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REVIEW ON TECHNOLOGICAL INTERVENTIONS TO ENHANCE FLOOD RESILIENCE IN THE BUILT ENVIRONMENT

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ABSTRACT

Floods are among the most common and destructive natural disasters worldwide, posing a substantial threat to the built environment and its socioeconomic stability. As climate change contributes to flood hazards, improving disaster resilience through technical means has become increasingly important. This paper aims to investigate the technological interventions that improve flood resilience in the built environment. Using a comprehensive literature review, the study investigates cutting-edge technologies such as Geographic Information Systems (GIS), Remote Sensing (RS), the Internet of Things (IoT), Smart Sensors, Artificial Intelligence (AI), and Digital Twin (DT) highlighting their contribution to flood resilience in the built environment by improving risk assessment, enhancing early warning systems, facilitating real time monitoring, and supporting resilient planning and design strategies that enhance flood resilience in the built environment. To create a more resilient built environment, the paper concludes with recommendations for combining technology adoption with practice and policy.

Keywords: *Built Environment; Disaster; Flood; Resilience; Technologies.*

1. INTRODUCTION

Disasters significantly affect the built environment (BE) and the failure of the built environment can have substantial effects on economic and social activities. Thus, as we move toward safer cities, it is critical to design the built environment to withstand natural disasters (Malalgoda & Amaratunga, 2015). The rising intensity and frequency of natural disasters pose a growing threat to the built environment, making the built environment vulnerable to natural disasters (Li et al., 2023; Rus et al., 2018; Zięba et al., 2020). Floods are among the most frequent natural disasters, and they create one of the most severe impacts worldwide (Dutta et al., 2023; Islam et al., 2016). Floods drastically disrupt the functioning of built assets, and the impact caused by floods on property devastation, disruptions to water, power, and utility supplies, and a halt to routine community operations hinder sustainable development targets for assets (Rathnasiri et al., 2023).

According to the Academy of Disaster Reduction and Emergency Management et al. (2024), flooding has been the most common disaster in the last 30 years, accounting for 46.63% of the total frequency of all the disasters, where a population of 3239.28 million

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was affected causing 7763 deaths along with 10.05% of the total direct economic loss. The resilience of the BE and its community relies on activities taken to prepare for disasters (Mannucci et al., 2022). In recent years, the notion of resilience has drawn significant interest from the scientific community, possessing considerable potential to manage and synthesize general perspectives by integrating many components to assess issues comprehensively (Tayyab et al., 2021). Technology is one such component that improves the ability to analyze natural disaster risks and build disaster relief strategies and risk management policies (Munawar et al., 2022). Flood resilience technologies possess the capacity to reduce damage related to and caused by flooding (Ebekozien et al., 2024; White et al., 2018).

The aim of this paper is to investigate the technological interventions to improve flood resilience in the built environment. In achieving this aim, a comprehensive literature review was conducted focusing on the key areas of study such as flood, disaster, resilience, technologies and the built environment. Integration of state-of-the-art technological developments, examining current practices, identifying the barriers to adoption of technologies, and proposing strategies to address such barriers were the main objectives of the literature review. The paper derived a conceptual framework incorporating the key technologies that can be used to enhance flood resilience in the context of built environment. The scope is limited to flood resilience and does not extend to other types of disasters or to non-technological approaches. As such, the next section reviews the flood resilience in the built environments, followed by the technological intervention to achieve flood resilience in the built environment.

2. FLOOD RESILIENCE IN THE BUILT ENVIRONMENT

2.1 IMPACT OF FLOOD ON THE BUILT ENVIRONMENT

Floods are one of the most devastating natural disasters, causing substantial loss of life, assets, and fortune (Dutta et al., 2023). The built environment consists of man-made building and infrastructure stocks that represent physical, natural, economic, social, and cultural capital (Hassler & Kohler, 2014). The built environment plays a vital role in societies as it serves to safeguard people and infrastructure from natural disasters (Wei et al., 2021). The built environment is significantly affected by flood disaster (Li et al., 2024). The occurrence of floods causes significant losses to ecology, flora and fauna, assets, and human lives. Economic repercussions include household damage, industry loss, and crop devastation. At the public level, economic consequences include the breakdown of power plants, water and sewerage systems, and damage to roads and bridges (Dube et al., 2018; Rathnasiri et al., 2023; Yereseme et al., 2022). Flooding can significantly damage the functionality, safety, and sustainability of the built environment, especially where urban development gets in with flood-prone areas (Alabbad & Demir, 2024). As such, floods are having a significant influence on the built environment because they compromise structural integrity and interrupt essential services, reflecting the vulnerability of the built environment.

2.2 FLOOD RESILIENCE

The term "resilience" refers to a system, community, or society's ability to tolerate, absorb, accommodate, adapt to, transform, and recover from the consequences of a danger in a timely and effective manner (Sarker et al., 2020). Resilient methods foster quicker recovery for individuals, communities, and buildings (White et al., 2018). Resilient construction involves planning and constructing buildings and infrastructure that can quickly recover from natural disasters, climate change, and other risks (Chmutina & Rose, 2018). Flood resilience measures may allow water intrusion but aim to reduce damage and improve recovery (White et al., 2018). In the flood domain, resilience is constantly characterized by the interplay of people (e.g., financial level, health status, past experience, and the physical environment) (Zevenbergen et al., 2020).

Reducing the vulnerability of the system or community while increasing its capacity would help to achieve resilience (Lanlan et al., 2024). The United Nations Office for Disaster Risk Reduction (UNDRR) has defined vulnerability as "the conditions determined by physical, social, economic, and environmental factors or processes that increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards". The degree of vulnerability is determined by the design, predisposition, fragilities, inborn capacity, or weakness of the exposed elements, whereas the capacity is the integration of all the assets, attributes, and capacities that a community, organization, or society has to manage and lower the risk of disaster (Chaudhary & Piracha, 2021). According to Lanlan et al. (2024), vulnerability often decreases with increased resilience, and identifying the weakest points in social-ecological systems is the focus of vulnerability.

Flood risks for vulnerable urban areas are being further increased by inadequate drainage systems and heavy runoff from impermeable surfaces in developing country urban settlements (Rana et al., 2021). Strengthening flood resilience in the built environment needs proactive planning and the combination of adaptive measures during planning and construction stages (Mannucci et al., 2022). Investing in physical infrastructure is critical for enhancing flood resilience technology (Ebekozien et al., 2024). Reducing vulnerability and increasing the capacity would therefore increase resilience, and vice versa (Graveline & Germain, 2022).

2.3 ROLE OF TECHNOLOGY IN ENHANCING FLOOD RESILIENCE IN THE BUILT ENVIRONMENT

Technology plays a vital role in enhancing disaster resilience and reducing vulnerability (Akinosho et al., 2020). Creating resilient technologies is essential for reducing threats to the built environment. However, a common emphasis is on designing these technologies to be responsive to the socio-economic conditions of the environment in which they will be applied (Bosher & Dainty, 2011). While other industries use technology to stay ahead, the construction industry's productivity is often unstable or declining due to underinvestment in technology, and the use of technology is showing potential to assist the pre- and post-event stages of disaster management (Akinosho et al., 2020; Galera-Zarco & Floros, 2024). With the global impacts of climate change intensifying, it is essential for stakeholders to adopt innovative approaches to strengthen climate resilience within the built environment (Ebirim et al., 2024).

Innovative technologies can significantly reduce risks both before and after disasters and they are expected to play an important role when it comes to the enhancement of resilience in the built environment (Galera-Zarco et al., 2024). Flood-resilient technologies have the capacity to reduce damage caused by flooding (White et al., 2018). Digital innovations related to Industry 4.0 have emerged as essential instruments for this purpose. As a result, technologies and digital transformation have become crucial options for disaster risk management (Ariyachandra & Wedawatta, 2023). In this regard the next section further reviews the technological interventions in flood disaster resilience in the built environment.

3. TECHNOLOGICAL INTERVENTIONS IN FLOOD RESILIENCE IN THE BUILT ENVIRONMENT

The use of cutting-edge technologies will result in notable successes in terms of risk reduction both before and after the disaster (Arabameri et al., 2022). Improving assessment methodologies and understanding of flood risk vulnerability can help decision-makers reduce damage and fatalities (Nasiri et al., 2016). Technologies such as Geo-visualisation, Geographical Information Systems (GIS), Remote Sensing (RS), Internet of Things (IoT) and smart sensors, Artificial Intelligence (AI) and Digital Twins (DT) have significant potential in reducing the vulnerability to flood disasters and intensifying resilience (Ge & Qin, 2025; Hussain et al., 2021; Liu et al., 2025; Munawar et al., 2022; Rehman et al., 2019; Sengupta, 2025; Samarakkody et al., 2023).

Okem et al. (2024) highlighted that the combination of early warning systems and smart technologies has emerged as a factor that is revolutionizing disaster resilience. By enabling real-time monitoring, precise flood prediction, and prompt notifications, these innovations enhance disaster preparedness and lessen the negative impact of floods on infrastructure and communities (Sengupta, 2025). Buildings can be outfitted with IoT sensors that monitor flood levels in real time. These devices transmit alarms to building occupants, prompting them to take action (Jan et al., 2022; Kamal et al., 2025). As a result, incorporating these technologies into the built environment enhances protection and safety while also encouraging adaptive solutions that improve flood resilience.

3.1 KEY TECHNOLOGIES USED FOR FLOOD RESILIENCE

This section elaborates on the key technologies that can be used to improve flood resilience by analyzing the features of each technology.

3.1.1 Internet of Things (IoT) and Smart Sensors

The Internet of Things (IoT) has become an essential tool for disaster management, helping to create resilient and sustainable cities and promoting the collection and analysis of real-time data, offering prospects for urban catastrophe management and enabling inter-device communication through the internet (Zeng et al., 2023). The incorporation of sensors and monitoring systems into critical infrastructure is the foundation of smart technologies in disaster resilience. Real-time data on the performance of buildings, bridges, dams, and other infrastructure elements is obtained through the deployment of sensors, which allows engineers to identify early indications of distress or vulnerabilities (Okem et al., 2024). Sensor systems can continuously observe and analyze certain occurrences, including their geospatial distribution and temporal evolution. The combination of sensor data, GIS, and the Internet has become the primary mode of operation for disaster response systems. It is commonly used for data processing, spatial analysis, and visual representation of disasters. Real-time observations from sensor systems should be continuously updated and interpreted accurately for their intended purposes (Hong & Shi, 2023).

3.1.2 Geographical Information Systems (GIS) and Remote Sensing (RS)

GIS and RS are used for assessing and mapping flood vulnerability (Hussain et al., 2021). According to Leeonis et al. (2025), GIS is a useful tool for assessing flood impacts after they have occurred, assisting with recovery planning, and updating risk assessments going forward. Remote sensing technologies have become essential for flood management, offering prompt and comprehensive information vital for disaster response and damage evaluation (Sengupta, 2025).

Post-flood damage assessments use GIS technology to compare pre- and post-disaster images, identifying affected areas and calculating recovery costs. GIS maps are commonly used in community awareness campaigns to educate residents about flood preparedness and evacuation routes (Leeonis et al., 2025). Sengupta (2025) further stated that GIS enables complete flood risk assessments by combining varied information, including topography, bathymetry, and flood defense infrastructure. Nakhapakorn et al. (2022) explored the application of geospatial technologies such as GIS to assess the physical vulnerability of buildings to the risk of urban floods, and the study was focused on Warin Chamrap municipality in Thailand, which is a region vulnerable to frequent flooding. This demonstrates that the availability and utilization of technology has the potential to reduce the physical vulnerability of building structures to floods.

3.1.3 Artificial Intelligence (AI)

Artificial intelligence techniques utilize algorithms for the examination of extensive datasets, encompassing machine learning techniques (algorithms capable of learning from data without dependence on rule-based programming) and deep learning techniques (a subset of machine learning consisting of algorithms that enable software to execute tasks, such as image recognition, by exposing multilayered neural networks to substantial volumes of data) and these technologies are capable of providing four main analytics types namely, (1) descriptive analysis; analysis of past and current situations, (2) diagnostic analysis; casual factor analysis for a given event, (3) predictive analysis; analysis of the potential future scenarios (4) prescriptive analysis; analysis of the actions which has to be taken (Asian Development Bank, 2020). With respect to design specifications, understanding the nature of potential floods permits engineers to include appropriate flood resistant features into the design of the buildings, such as reinforced materials and elevated structures. This reflects that the application of AI in flood resilience for planning and construction is a game changer, and decision-makers will be able to design, construct, and maintain infrastructure that is well prepared for severe flood events by leveraging AI-driven data analysis, predictive modelling, and real-time monitoring, which would significantly reduce the vulnerabilities in the built environment (Saravi et al., 2019).

The study carried out by Saravi et al. (2019), explores innovative applications of AI, specifically Machine Learning (ML) to strengthen flood resilience and preparedness. Moreover, the study elaborated on how hydrological patterns, historical flood data, and climate variables can be analyzed by the application of AI driven models to notify on the development of flood-resilient infrastructure, and regarding risk assessment, precise flood classification informs planners regarding potential flood risks in specific areas, accompanying decisions on site selection and zoning to keep away from high-risk zones. Furthermore, Liu et al., (2025) have highlighted that machine learning models can be applied in flood vulnerability assessment.

3.1.4 Digital Twin (DT)

A digital twin is a digital replica of a real-world physical asset that includes a time dimension for all of its features. This model adapts to changes over time and represents various virtual instances at a particular time point. Digital twins evolve with the physical item throughout its life cycle, allowing for real-time bidirectional mappings between physical and virtual assets (Ariyachandra & Wedawatta, 2023). To improve urban flood resilience, digital twin-based resilience management systems have become essential because they allow lifecycle-oriented emergency management to be implemented continuously rather than in discrete phases (Ge & Qin, 2025). Wang et al. (2024) elaborated on the application of digital twin technology during design and construction phases to prevent flooding and to enhance urban resilience.

Amidst severe flooding caused by Hurricanes Irene (2011) and Ida (2021), the town of Manville, New Jersey, encountered major challenges in recovering from flood damage. To support successful and resilient recovery, researchers developed an Urban Digital Twin, a virtual, data-rich replica of the built environment that can be used to guide rebuilding decisions, prioritize actions, and increase community resilience to future floods (Josephs et al., 2024). During the design phase, DT assists in planning of flood mitigation infrastructure such as flood gates, levees and drainage networks, whereas during the construction phase DT could be used for real-time monitoring of the construction activities with regard to material selection for flood resilience. Digital twins not only help to improve the speed and quality of management decisions by visualizing complex data in a simple and accessible way during a disaster, but they can also simulate the evolution of a disaster while taking into account the unique characteristics and conditions of a city, thus acting as a critical element of an early warning system (Josipovic & Viergutz, 2023).

3.1.5 Summary

Table 1 highlights the technological interventions in improving flood resilience, and the corresponding disaster management stage these are applied.

Table 1:Technological interventions for flood resilience

Technology	Interventions	Disaster Stage
Internet of Things & Smart Sensors	Real time monitoring of flood levels, Alerts to building occupants, Monitoring of infrastructure performance	Pre-disaster and post-disaster
Geographical Information Systems and Remote Sensing	Public awareness, Damage assessment, Evacuation route planning	Pre-disaster and post-disaster
Artificial Intelligence	Vulnerability assessment, Predictive flood modelling, Risk informed design and planning	Pre-disaster
Digital Twin	Real time monitoring, Flood mitigating infrastructure design, Simulation of disaster evolution	Pre-disaster and post-disaster

3.2 Barriers and Strategies in Implementing Technologies to Enhance Flood Resilience in the Built Environment

The above sections discussed the key technologies that can help to improve the flood resilience in the built environment while reducing the vulnerability of the built environment against floods. However, there are practical barriers to the implantations of such technologies. Lack of awareness, lack of finances, resistance to adopt resilient measures, lack of reliable information, and absence of clear policies and regulatory frameworks to integrate flood-resilient technologies were identified as the key barriers hindering the implementation of flood-resilient technologies (White et al., 2018; Müller et al., 2024; Asian Development Bank, 2020; McBean & Rodgers, 2010). Collaborative approaches, enhancing awareness, developing the strategies and policies, and encouraging community engagement are some of the measures that can be taken to address these challenges (White et al., 2018; Müller et al., 2024; Nakhapakorn et al., 2022; Nasiri et al., 2016; Okem et al., 2024). Further research is needed to clearly identify the right measures to minimize the implementation of technologies to achieve flood disaster resilience in the built environments (Nakhapakorn et al., 2022).

As per these barriers, it is clear that technology alone is insufficient in order to achieve flood resilience in the built environment. Stakeholder cooperation, institutional preparedness, and strategic planning are also equally important. Hence, construction professionals, urban planners, and developers need to work together in order to bridge the gap between technological interventions and real-world implementation. Construction and urban planning stakeholders should include flood-resilient technologies in design and planning rules, backed up by financial incentives, trustworthy data, and clear regulatory frameworks. Strengthening stakeholder collaboration, creating awareness, and engaging communities are all necessary to overcome opposition and ensure effective implementation.

3.3 A Conceptual Framework to Integrate Technological Interventions to Improve Flood Resilience in the Built Environment

The literature explored the key technologies that can be used to improve the flood resilience in the built environment. It also briefly revealed the barriers in implementing such technologies along with a few high-level strategies. Based on this review, a conceptual framework has been developed, as shown in Figure 1, which will act as a guide to inform this research to further explore the key features of these technologies in reducing the level of vulnerability and increasing the level of capacity of the built environment against flood disaster, while also trying to propose practical strategies to overcome the barriers in implementing such technologies in the context. It maps the relationship between flood resilience in the built environment, vulnerability, and capacity, and identifies essential technological interventions.

In this regard, the framework intends to improve the resilience of built environment, which is the context, against the flood disaster, which is the main disturbance, as stipulated in the focus of this study. As per the theoretical understanding, resilience can be increased by reducing vulnerability and increasing the capacity of the built environment. In doing so, the identified essential technological interventions such as IoT, GIS, AI, and DT play a key role in reducing vulnerability while increasing the capacity of the built environment. However, the barriers for implementation of these technologies mainly in terms of lack of knowledge and understanding, lack of funding and lack of policies or regulatory frameworks are also incorporated in the framework as it helps to make informed decisions in effectively adopting such technologies. Higher level strategies are proposed which will need to be further translated into actions to effectively implement the technological intervention to improve flood resilience in the built environment.

In this context, this conceptual framework provides a basis for expanding this study in terms of exploring the key features of the identified technological interventions to clearly show how such features and technologies would help to enhance flood resilience in the built environment, while also proposing actionable strategies to address the barriers to effectively implement the technological interventions in the context of the built environment.

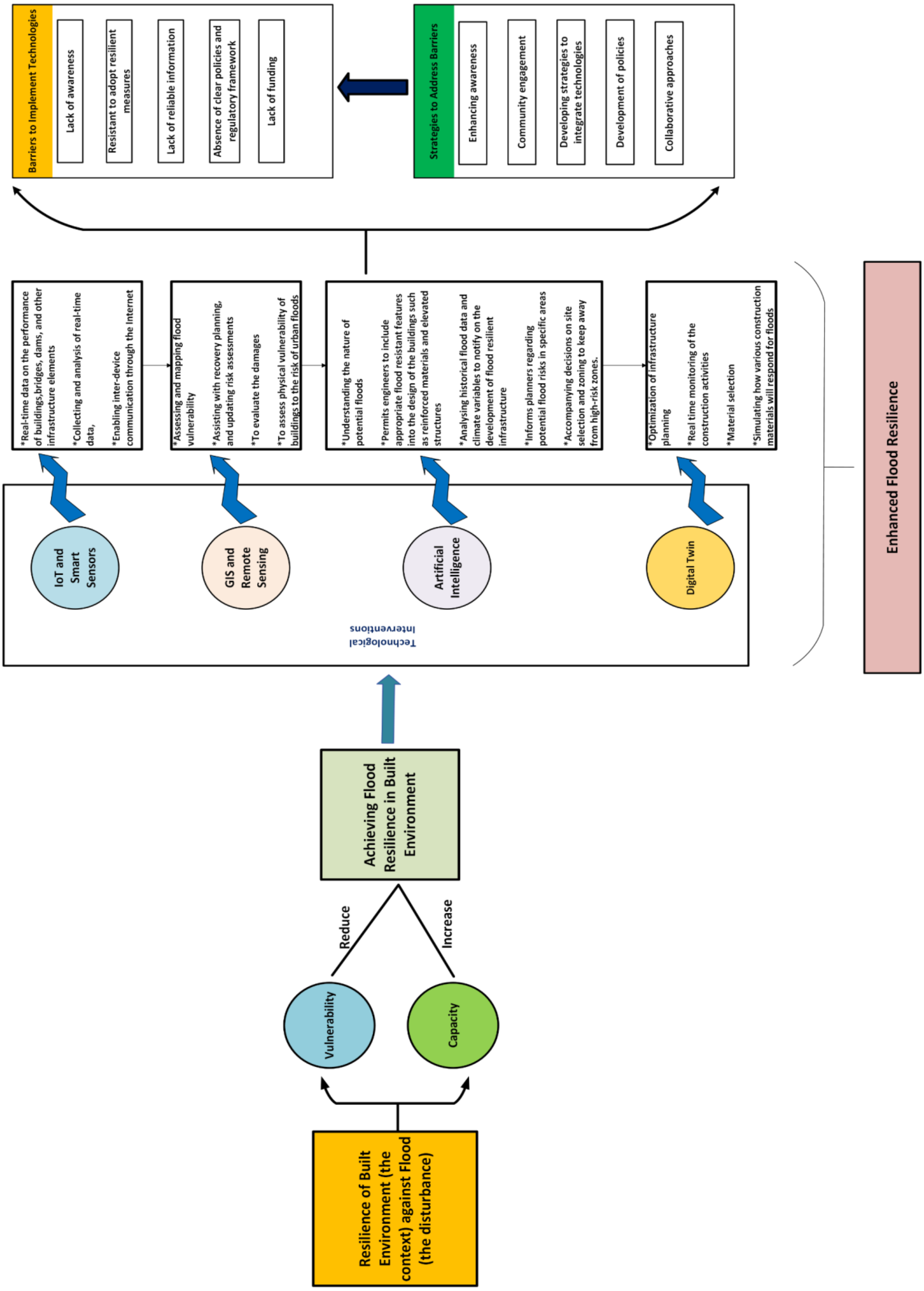

Figure 1: Conceptual framework to increase flood resilience in the built environment

4. CONCLUSIONS

The rising frequency and intensity of floods require a dramatic change in disaster-resilient strategies. This study reviews the key technologies, such as IoT and Smart Sensors, GIS and Remote Sensing, Artificial Intelligence and Digital Twin to enhance flood disaster resilience in the built environment. These technological interventions provide predictive analysis, real-time monitoring, climate-adaptive infrastructure, and advanced simulation modeling in order to enhance flood disaster resilience in the built environment. Integrating these technologies has the potential to provide proactive, more efficient, well as sustainable practices for flood disaster resilience in the built environment. Importantly, to maximize the effectiveness of these technologies, it is recommended that the policymakers integrate them into disaster management frameworks, urban planning regulations, and infrastructure development guidelines. Practical adoption can also be fostered by focused professional training and incentives that encourage technological integration in the built environment. The paper also highlights the barriers in implementing such technologies along with high-level strategies to address such barriers. This paper is based on an ongoing research degree that is at its initial stage. The conceptual framework developed in this paper will be used to further investigate the technologies, barriers, and strategies in detail to improve the flood resilience of the built environment.

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