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Rising Above the Waters: Pioneering Flood Resilient Housing Development Strategies

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ABSTRACT

The escalating impacts of climate change, particularly the increasing frequency and severity of flooding, necessitate innovative approaches to housing development, especially in flood-prone areas. Hence, this study aims to bridge the gap in Malaysia's current housing development practices as the flood disaster in the country worsen. This study adopts a qualitative research methodology, utilising content analysis of published literature and government policies from four pioneering countries in flood-resilient housing: the Netherlands, United States, Australia, and the United Kingdom. Through a comprehensive review, the article identifies key strategies and attributes for enhancing flood resilience, including adaptive architectural designs, sustainable urban planning, and advanced technological integration. These findings underscore the importance of a forward-thinking, holistic approach to housing development that anticipates future climate challenges. By adopting these cutting-edge strategies and attributes, communities in Malaysia can better withstand and adapt to flooding, ensuring long-term resilience and sustainability. This study offers valuable insights for policymakers, urban planners, architects, and developers focused on building flood-resilient housing solutions.

INTRODUCTION

In the 21st century, geological disasters such as droughts, floods, landslides, debris flows, and ground subsidence have become widespread globally. These natural disasters have severely damaged the ecological environment and threatened human property and economic development (Shah et al., 2023). Flooding is the second most common geological disaster, following landslides and debris flows, and is prevalent

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worldwide (Han et al., 2023; National Geographic, 2023; Zhou et al., 2023). It was predicted that climate change will expose over 90 percent of the global population to flood disasters between 2035 and 2044 (World Bank, 2021). In addition to climate change, rapid urbanisation, and an increasing global population, settlements in flood-prone areas have heightened community vulnerability to flood disasters (Mitchell et al., 2021; Hardoy et al., 2013). Between 1970 and 2019, more than 11,000 flood disasters were reported worldwide, resulting in losses of USD 3.6 trillion and at least 2 million deaths (Santos et al., 2022). In Malaysia, it was reported that the losses incurred in 2021 were the most critical, amounting to RM6.1 billion, equivalent to the total losses over 20 years (Department of Statistics Malaysia, 2023). In addition, the cost of losses related to the demolition of residential areas ranks second highest, at RM1.6 billion, following the destruction of public assets and infrastructure. According to the World Bank (2021), Malaysia ranked 42nd out of 181 nations regarding vulnerability to climate change. This research evaluates a nation's susceptibility to the impacts of climate change and other worldwide concerns to strengthen its ability to recover and adapt. Based on this score, Malaysia still needs to attain disaster resilience due to inadequate adaptation and mitigation measures. This is evident as significant floods started occurring in previously unaffected regions.

Hence, planning to develop flood resilience housing requires a comprehensive assessment and integration among the involved technical agencies to adapt the climate change and create liveable community environments (Hemmati et al., 2020). This is because rapid urbanisation, especially in developing countries, and the threat of climate change impacts present significant challenges to human rights, particularly in accessing land for suitable housing (Mitchell et al., 2015). Rapid development activities have led to urban sprawl into flood-prone areas, necessitating adequate planning controls to avoid severe impacts on communities (Asibey et al., 2022; Oates et al., 2020). The risks communities face includes the destruction of settlements, infrastructure damage, property losses, and loss of life, which require serious attention (National Geographic, 2023; Zhou et al., 2023; Muzamil et al., 2022; Abdeldayem et al., 2020). The fatalistic point of view that considers flood disasters as an “act of God” should not be seen as a justification to accept them as a test. Instead, it necessitates a change in approach by responsible organisations to implement more effective strategies and minimise the consequences of such events as much as possible (Keating et al., 2016; Reynard et al., 2017; Manyena et al., 2011; Pohekar, 2023).

From the perspective of housing development control in Malaysia, various legislations have been enacted, such as the National Land Code 1965, the Town and Country Planning Act 1976, the Local Government Act 1976, the Land Conservation Act 1960, the Irrigation Areas Act 1953, the Drainage Works Act 1954, the National Forestry Act 1984, the Uniform Building By-Laws (UBBL) 1984, as well as planning guidelines such as the Housing Development Planning Guidelines and the Resilient City Planning Guidelines. In April 2023, the 41st National Physical Planning Council agreed with the proposal to adopt the ‘Pelan Induk Saliran Mesra Alam’ (PISMA) in the approval process for Planning Permission and at the local plan review stage. However, implementation at the regional level remains a question as flood disasters continue to worsen (Norizan et al., 2021). Furthermore, these legislations have yet to have specific provisions to address flood disasters (Hawa et al., 2023; Sobian, 2016; Saifulsyahira et al., 2016). This situation indicates that flood disaster management in the country still needs to be strengthen and integrated between effective legislative frameworks and flood management mechanisms (Ridzuan et al., 2022; Elias et al., 2013). In the current process of considering housing application approvals, assessment of flood disaster resilience attributes is given less emphasis, which makes community settlements vulnerable to flood disasters (Osei-Kyei et al., 2023). Assessing flood disaster resilience attributes is essential to enable housing projects to adapt to the impacts of climate change and minimise the flood disaster consequences faced by communities living in those areas.

In the context of planning, the pre-development phase of housing requires the application for Planning Permission (PP) under the provisions of Section 19(1) Town and Country Planning Act 1976 (Act 172). The Local Planning Authority and the involved technical departments will consider the PP application

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based on the criteria detailed in the Development Proposal Report or 'Laporan Cadangan Pemajuan' (LCP). For example, the third criterion of the MyLCP Score Card considers site planning analysis that includes the current site conditions, topographic profile, site landscape, environmental quality, drainage, and so on, along with the application of the PISMA; there is still a need to add an assessment of flood disaster resilience attributes at the planning approval stage of housing development. For example, flood hotspots and flood-prone areas must be integrated into the evaluation workflow to consider housing development application approvals. This assessment should be part of the decision-making workflow at the local authority level to consider the approval of PP applications. The absence of this assessment could potentially result in flood disaster risks faced by communities due to the increasingly evident threat of climate change, such as hefty rainfall exceeding the capacity of existing drainage systems to handle the volume of surface runoff produced. The impact of flood disasters in residential areas has posed significant challenges to local authorities, highlighting the need for strategies to improve current planning approvals to enhance the resilience of community settlements to be built, enabling them to adapt to future climate change (Haryanti, 2023).

Nonetheless, land management is crucial and needs to be more prepared to address the threats of climate change, involving appropriate settlements to strengthen disaster resilience capacity (McEvoy et al., 2020; Unger et al., 2017; Mitchell et al., 2019). The threat of climate change can lead to human mobility, involving migration, relocation, and resettlement of communities (Mitchell et al., 2019). Hence, land management should be seriously emphasised to enhance disaster resilience, especially in housing development, as a strategy for climate change adaptation and more efficient disaster risk management (Oates et al., 2020). In addition, housing is a basic human need and constitutes a permanent asset. Thus, local authorities play a crucial role in ensuring the well-being of communities in line with the provisions of the Local Government Act 1976 (Act 171), which includes providing safe and resilient settlements. With the implementation of flood disaster resilience attribute assessments, the impacts and risks borne by the community can be minimised, especially for developments in flood hotspot areas. Thus, assessing flood disaster resilience attributes can be an early strategy to reduce the long-term risks of flood disasters. Therefore, this article is crucial for identifying flood-resilient attributes from global best practices that should be integrated into Malaysia's housing development process to enhance flood resilience. Understanding these theoretical scenarios will form a foundation for future directives in Malaysia's planning framework, particularly in implementing strategies to enhance flood-resilient housing across the nation which is aligns with the Eleventh and Thirteenth Principles of the Sustainable Development Goals (SDG-11 and SDG-13) to create more climate-resilient community settlements.

METHODOLOGY

This article employs a qualitative research methodology, underpinned by content analysis of published articles and government policies related to flood-resilient housing development attributes. According to Green et al. (2006) the primary categories of narrative literature reviews include editorials, comments, and overview articles. This article applies a comprehensive narrative synthesis for reviewing published articles governments policies from chosen countries that are pioneers in global flood-resilient housing development. This review briefly summarises key findings on flood-resilient housing development, highlighting strategies and attributes that enhance its effectiveness. The first step is identifying related articles from databases of Web of Science, Scopus, Emerald Publishing and Google Scholar. This search was based on keywords of "flood resilient in housing development", "flood resilient strategies", and "enhancing flood resilient in housing development". This yielded 145 relevant articles, with 99 selected after screening. The study focuses on four benchmark countries—recognised by World Bank (2022) as pioneers in flood risk management in housing development: the Netherlands, the United States, Australia, and the United Kingdom. Data from previous studies and government documents form the foundation for this review, which summarises key strategies and attributes that enhance flood-resilient housing development across these nations.

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These countries also were selected for their innovative and adaptive strategies in mitigating the risks of flooding, particularly in urban development. Their approaches serve as global models for addressing the challenges posed by increasing flood risks due to climate change, offering valuable insights for flood-resilient housing development. Thus, the primary data for this study were sourced from published articles and governmental policies specifically targeting housing development attributes in flood-prone areas within these nations. Next, content analysis was conducted to identify key attributes and strategies embedded in these documents, particularly focusing on flood resilience features such as infrastructure adaptability, housing design, and material use. The content analysis involved systematically coding and categorising policy attributes to detect recurring themes and strategies that contribute to flood resilience in housing developments.

This approach facilitates a comprehensive understanding of the various approaches used by these nations to integrate flood resilience into housing design and urban planning. For example, in the Netherlands, the focus on integrated water management strategies, including amphibious housing and flexible infrastructure, represents a shift toward living in harmony with water. In the United States, post-Hurricane Katrina reforms in New Orleans promoted elevated housing and sustainable building materials to withstand future floods. Similarly, Australia's Queensland region revised its building codes to encourage elevated and reinforced housing designs to combat frequent cyclones. In the United Kingdom, flood resilience measures emphasise adaptive infrastructure and community programs aimed at raising awareness and using water-resistant materials in construction. Through content analysis, this study categorises these diverse approaches and identifies key attributes that can serve as best practices for flood-resilient housing developments globally. The findings from this research are elaborated upon in the subsequent subsections, which examine case studies from each country.

RESULTS AND DISCUSSION

Lesson on The Best Practices: Flood Resilient Housing in the Netherlands

The Netherlands, known for its expertise in water management, including flood resilience, has also pioneered the development of guidelines and infrastructure to prevent flooding. The country's geography is located at the rivers Rhine, Meuse, and Scheldt delta. Approximately two-thirds of the country is situated below sea level. Given its geography, the country has long invested in innovative approaches to living with water, including flood-resilient housing. According to Tromp et al. (2022), without a comprehensive flood defence system, a significant part of the county would be susceptible to floods caused by high water levels in the sea, rivers, or lakes. Historically, the Dutch have implemented comprehensive water management strategies integrating flood-resilient housing into broader urban planning efforts. One of the most notable projects is the 'Ruime voor de Rivier' (Room for the River), which began in 2007 by the national government (Bos et al., 2018). This initiative aims to give rivers more space to overflow safely by relocating dikes and creating water retention areas using the Nature-Based Solution Concept.

In tandem, innovative housing developments like the amphibious housing in Maasbommel demonstrate how residential areas can adapt to rising water levels (Nillesen, 2022). According to European Environment Agency (2024), these amphibious homes in Maasbommel comprise a broader riverside project, including 14 floating and 32 amphibious houses. These dwellings have a light timber-frame structure built on top of a concrete barge, which may be utilised for storing items in the basement (refer to Figure 1). Each pair of residences is equipped with guidance posts and utility connections in the centre. In addition, this design enables them to effectively manage water level changes of up to 5.5 meters, which is particularly important as these homes are situated outside the protective boundaries of the regional dike system (Ahmed, 2023). In 2011, after being built for six years, the houses experienced their first flood without any problems, and the residents expressed great happiness with their homes. Although developers and many floating homes

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already exist in the Netherlands, the project faced legal obstacles because of ambiguous legislation concerning amphibious construction and zoning regulations (Penning-Rowsell, 2020). In 2020, the Netherlands had several hundred "water houses," a type of amphibious housing (Tatlı, 2024).

Fig. 1. The Amphibious Houses in Maasbommel

Source: European Environment Agency (2024)

Regarding Maasbommel, there was both suitable technology and a developer who expressed interest (European Environment Agency, 2024). Nevertheless, acquiring the necessary permission to build proved challenging due to a lack of expertise with the regulatory requirements and reluctance to construct in regions deemed hazardous (Nillesen, 2022). Although stakeholders engaged in the development of floating houses are highly enthused about the concept, the planning process for new ventures continues to be challenging due to three primary concerns (Penning-Rowsell, 2020). There is a persistent lack of clarity on the understanding and application of regulations by the municipality and Rijkswaterstaat, resulting in substantial delays in the construction process. Enacting consistent legislation could facilitate the establishment of a steady market for these advancements (Tatlı, 2024). Existing land use plans frequently need to incorporate floating dwelling designs, impeding their acceptance. One way to address this problem is to create clear instructions for local governments on understanding and applying national laws based on local circumstances.

Furthermore, developers need more confidence in the volatile housing market, which hinders the rate at which it is embraced (English et al., 2016). As an illustration, the Maasbommel project received approval under a trial policy program initiated by the Dutch Ministry. However, this program has now concluded, implying that new projects must adhere to the conditions set by Rijkswaterstaat. This entails developers assuming financial responsibility for implementing steps to mitigate any interference with water flow caused by the housing (Ameh et al., 2024; Purification, 2024). This significant challenge arises from the unusual construction methods, which result in increased construction expenses and a restricted pool of potential buyers. The municipality also classified amphibious homes as holiday homes, but some were occupied permanently, which the municipality strongly condemned (Piątek, 2023). Nevertheless, this is a negligible legal matter unrelated to the project's adaptability and has no impact on its overall societal acceptability. This indirectly indicates a rise in the popularity of floating houses. Despite the initiation of legislative drafting by the Netherlands Ministry of Housing and Civil Service in 2015 to clarify laws for amphibious houses, modifications still need to be implemented as of 2022.

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Lesson on the Best Practices: Flood Resilient Housing Practise in the United States

The United States of America, with its vast and diverse geography, is frequently affected by hurricanes and massive floods, particularly in its coastal and low-lying areas. This country encompasses diverse geographical features, including coastlines, mountain ranges, plains, and river systems. The varied terrain in this area significantly influences the trajectory and consequences of hurricanes, which predominantly impact the Atlantic and Gulf Coast regions (Park, 2021). The Atlantic and Gulf Coasts of the United States, encompassing states such as Florida, Texas, Louisiana, and North Carolina, are highly vulnerable to hurricanes because of the warm waters of the Atlantic Ocean and Gulf of Mexico, which provide the necessary energy for the formation of these intense tropical storms (Corkran, 2024). The absence of significant elevation in the southern shore facilitates the preservation of hurricanes' strength as they go inland, frequently resulting in extensive destruction. States around the eastern seaboard, such as South Carolina and Virginia, are susceptible to adverse weather conditions, including powerful winds, substantial rainfall, and storm surges, which can lead to floods and infrastructure destruction (Ingram et al., 2013). Furthermore, the Atlantic hurricane season, from June 1 to November 30, reaches its highest point between August and October, when ideal circumstances for hurricane formation are present, raising the probability of storms affecting the country.

Therefore, the vulnerabilities associated with these circumstances have positioned the United States government as a global leader in establishing guidelines. Specifically, the Federal Emergency Management Agency (FEMA) has significantly developed flood resilience guidelines (Cutter & Smith, 2009). For many years, FEMA has issued recommendations and standards for floodplain management and resilient construction methods. The National Flood Insurance Program (NFIP), formed in 1968, incorporates construction regulations to mitigate flood-related destruction (Zhang, 2024). One of the massive impacts on the country was Hurricane Katrina in 2005, which hit New Orleans and embarked on a massive rebuilding effort focusing on flood resilience (Nigg et al., 2006). Historically, Hurricane Katrina resulted in the most significant displacement of individuals within the United States since the Dust Bowl of the 1930s (Gutmann, 2010). Approximately 1.2 million individuals relocated from their residences and towns in a matter of hours or days before the arrival of Hurricane Katrina on the Gulf Coast on August 29, 2005 (Cutter & Smith, 2009). The subsequent flooding of New Orleans forced the remaining 100,000 to 120,000 residents to quickly evacuate, creating an urgent need for shelter and housing (Seidman, 2013).

United States Department of Housing and Urban Planning launched the Resilient Building Codes Toolkit in June 2022 to assist communities in developing and implementing building codes that enhance resilience to natural disasters. This toolkit provides guidance, resources, and best practices to help local governments and stakeholders improve the safety and durability of their buildings in the face of climate change and other hazards. Regarding Hurricane Katrina in New Orleans, the government has implemented multiple steps to enhance flood resistance in the aftermath of Hurricane Katrina. The U.S. Army Corps of Engineers has improved the levee and floodwall systems to provide better protection from storm surges (Adesina et al., 2024; Carter, 2005). Additionally, there have been initiatives to restore coastal wetlands, which serve as natural buffers. Local participation has been crucial in fostering community engagement in resilience planning and educating about flood threats (Morello-Frosch, 2011). Public awareness of these dangers is enhanced by initiatives that promote individual mitigation techniques. The National Flood Insurance Program (NFIP) provides financial protection, while initiatives such as the Hazard Mitigation Grant Program offer property elevation and floodproofing assistance (Horn & Brown, 2017). The collective endeavours seek to establish a more robust New Orleans, capable of enduring future floods and adjusting to the effects of climate change.

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One notable example of a flood-resilient house in the country is a floating house in New Orleans (refer to Figure 2). Morphosis, an architecture firm, constructed a floating house in New Orleans as a component of the "Make It Right" initiative following Hurricane Katrina (Wagner & Frisch, 2014; Moon, 2015). In addition, the house incorporates affordable, preassembled components and is specifically engineered for convenient relocation and customisation in diverse flood-prone regions. The basis of the structure is constructed using polystyrene foam, which is then coated with a layer of glass fibre and concrete. This base serves as a containment for the plumbing and electrical systems. The house could remain buoyant up to 3.6 meters above the ground during a flood. It is secured and put in place by guideposts to prevent it from drifting away.

Fig. 2. (left) The Floating House in New Orleans; (right) one of the rebuilt houses in Lower Ninth Ward

Source: Moon (2015)

Although many recovery plans after Storm Katrina have recognised the importance of considering future hazards, they have yet to directly address the growing threat of floods caused by subsidence, rising sea levels, and potentially more intense storm activity (Grossi & Muir-Wood, 2006). The Louisiana Recovery Authority (LRA) is spearheading the recovery endeavours, utilising the Unified New Orleans Plan (UNOP) as a blueprint for directing federal funding toward reconstruction (Amdal, 2013). UNOP aims to revamp the storm flood protection system and provide people and investors with information regarding recovery decisions. Policymakers must comprehensively understand inherent flood threats that cannot be controlled and modifiable elements such as property elevation and vulnerability. To reduce future flood damage, it is advisable to construct buildings that are flood-resistant or capable of enduring temporary flooding (Wilson, 2008). Policymakers require impartial and specialised guidance to assess their influence on flood vulnerability appropriately. Despite implementing enhanced levees or raised properties, the risk levels associated with flood threats will persistently escalate. FEMA's current flood risk maps may no longer accurately depict the evolving dangers of floods.

Lesson on The Best Practices: Flood Resilient Housing Practise in Australia

Australia is known as an archipelago nation, bordered by three prominent oceans: the Indian Ocean to the west and northwest, the Pacific Ocean to the east and northeast, and the Southern Ocean to the south. Australia's coastline is adjacent to several seas. Australia's seas include the Arafura Sea, which is positioned between northern Australia, Papua New Guinea, and Timor, as well as the Coral Sea, which is placed between the northeast coast of Australia, Papua New Guinea, and the Solomon Islands, according to (Strating & Wallis, 2024). The Tasman Sea is in the south-eastern region of Australia and serves as a marine demarcation between Australia and New Zealand.

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This nation's topography and climatic circumstances significantly contribute to its vulnerability to flooding Shanafield et al., 2024; Wilby & Keenan, 2012; Pittock et al., 2006). Coastal plains and low-lying regions of significant size are susceptible to the impacts of storm surges and floods from rivers (Hague et al., 2022). Tropical cyclones in Northern Australia result in substantial precipitation and flooding along the coast and inland. Also, the monsoon season in the northern region results in substantial precipitation (Dey er al., 2019). Furthermore, urbanisation and urban sprawl in flood-prone areas are exacerbated by the alteration of natural water flow and the resulting increase in runoff, which heightens flood risks (Ramezani et al., 2023). In addition, extended periods of rainfall can result in soil saturation, which diminishes the soil's capacity to absorb water and enhances surface runoff, contributing to flooding. Moreover, significant flood occurrences in the nation, such as the Brisbane Flood in 1974, the Queensland and Victoria Flood in 2011, and the more recent Eastern floods in 2022, exemplify the impact of urbanisation on flood dynamics through the augmentation of impermeable surfaces in urban regions. These factors and challenges emphasise the need to adopt effective urban design and flood control strategies to mitigate the impacts of floods in these regions.

Adapting to environmental changes has occurred since the beginning of human history, but it is becoming more critical as civilisations become aware of their susceptibility to the speed and direction of human-caused climate change (Singh et al., 2022; Wilby & Keenan, 2012). Dealing with floods necessitates acknowledging that some level of damage is unavoidable. However, the right policy and technical steps can lessen these unintended effects. Local groups and people are working to make their towns more resistant to and resilient in the face of flooding, while larger-scale river basin planning and city land management are also making adaptations.

The devastating 2022 floods in Queensland to Tasmania were among the costlier disasters in the country. It is the turning point, and there have been demands for building regulations to include provisions for flood-resilient design and land use planning to avoid building in areas with a high risk of flooding (Fryirs et al, 2023). Before the event, Australia already has their planning guideline for enhancing its flood resilience. For example, Lake Macquarie City Council also published the *Flood Resilient Housing Guideline* in February 2024, outlining strategies for building and modifying homes to withstand flood events better, focusing on design principles that enhance structural resilience and minimise damage and recovery time. Moreover, *Flood Resilient Building Guidance for Queensland Homes* was published in 2019 and provides strategies and recommendations for constructing and renovating homes to withstand flooding, focusing on elevating structures, using water-resistant materials, and implementing design features that minimise flood damage and facilitate recovery. In August 2022, the Queensland Government also published *Design Guidance for Flood Resilient Homes,* which provides recommendations for designing and constructing homes to withstand and recover from flood events, emphasising elevated structures, water-resistant materials, and features that facilitate rapid recovery and minimise damage. The most recent guideline published in May 2024 is Building Flood Resilience for Homes & Business by Cairn Reginal Council, Queensland. This recent guideline offers practical advice and strategies to improve the resilience of homes and businesses against flooding. It emphasises using flood-resistant materials, elevating structures, and implementing design changes that minimise damage and expedite recovery after a flood event.

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Table 1. Summary of flood resilient housing attributes guideline in Australia.

Guideline (Year of Publication)	**Strategies**
Lake Macquarie City Council Flood Resilient Housing Guideline (2014)	Site analysis: assess the site soil type and structure, surface water run-off or ponding, safest point of the site for building, drainage measures and appropriate outlets. Site design: utilise the safest part of the site, design appropriate protection works including raising of floor height, bearer and joist construction on piers and piles, increasing the height of concrete slab foundation, floatable foundations.
Flood Resilient Building Guidance for Queensland Homes (2019)	Landscaping: reduce impervious surface areas, permeable fencing to allow flood waters through, localised year-based drainage solution, bioswales, rain garden system, berms, water-resistant materials, relocate yard-based structures, yard levels, rainwater tanks. External services: anchor rainwater tanks and relocate board, elevate the electrical board, install separate circuits on ground & upper levels, elevate air conditioner condenser, elevate hot water unit, install non-return valves, elevate pool pump and electrical power system. External cladding and structure: install water-resistant external cladding, use single skin construction systems, use composite construction system, consult a registered RPEQ Structural Engineer for advice regarding damage to the external structure and cladding, provide adequate drainage and ventilation to the subfloor area, install air vents with automatic water prevention, replace water damage or non-water resistant structural bracing, allow water to drain from within steel columns, design without cavities under stairs. Others design: double brick construction, brick veneer construction, wall framing, insulation, consult for internal structural damage, and water-resistant internal floors and ceilings.
Design Guidance for Flood Resilient Homes Queensland Government (2022)	Stairs: make the bottom riser of stairs removable for easy cleaning and drying cut, replace closed riser stairs with open riser stairs made from flood resilient materials. Services: raise air conditioning condenser units, raise the electrical switchboard, raise storage hot water unit, raise the water tank pump and electrical systems, install separate circuits (with breakers) on the lower and upper levels. Walls: non-cavity walls to minimise the chance of mould, flood resilient wall framing to minimise the chance of mould or damage, paint existing pine frame cavity walls to assist in future cleaning and prevent mould growth, replace loose-fill insulation with rigid cell insulation in cavity walls, replace wall linings with flood resilient wall linings, add additional weep holes to help dry out the wall cavity or sub-floor, replace non-resilient mouldings and skirtings with water impervious mouldings, replace non-resilient flooring and skirting with flood resilient flooring and skirting, use flood resilient grout and apply flood resilient sealant when tiling or re-tiling wet areas, surface control on sub-floor ground to increase resilience. Openings: replace hollow core doors with solid core doors, install flush door sills to ensure easy cleaning after a flood event, replace cavity sliding doors with a swing or face-of-wall sliding doors, door changes to maximise the existing opening, retrofit garage doors with permeable doors to allow water to flow through. Cabinetry, bathrooms, and laundry: replace non-resilient cabinetry with flood resilient cabinetry, allow cabinetry kickboards to be removable, install raised cabinetry, raise kitchen appliances, raise storage shelves, install a removable panel, or replace the built-in bathtub with a freestanding bathtub or a shower, install wall hung cabinetry, or install wall hung vanity bench with no cabinetry, raise the washing machine and dryer. Fixtures: raise data and electrical points, install corrosion- resistant door and window hardware.
Flood Resilience for Homes & Business by Cairn Reginal Council, Queensland (2024)	Inside the building: raise electrical outlets and appliances, replace plasterboard with flood-resistant fibre-cement, wall cavities, replace carpet with flood-resilient flooring, compact laminate cabinetry, aluminium or glass doors, small steps, or level changes at or near entry doors, upper level for survival essentials for two-storey homes, and install resilient wall lining.

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Guideline (Year of Publication)	Strategies
	Outside the building: raise living area, raise air conditioning units, battery storage, electrical meter board and hot water unit, replace walls with non-cavity alternatives, metal door handles, solid garages, open stairs with no riser, floating structural, redesign electrical circuit.
	Yard: raise pool filter and pumps, rainwater tanks, using permeable paving, replace hard surfaces with grass and planting, replace solid fencing with gaps and flood-resilient materials, use swales, surface drains, spoon drains, channels, and mound for water flow, planting native groundcover species to stabilise soil, sandbag in toilet to stop sewer water backing up into the house.

Source: Authors (2024)

One of the successful flood-resilient housing designs is Mod Scape's house, which includes a buoyancy raft to allow the structure to "float" as floodwaters rise while guiding piers to ensure stability and enable vertical movement. According to (Pieper, 2021), the house also features a unique "zig-zag" connection system inspired by cement trucks, which keeps essential services compact under normal conditions and extends them as the building rises (refer to Figure 3). This design allows the house to maintain functionality and resilience during floods by adapting to changing water levels. This approach offers a practical and innovative solution to buildings in flood-prone areas, allowing for continued habitation and reducing the need for extensive repairs following flood events. According to English et al. (2016) and Nguyen (2021), this concept has been adopted from amphibious houses in the United States built flood-resilient houses after the Katrina Hurricane. Moreover, although residents would still evacuate during floods, buoyant designs help prevent the distress of returning to homes and belongings destroyed by mud, debris, and water. This initiative has led to the construction of full-scale prototypes in North America and the successful retrofitting of several houses in Vietnam's Mekong Delta.

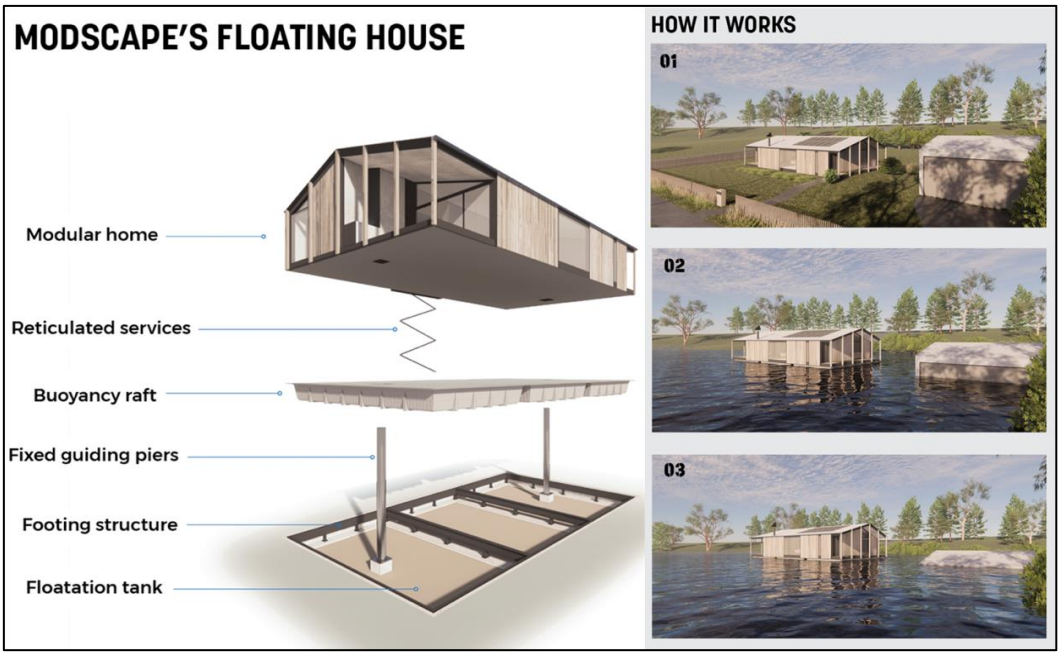

Fig. 3. The Modscape's Floating House

Source: Pieper (2021)

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Lesson on The Best Practices: Flood Resilient Housing Practise in United Kingdom

The United Kingdom's geographical features cause it to be highly vulnerable to flooding. The nation's varied topography includes expansive shorelines, numerous waterways, and low-lying regions, leading to regular flooding (Alotaibi, 2024). The United Kingdom's geographical position in the trajectory of Atlantic weather systems leads to substantial precipitation, especially during winter (Scaife, 2024). Additionally, increasing sea levels and storm surges intensify coastal flooding. Flooding is a substantial concern in regions such as the Thames Valley and Somerset Levels, along the River Severn and River Trent.

Due to these hazards, enhancing flood resilience in house development has become a crucial priority in the UK (Reynoso et al., 2024). Flood risk evaluations play a crucial role in shaping development decisions, ensuring that new homes are equipped with flood-resilient elements such as elevated foundations, permeable surfaces, and adequate drainage systems (Renders, 2024; Mabrouk et al., 2024; Beddoes et al., 2018). The UK government and local councils have enacted laws to foster sustainable development and safeguard communities from the consequences of flooding. As an illustration, the flood risk management policies of the Environment Agency and the Building Regulations in England incorporate specific criteria for ensuring that new developments are resistant to and resilient to flooding (Puzyreva & Vries, 2021). Implementing these measures is crucial for protecting homes and communities from the growing risk of floods caused by climate change. Enhancing flood resilience in house development across the UK involves strategic planning, investing in infrastructure, and following building rules.

In England, the Environmental Agency (EA) oversees of carrying out the policies that the Department of Environment, Food, and Rural Affairs (Defra) formulates regarding flood risk (Goodden & Vantaggiato, 2024; Defra, 2009). While the government of the United Kingdom is not obligated by law to prevent flooding in homes (Porter & Demeritt, 2012), the EA has taken various measures to make communities more flood-resilient, including building flood defences and implementing warning systems (Butler & Pidgeon, 2011; Environment agency, 2020). Hence, the critical component of flood management, taken within a risk-based framework, is to mitigate the growing vulnerability by guiding urban expansion towards locations with the least susceptibility to flooding (Environment Agency, 2018).

To tackle this issue, Planning Policy Guidance Note 25 (PPG25) was implemented in England and Wales in 2001 (Rözer et al, 2022; Rözer et al., 2020). This document designated the Environment Agency as a legal advisor for planning applications in regions at risk of flooding. This regulation mandates that local planning authorities, who usually have the freedom to establish local development plans, must conduct a sequential test. This test aims to verify that fresh advancements are not authorised in regions acknowledged to be susceptible to flooding. If avoiding such locations is impossible, one can consider applying an exception test. This test permits the advancement of projects in regions with higher levels of risk on the condition that the long-term advantages of sustainability surpass the amplified danger of flooding and that the new development demonstrates both resilience and resistance to flooding (MHCLG, 2020). Despite planning regulations, UK local authorities often permit new developments in flood zones due to competing interests and pressure to meet national housing targets. The UK's Committee on Climate Change estimated that 54,500 new properties were built in flood areas between 2014 and 2017 (Adaptation Sub-Committee, 2019). However, there are no nationwide data sets to verify compliance with flood resilience standards, which primarily address current flood risks and often ignore future increases due to climate change (Westcott et al., 2019).

The Environmental Assessment Agency also used a risk-based strategy to determine the optimal locations for flood defences (Lane et al., 2011). This means that funding and assistance should be targeted to areas most in danger of flooding. For example, The EA utilises a key performance indicator to evaluate its effectiveness in fulfilling its flood risk management responsibilities. This indicator measures the number of homes that have been "better" protected from floods, meaning their risk of flooding has been decreased

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as a direct result of the installed flood schemes (National Audit Office, 2020). The EA employs its categorisation of England's geography, which it partitions into nine areas. From 2015 to 2021, the EA allocated £2.6 billion to enhance the protection of 300,000 houses in England. Specifically, 54,852 dwellings in the administrative regions of East Midlands, Lincolnshire, and Northamptonshire, which fall under EA regions 5 and 6, were included in this initiative. Eighty-nine projects were funded in these locations, with some explicitly targeting cities such as Nottingham, Derby, and Lincoln, while others focused on safeguarding homes along the East Coast.

From an architectural standpoint, flood-resilient houses require various inventive techniques (Edem et al., 2024). Natural calamities such as hurricanes, floods, earthquakes, and wildfires have brought attention to the vulnerability of conventional buildings and infrastructure. Therefore, it is crucial to embrace design approaches that are more sustainable and resilient. Disaster-resilient housing and sustainable building approaches have various social, technological, economic, and environmental effects. According to UNDRR (2021), an essential characteristic of disaster-resilient housing is its ability to mitigate environmental deterioration and minimise resource depletion. One example of a successful flood-resilient house is in Stratford-upon-Avon, United Kingdom, and was constructed by Baca Architects. Baca Architects has successfully transformed 22,000 square feet of brownfield land on the primary route of Stratford upon Avon into a residential project consisting of 11 high-quality residences. This location was formerly at risk of flooding and falls between Flood Zones 2 and 3 (refer to Figure 4). As specified by the EA, this development is poised to be the inaugural of its type in the UK, consisting of flood-resilient houses.

Baca Architects has developed flood-resistant houses in the United Kingdom with numerous inventive characteristics (Mahmoud et al., 2024). The features encompass rain gardens, shallow depressions planted with vegetation to store surplus rainwater before its absorption, and artificial basins designed to detain, retain, or absorb water. The dwellings are equipped with permeable pavement surfaces, which enable water to infiltrate the ground, slowly replacing conventional impermeable surfaces. In addition, a flood trim surrounding the basement permits water to permeate and a raised route that can gradually increase height during flood seasons (Oberti et al., 2020). These factors jointly improve the ability of the structures to withstand and recover from floods. Constructing on the floodplain necessitates elevating homes to a secure height above the probable inundation level.

Fig. 4. (left) Flood-resilient houses in flood; (right) Flood-resilient houses in normal

Source: Mahmoud et al. (2024) and Oberti et al. (2020)

Nevertheless, the planning authority raised concerns about the acceptability of the threshold heights proposed by the Environment Agency, as they exceeded the planning authority's guidelines. In addition, flood plains must be designed to allow for the controlled and planned movement of flood water within the

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site. This will help improve the current state of groundwater permeability. The design underwent modifications to fulfil these rigorous criteria. The property features a gradually sloping road that provides access to the elevated houses and an elevated walkway for pedestrians and cyclists to the west. This allows for a continuous route throughout the site and provides a safe area during floods. The houses are constructed on elevated stilts, with a lower area that may be flooded, protected from debris by louvred screens. The remaining green space is designed with rain gardens and swales to effectively manage and contain water run-off.

CONCLUSION

In conclusion, addressing the escalating challenges posed by climate change and increasing flood risks is essential for sustainable housing development, particularly in flood-prone regions. This study highlights the need for integrating specific flood-resilient strategies, such as adaptive architectural designs, sustainable urban planning, and the application of advanced technologies, into housing projects. For instance, incorporating elevated foundations, flood-adaptive materials, and drainage systems, as well as the "Room for the River" project from the Netherlands, provides concrete examples of how to mitigate flood risks effectively. By learning from the best practices of pioneering nations like the Netherlands, the United States, Australia, and the United Kingdom, Malaysia can improve its flood risk management and housing development strategies. Currently, Malaysia's approach to flood disaster management is inadequate, with significant gaps between legal frameworks and practical implementation. This review offers a foundation for identifying key flood-resilient attributes that should be embedded into the housing development approval process. At present, the absence of a rigorous flood resilience assessment for housing projects leaves communities vulnerable. Future policies must mandate flood resilience evaluations to ensure that housing developments can adapt to changing climate conditions, protecting both lives and property. Moving forward, Malaysia should implement proactive policies that prioritise flood resilience in urban planning and development. This includes strengthening legislative frameworks, promoting integrated disaster management, and embedding resilience criteria in housing approvals. By doing so, the country can mitigate the effects of severe flooding and foster disaster-resilient communities. Future research should focus on exploring region-specific case studies and refining flood-resilience frameworks for Malaysia. This comprehensive strategy and attributes will pave the way for more sustainable, disaster-resilient communities, aligning with the broader goals of climate adaptation, sustainable development, and long-term human security, ensuring that communities can not only survive but thrive in an evolving climate landscape.

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CONFLICT OF INTEREST STATEMENT

The authors confirm that this research was conducted with integrity and consent for its publication as presented.

AUTHORS' CONTRIBUTIONS

Nur Khairiyah Mohammad conducted the research, wrote the initial draft, and led the revisions of the article. Maryanti Mohd Raid conceptualised the main research idea and contributed to the writing. Robiah Suratman and Zafirah AB Muin designed the research methodology and supervised data collection. Aminah Mohsin and Amirul Haffiz Ariff provided critical feedback during the research process and assisted in data

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analysis. Mariney Mohd Yusoff and Nor Shahida Azali contributed to reviewing and revising the manuscript and approved the final version for submission.

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