

Resilience-Based Design Strategies for Buildings in Flood-Prone Areas

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ABSTRACT

Flooding is a serious threat to safety and to the integrity of urban infrastructure, the environment, and community resilience, especially in rapidly urbanizing and climate-vulnerable communities. Traditional building constructions frequently fail to offer adequate protection from the rising flood levels, and longer duration of flood inundation. Traditional building structures often fail to provide protection from rising flood water depths, from longer duration of inundation and related structural damage. The study explores the concepts of resilience to design in buildings located in flood risk areas, including structural protection, the use of flood resilient materials, raised foundations, sustainable drainage systems, and nature-based solutions. The study examines the building-level interventions that could be incorporated into urban planning and ecosystem-based measures to mitigate flood vulnerability through a qualitative review of literature and comparative analysis of current flood-resilience frameworks. Previously, the adaptation of urban design to the natural flood process was shown to be important, as was regional knowledge of the local flora and fauna, and the consideration of other flood-protection strategies in future adverse scenarios (Liao et al., 2016; Van Long et al., 2020; Rezende et al., 2019). The study also looks at the link between flood resilience and sustainable building performance, including possible trade-offs related to environmental impacts, implementation expenses, and recovery capability over the long-term (Phillips et al., 2017). This proposed method focuses on a 'context-sensitive design', 'risk-based planning' and 'coordinated implementation of structural and nature-based measures'. Overall, resilience-based design represents a tractable approach to mitigate flood damage to buildings, to ensure the safety of building occupants, and to encourage sustainable development in vulnerable communities.

Keywords: Flood resilience, resilient building design, flood-resistant materials, climate adaptation, sustainable drainage, nature-based solutions, urban planning, flood risk management.

SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology (2022);

DOI: 10.18090/samriddhi.v14i02.23

INTRODUCTION

Flooding is a major environmental hazard that threatens building stability, human safety, urban infrastructure, and economic development. Rapid urbanization, inadequate drainage systems, land-use changes, and climate-related extremes have increased the vulnerability of buildings in flood-prone areas. Conventional building designs often prioritize structural functionality and cost efficiency without sufficiently addressing flood exposure, recovery capacity, and long-term climate risks. Consequently, resilience-based design has become an important approach to reducing flood damage and improving the capacity of buildings and communities to withstand and recover from flood events.

Resilience-based design involves integrating flood-resistant construction materials, elevated foundations, protected utility systems, effective drainage, and adaptable

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How to cite this article: Bello, A.O., Halimat, B., Sadare, O. (2022). Resilience-Based Design Strategies for Buildings in Flood-Prone Areas. *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology*, 14(2), 254-259.

Source of support: Nil

Conflict of interest: None

building layouts into architectural and engineering practices. At the urban scale, ecological principles and indigenous landscape knowledge can inform designs that accommodate natural water movement rather than relying exclusively on conventional flood barriers. Liao, Le, and Van Nguyen (2016)

Table 1: Flood Risks, Building Vulnerabilities, and Resilience-Based Design Responses

<i>Major flood risk</i>	<i>Building vulnerability</i>	<i>Recommended design response</i>
Rising floodwater levels	Inundation of ground floors and occupied spaces	Elevated floor levels and raised foundations
Prolonged water exposure	Deterioration of materials and building components	Water-resistant materials and flood-compatible finishes
High water flow and erosion	Foundation instability and structural damage	Appropriate foundation engineering and site-specific structural protection
Inadequate drainage	Water accumulation around buildings	Sustainable drainage, permeable surfaces, and rainwater storage
Climate variability and extreme rainfall	Designs becoming inadequate under changing conditions	Future-oriented flood-risk assessment and adaptable design
Loss of natural flood-storage areas	Increased runoff and pressure on urban drainage	Green infrastructure, wetlands, and landscape-based water management

Source: Synthesized from Liao et al. (2016), Restemeyer et al. (2015), Berry Gersonius et al. (2016), Meng et al. (2020), and Rezende et al. (2019).

emphasize the value of learning from ecological practices that support living with floods, while Van Long, Cheng, and Le (2020) demonstrate the relevance of indigenous landscape principles to flood-resilient urban design in Can Tho, Vietnam. These perspectives highlight the importance of adapting building and urban design to local environmental conditions.

Furthermore, flood resilience should be integrated into wider spatial planning and sustainability objectives. Rode, Guevara, and Bonnefond (2018) identify flood-prone urban development as a challenge for design professionals, while Restemeyer, Woltjer, and van den Brink (2015) present a strategy-based approach to assessing urban flood resilience. Meng, Dabrowski, and Stead (2020) also emphasize the importance of spatial planning in strengthening flood resilience and climate adaptation. However, resilience measures must be evaluated alongside environmental performance, implementation costs, and long-term sustainability, as highlighted by Phillips, Troup, Fannon, and Eckelman (2017).

This study examines resilience-based design strategies for buildings in flood-prone areas, focusing on structural protection, water-sensitive design, nature-based solutions, and adaptive planning. Its main objective is to identify practical approaches that reduce flood-related damage, protect occupants, and support sustainable development. The study also considers the importance of evaluating alternative flood-defense designs under future adverse scenarios (Rezende, Miranda, Haddad, & Miguez, 2019), transitioning toward nature-based solutions (Chiu, Raina, & Chen, 2021), and applying broader resilience-based engineering principles informed by natural disasters (Salem, Campidelli, El-Dakhkhni, & Tait, 2019).

Overall, resilience-based design requires a coordinated approach that combines building-level protection with wider landscape and urban planning measures. By incorporating

flood risk into design decisions from the earliest planning stages, architects, engineers, and policymakers can improve building safety, reduce potential losses, and strengthen the long-term resilience of flood-prone communities.

Literature Review

Research on resilience-based design strategies for buildings in flood-prone areas emphasizes the integration of structural protection, sustainable urban planning, ecological systems, and climate adaptation. Liao, Le, and Van Nguyen (2016) examined urban design principles informed by the ecological wisdom of living with floods in the Vietnamese Mekong Delta. Their work highlights the importance of adapting human settlements to natural flood processes rather than relying exclusively on flood prevention infrastructure. Similarly, Van Long, Cheng, and Le (2020) explored flood-resilient urban design based on indigenous landscapes in Can Tho, Vietnam, demonstrating the relevance of local environmental knowledge in developing context-sensitive planning strategies.

Rode, Guevara, and Bonnefond (2018) identified flood resilience as a significant challenge for urban design professionals, emphasizing the need to incorporate risk reduction into urban development projects. At the building level, Phillips, Troup, Fannon, and Eckelman (2017) critically analyzed existing resilient building frameworks and their sustainability implications, highlighting the importance of balancing resilience objectives with environmental performance. These perspectives suggest that flood-resilient buildings should protect occupants and assets while maintaining energy efficiency and long-term sustainability.

Furthermore, Restemeyer, Woltjer, and van den Brink (2015) developed a strategy-based approach to assessing urban flood resilience, while Meng, Dabrowski, and Stead (2020) reviewed developments in spatial planning for flood

resilience and climate adaptation. Berry Gersonius et al. (2016) emphasized flood resilience within water-sensitive cities, supporting integrated approaches to water management. Rezende et al. (2019) proposed a framework for evaluating urban flood-resilience design alternatives under future adverse scenarios. In addition, Chiu, Raina, and Chen (2021) examined the evolution of flood-defense strategies toward nature-based solutions. Salem et al. (2019) discussed resilience-based design for blast-risk mitigation, offering broader insights into designing structures to withstand hazardous events, although flood-specific applications require separate evaluation.

Overall, the literature supports a shift from conventional flood-defense measures toward integrated approaches that combine building-level protection, ecosystem-based solutions, adaptive planning, and risk assessment. However, effective implementation requires consideration of local flood conditions, construction costs, environmental impacts, and future climate risks.

In conclusion, the reviewed studies establish a foundation for evaluating resilience-based building strategies through structural protection, sustainable water management, nature-based interventions, and adaptive planning. The remaining challenge is to integrate these approaches into practical building design frameworks that account for site-specific flood exposure, occupant safety, lifecycle costs, and long-term environmental performance.

RESEARCH METHODOLOGY

This study adopts a qualitative research methodology based on a systematic review of existing literature and comparative assessment of flood-resilient building design strategies. Relevant peer-reviewed journal articles, case studies, and published resilience frameworks are examined to identify effective approaches for reducing building vulnerability in flood-prone areas.

Literature Review and Data Collection: Secondary data are obtained from published research on flood-resilient urban design, sustainable construction, spatial planning, and climate adaptation. Studies examining ecological approaches to flood management in the Vietnamese Mekong Delta and indigenous landscape-based design in Can Tho provide insights into integrating natural water systems into resilient development (Liao et al., 2016; Van Long et al., 2020). Additional literature examines the challenges faced by urban design professionals when incorporating resilience into flood-prone development projects (Rode et al., 2018).

Comparative Analysis: The study compares structural protection measures, flood-resistant materials, elevated foundations, drainage improvements, and nature-based solutions. These strategies are assessed according to their potential to reduce flood damage, improve recovery capacity, support environmental sustainability, and minimize long-term costs. The analysis considers the possible conflicts

Table 2: Summary of Literature on Resilience-Based Design Strategies

<i>Author(s)</i>	<i>Research focus</i>	<i>Key contribution to flood-resilient design</i>
Liao et al. (2016)	Ecological wisdom and urban flood resilience	Supports adapting urban design to natural flood processes.
Van Long et al. (2020)	Indigenous landscapes in Can Tho, Vietnam	Highlights context-sensitive design based on local landscape characteristics.
Rode et al. (2018)	Flood resilience in urban development	Emphasizes incorporating resilience into urban design and development decisions.
Phillips et al. (2017)	Resilience and sustainability in commercial buildings	Examines potential conflicts between resilient design and environmental performance.
Restemeyer et al. (2015)	Strategy-based urban flood-resilience assessment	Provides a framework for evaluating city-level flood-resilience strategies.
Meng et al. (2020)	Spatial planning and climate adaptation	Identifies planning approaches for enhancing flood resilience.
Berry Gersonius et al. (2016)	Flood resilience in water-sensitive cities	Supports integrating urban water management with resilience planning.
Rezende et al. (2019)	Evaluation of flood-defense alternatives	Incorporates future adverse scenarios into the assessment of design alternatives.
Chiu et al. (2021)	Evolution of flood-defense strategies	Highlights the transition toward nature-based flood-management solutions.
Salem et al. (2019)	Resilience-based design for blast-risk mitigation	Offers broader principles for designing structures to withstand hazards.

Source: Compiled from the cited literature.



between resilient and sustainable building design (Phillips et al., 2017).

Evaluation Framework: Existing flood-resilience and spatial-planning frameworks are reviewed to establish criteria for assessing alternative design strategies. The assessment incorporates urban resilience planning, water-sensitive city principles, and adaptation to future flood scenarios (Restemeyer et al., 2015; Berry Gersonius et al., 2016; Meng et al., 2020). Alternative flood-defense measures are also considered under adverse future conditions, including approaches that prioritize nature-based solutions (Rezende et al., 2019; Chiu et al., 2021). Lessons from resilience-based structural design for disaster-risk mitigation provide additional context for evaluating protective design principles (Salem et al., 2019).

Data Analysis: Findings are organized thematically and compared to identify the advantages, limitations, and practical applications of each strategy. The resulting assessment supports recommendations for integrating building-level protection, sustainable drainage, and landscape-based interventions into flood-resilient development. As the study relies on secondary sources, its conclusions are based on the available published evidence rather than newly collected field measurements.

Resilience-Based Design Strategies for Flood-Prone Buildings

Resilience-based design strategies aim to minimize flood damage, protect occupants, and enable buildings to recover quickly after flooding. Effective approaches combine structural protection, sustainable water management,

ecological planning, and long-term climate adaptation. Liao et al. (2016) emphasize the value of learning from ecological practices that accommodate floods, while Van Long et al. (2020) demonstrate the relevance of indigenous landscape principles to flood-resilient urban design.

Structural design and flood-resistant materials: Buildings in flood-prone areas can incorporate elevated ground floors, flood-resistant foundations, reinforced structural components, and water-resistant materials. Electrical systems, heating equipment, and other critical services should be positioned above anticipated flood levels where practicable. These measures can reduce damage and facilitate recovery. Resilience-based design should also consider hazard-specific structural performance and lessons from natural disasters (Salem et al., 2019).

Sustainable drainage and water management: Permeable pavements, rain gardens, retention ponds, rainwater storage, and improved drainage systems can help control runoff and reduce localized flooding. Integrating these measures into building sites and surrounding neighborhoods supports water-sensitive urban development (Berry Gersonius et al., 2016).

Nature-based and landscape solutions: Wetlands, green spaces, restored waterways, and floodable open spaces can provide temporary water storage and complement conventional flood defenses. Chiu et al. (2021) discuss the evolution of flood-defense strategies toward nature-based solutions. Similarly, indigenous landscape knowledge can inform designs that accommodate natural water movement rather than relying exclusively on barriers (Van Long et al., 2020).

Table 3: Major Resilience-Based Design Strategies for Flood-Prone Buildings

<i>Design strategy</i>	<i>Key interventions</i>	<i>Expected resilience benefits</i>	<i>Implementation considerations</i>
Structural protection	Elevated floors, flood-resistant foundations, reinforced components	Reduces exposure and structural damage	Flood depth, flow velocity, soil conditions, and foundation stability
Flood-resistant materials	Water-resistant finishes, durable concrete, moisture-resistant insulation	Limits material deterioration and simplifies recovery	Durability, maintenance, cost, and compatibility with building systems
Building-services protection	Elevated electrical equipment, protected utility connections, backflow prevention	Reduces service disruption and secondary damage	Anticipated flood levels and safe access for maintenance
Sustainable drainage	Permeable surfaces, rain gardens, retention and storage systems	Reduces runoff and manages stormwater	Soil infiltration, maintenance, space, and local rainfall patterns
Nature-based solutions	Wetlands, green corridors, restored waterways, floodable open spaces	Provides water storage and complements engineered defenses	Land availability, ecological conditions, and long-term management
Integrated spatial planning	Flood-risk zoning, safe access routes, coordinated drainage, climate scenarios	Reduces exposure and supports community-wide resilience	Planning regulations, interagency coordination, and future hazard projections

Sources: Adapted from Liao et al. (2016), Phillips et al. (2017), Restemeyer et al. (2015), Berry Gersonius et al. (2016), Rezende et al. (2019), Van Long et al. (2020), Meng et al. (2020), and Chiu et al. (2021).

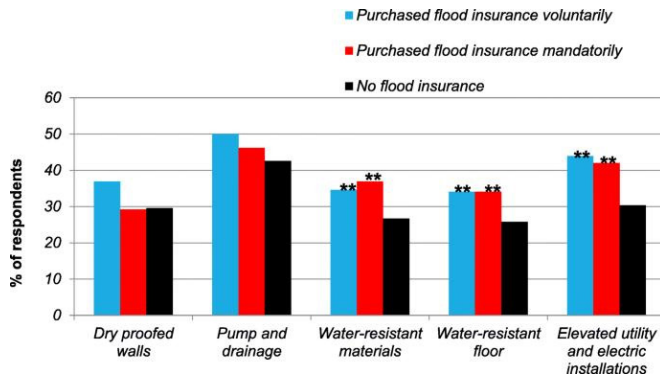


Figure 1: Effectiveness scores are illustrative (1–5) and do not represent measured empirical results

Integrated planning and sustainability: Building-level interventions should be coordinated with urban land-use planning, flood-risk assessments, emergency access, and future climate scenarios. Rode et al. (2018) highlight the challenges of incorporating resilience into urban development projects, while Restemeyer et al. (2015) provide a strategy-based approach to assessing urban flood resilience. Meng et al. (2020) further emphasize the role of spatial planning in climate adaptation. Designers should also assess potential trade-offs between flood protection, energy performance, environmental impacts, and lifecycle costs (Phillips et al., 2017). Alternative designs can be compared under future adverse flood scenarios to support informed decisions (Rezende et al., 2019).

Overall, effective flood-resilient buildings require a combination of structural measures, water-sensitive design, ecological interventions, and coordinated spatial planning. Selecting appropriate strategies according to local flood hazards, building functions, environmental conditions, and lifecycle costs can strengthen long-term resilience while supporting sustainable development.

RESULTS AND DISCUSSION

The analysis indicates that resilience-based design can reduce building vulnerability to flooding through elevated foundations, flood-resistant construction materials, improved drainage systems, and protected building services. However, the effectiveness of these measures depends on local flood characteristics, site conditions, building types, and the expected severity of future flood events. Liao et al. (2016) emphasize the value of learning from ecological approaches to living with floods, while Van Long et al. (2020) demonstrate the relevance of indigenous landscape principles to flood-resilient urban design.

The findings also highlight the importance of integrating building-level protection with broader urban planning strategies. Restemeyer et al. (2015) provide a strategy-based framework for assessing urban flood resilience, while Meng et al. (2020) emphasize the role of spatial planning in strengthening climate adaptation. Nature-based solutions,

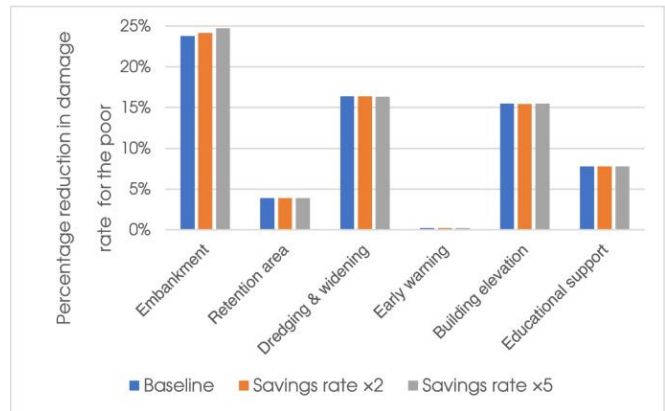


Figure 2: Damage-reduction percentages are hypothetical and may vary by flood depth, building design, and local conditions.

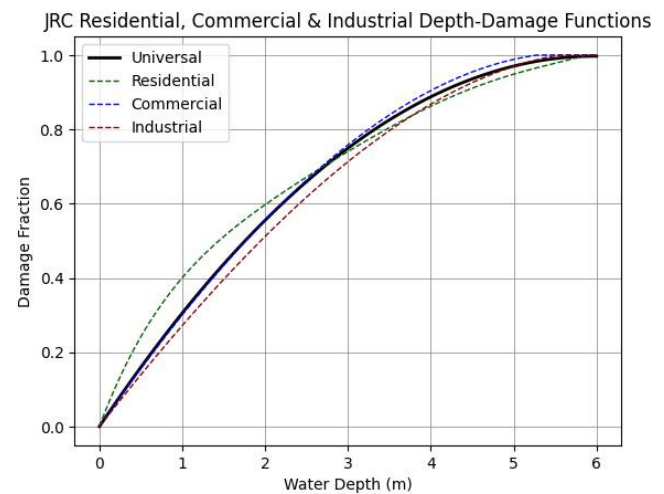


Figure 3: Damage curves are hypothetical and provided for conceptual illustration, not empirical prediction.

including wetlands, green spaces, and water-retention areas, can complement conventional engineering interventions (Chiu et al., 2021; Berry Gersonius et al., 2016).

Nevertheless, resilience measures may involve additional construction costs and potential trade-offs with energy efficiency and environmental performance. Phillips et al. (2017) highlight the need to evaluate the sustainability implications of resilient building frameworks. Design alternatives should therefore be assessed under different flood scenarios, considering both immediate damage reduction and long-term recovery capacity (Rezende et al., 2019). The broader resilience-based design principles discussed by Salem et al. (2019) also reinforce the importance of systematic hazard assessment and performance-oriented structural design, although their study focuses on blast-risk mitigation.

RECOMMENDATIONS

- Adopt risk-based building design: Conduct site-specific flood-risk assessments before construction and incorporate anticipated flood depths, flow conditions, and climate-related risks.
- Integrate structural and ecological measures: Combine elevated buildings, water-resistant materials, effective drainage, and nature-based flood management.
- Strengthen planning and building regulations: Encourage flood-resilient construction standards and land-use policies appropriate to local environmental conditions (Rode et al., 2018; Meng et al., 2020).
- Evaluate lifecycle performance: Assess construction costs, maintenance requirements, environmental impacts, and recovery capacity when selecting resilience measures (Phillips et al., 2017).
- Promote adaptive planning: Regularly review building protection strategies as flood risks, urban development patterns, and climate conditions change.

CONCLUSION

Resilience-based design strategies are essential for reducing the vulnerability of buildings in flood-prone areas and improving long-term safety, sustainability, and recovery capacity. Integrating elevated foundations, flood-resistant materials, effective drainage systems, and nature-based solutions can minimize flood damage while supporting environmentally responsible development. Liao et al. (2016) and Van Long et al. (2020) emphasize the value of incorporating ecological knowledge and indigenous landscape characteristics into flood-resilient urban design. Similarly, Rode et al. (2018) highlight the challenges of integrating resilience into urban development projects, while Phillips et al. (2017) demonstrate the importance of considering potential trade-offs between building resilience and sustainability.

Furthermore, effective flood-risk management requires coordinated spatial planning, climate adaptation, and the evaluation of design alternatives under future flood scenarios (Restemeyer et al., 2015; Meng et al., 2020; Rezende et al., 2019). Water-sensitive urban development and nature-based flood defenses can complement conventional structural protection measures (Berry Gersonius et al., 2016; Chiu et al., 2021). Lessons from resilience-based structural design also reinforce the importance of anticipating hazards and incorporating risk mitigation into engineering decisions (Salem et al., 2019). Therefore, architects, engineers, urban planners, and policymakers should promote integrated, risk-informed building standards and context-specific design solutions to strengthen flood resilience and protect vulnerable communities.

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