.

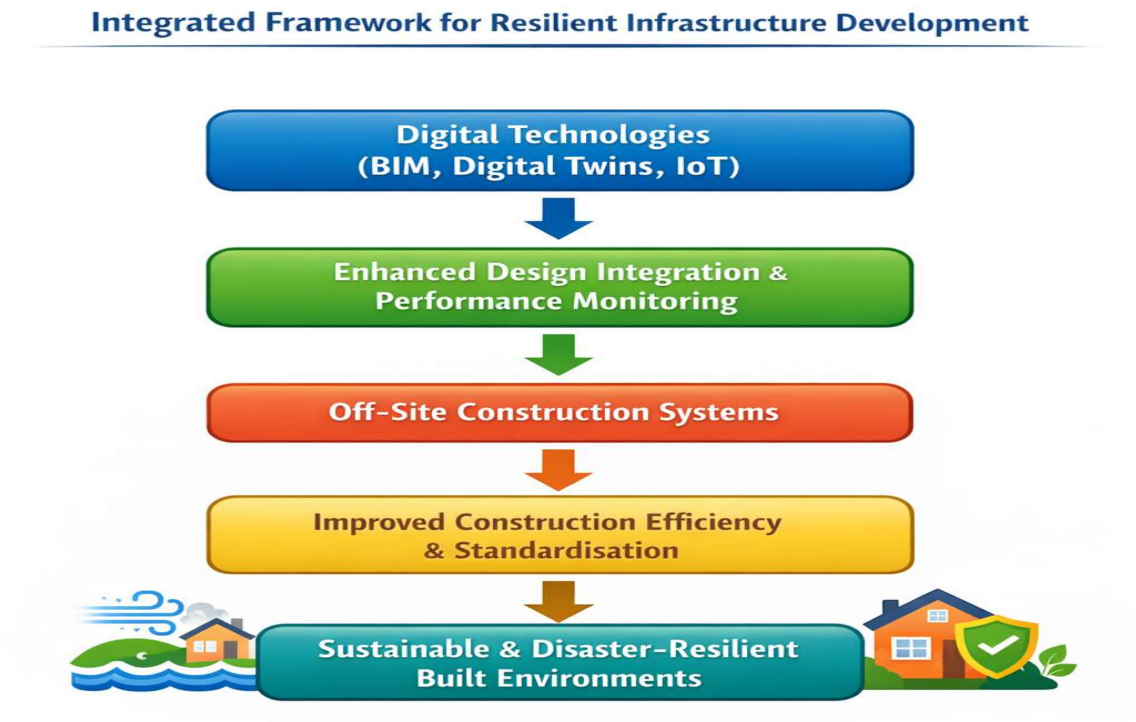

Figure 2: Integrated framework for resilient infrastructure

The conceptual framework presented in Figure 2 demonstrates how the integration of digital technologies such as Building Information Modelling (BIM), digital twins, and the Internet of Things (IoT) serves as a foundational enabler for enhancing design integration and real-time performance monitoring within construction projects. These capabilities facilitate improved decision-making, early risk detection, and lifecycle management of infrastructure systems. Building on this digital foundation, the framework highlights the role of off-site construction systems as a critical intermediary that translates enhanced design and monitoring capabilities into practical construction processes. Off-site approaches promote greater precision, reduced material waste, and improved quality control through standardized and controlled manufacturing environments. The interaction between digital technologies and off-site construction ultimately leads to improved construction efficiency and standardisation. These improvements contribute significantly to the delivery of infrastructure that is not only sustainable but also capable of withstanding and adapting to disaster-related disruptions. Consequently, the framework provides an integrated pathway linking technological innovation and modern construction methods to the achievement of resilient built environments.

6. DISCUSSION

The findings of this study highlight the significant potential of integrating digital technologies with off-site construction (OSC) to enhance disaster resilience in the built environment. While prior studies have examined disaster resilience, OSC, and digitalisation as separate domains, this study demonstrates that their integration offers a more comprehensive approach to addressing infrastructure vulnerability. Existing literature has emphasised that resilience implementation remains constrained by governance fragmentation and weak coordination mechanisms (Palliyaguru, Amaratunga, and Haigh 2010; Malalgoda, Amaratunga, and Haigh 2014). The proposed framework advances this discourse by identifying digital-enabled OSC as a practical pathway for operationalising resilience within construction delivery processes. From a technical perspective, the integration of digital technologies such as BIM, digital twins, and IoT enhances the performance and adaptability of OSC systems. BIM facilitates improved design coordination and supports the integration of modular components, thereby reducing construction errors and enhancing efficiency (Awodele, Mewomo, and Eze 2023). Digital twin technology extends these capabilities by enabling real-time monitoring, predictive analysis, and lifecycle optimisation of infrastructure systems, which are critical for proactive risk management in disaster-prone environments (Awodele et al. 2025). Similarly, IoT-enabled systems provide continuous data streams that support performance monitoring and early detection of potential structural or environmental risks, thereby strengthening the adaptive capacity of built assets (Awodele et al. 2024).

The discussion also highlights that OSC provides a technically robust platform for implementing resilience strategies due to its inherent characteristics of standardisation, precision manufacturing, and rapid deployment. These features enable the incorporation of resilient design principles within prefabricated components, improving structural reliability and performance under extreme conditions. However, without digital integration, the full potential of OSC in enhancing resilience remains limited. The findings therefore reinforce the argument that digital technologies act as critical enablers that enhance the effectiveness of OSC systems in delivering resilient infrastructure. Despite these opportunities, the study identifies several persistent challenges that may hinder the adoption of digital-enabled OSC systems. Consistent with existing research, barriers such as lack of technical expertise, high implementation costs, resistance to change, and inadequate infrastructure continue to constrain digital technology adoption in construction (Awodele et al. 2024; Awodele, Mewomo, and Eze 2023). These challenges are particularly pronounced in developing economies, where institutional capacity and technological readiness may be limited. Furthermore, issues related to interoperability, data management, and standardisation remain critical concerns affecting the integration of digital tools within construction processes (Awodele, Mewomo, and Eze 2023).

From a theoretical standpoint, this study contributes to the growing body of knowledge by bridging the gap between resilience theory and construction practice. The study further contributes by providing an integrated perspective that connects digital technologies, off-site construction systems, and disaster resilience within a unified conceptual structure. Unlike existing studies that predominantly examine these domains independently, the proposed framework demonstrates how digital-enabled OSC approaches can support the operationalisation of resilience objectives through improved design integration, lifecycle monitoring, and adaptive infrastructure delivery. While previous studies have largely focused on conceptual discussions of resilience, this research provides a structured framework that links resilience objectives with specific construction methods and enabling technologies. This integrated perspective advances existing literature by demonstrating how digital transformation can be aligned with modern construction approaches to achieve resilience outcomes. From a practical perspective, the findings have important implications for policymakers and industry practitioners. The integration of digital technologies with OSC requires supportive regulatory frameworks, investment in digital infrastructure, and capacity development among construction professionals. Training and education are essential to improve awareness and technical competence, while policy interventions are needed to promote the adoption of innovative construction methods and digital tools. In addition, improved collaboration among stakeholders is necessary to facilitate the successful implementation of digital-enabled OSC systems. Overall, the discussion underscores that achieving disaster-resilient built environments requires a shift from fragmented approaches towards integrated and technology-driven construction practices. By combining the efficiency of OSC with the capabilities of digital technologies, it is possible to enhance infrastructure performance, improve risk management, and support sustainable development objectives.

7. CONCLUSION

This study examined the intersection of disaster resilience, off-site construction (OSC), and digital technologies within the built environment through a systematic literature review. The findings reveal that, although these domains have received increasing scholarly attention, their integration remains limited, resulting in fragmented approaches to resilient infrastructure delivery. The study demonstrates that the integration of digital technologies with OSC provides a practical pathway for enhancing construction efficiency, improving structural performance, and strengthening the adaptive capacity of infrastructure systems in disaster-prone environments. By enabling improved design coordination, real-time monitoring, and data-driven decision-making, digital-enabled OSC systems offer significant potential for advancing resilient and sustainable built environments. The proposed conceptual framework contributes to knowledge by providing an integrated perspective that links digitalisation, construction innovation, and resilience objectives within a unified structure. This contribution addresses a critical gap in existing literature and offers a foundation for both theoretical development and practical application. The study also advances current discourse on resilient infrastructure development by demonstrating the importance of integrating digital innovation with modern construction approaches to enhance infrastructure adaptability, efficiency, and long-term sustainability in disaster-prone environments. Future research should focus on empirically validating the proposed framework and developing implementation strategies that support the adoption of digital-enabled OSC systems across different contexts.

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