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Design Guideline for Resilient Floating Housing in Tambak Lorok Coastal Settlement

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Abstract

This study formulates design guidelines for resilient floating housing in Tambak Lorok, Semarang, a coastal area highly vulnerable to tidal flooding, land subsidence, and sea-level rise. Using a qualitative descriptive approach, the research identifies contextual issues through literature study, field observation, and review of relevant references, which are then synthesized into adaptive design principles. The main findings emphasize strategies for structural adaptation to fluctuating water levels, the use of sustainable materials, modular spatial systems, energy efficiency, as well as sanitation and waste management in flood-prone coastal areas. Feedback from the community indicates preferences for both floating and stilt housing types, with particular attention to materials, modular layouts, and communal infrastructure systems. The results highlight the potential of floating architecture as a flexible and sustainable adaptive solution compared to conventional approaches such as seawalls. This study contributes conceptually and practically by providing guidelines that can be applied in the planning of resilient coastal housing and replicated in other vulnerable urban coastal areas.

INTRODUCTION

The coastal zone is a unique geographical area where marine and terrestrial systems meet, interact, and overlap. As one of the most dynamic natural environments, it is characterized by diverse natural phenomena and processes, abundant resources, and favorable conditions for development. The coastal zone is intrinsically linked to human survival and development, with around 70% of the global population living in this region (Nguyen et al., 2025). Furthermore, according to Vousdoukas et al. (2018) in Kirby et al. (2021), the coastal zone is considered one of the most important areas for many countries and coastal communities due to the presence of vital infrastructure, significant economic activities, and its overall utility value. At the same time, the coastal zone is also among the most impacted and vulnerable regions in the world to climate change (Kirby et al., 2021). The widespread impacts of global climate change exert tremendous pressure on human communities and ecosystems worldwide (Ohenhen et al., 2024).

In recent decades, urban areas have experienced growth that outpaces population increases (Dijkstra et al., 2021 in Rodrigues et al., 2024). This condition exacerbates global climate change, creating challenges for the sustainability of urban systems and ecological resilience, particularly in large cities (Rodrigues et al., 2024). Climate change has led to an increase in the frequency and intensity of heatwaves, storms, and wildfires, and has significantly affected the world's freshwater resources through sea level rise (SLR), more frequent droughts, and changes in precipitation and evapotranspiration. These impacts are almost certain to intensify in the future (Ohenhen et al., 2024). Coastal cities have become critical hotspots as they are on the frontline in facing the impacts of climate change (Griggs and Reguero, 2021 in Islam et al., 2025; Rodrigues et al., 2024).

As an archipelagic country with 17,504 islands and a coastline stretching 99,093 km, Indonesia is in a highly vulnerable position to the impacts of climate change. Data from BPS (2020) shows that around 42 million Indonesians live in areas less than 10 meters above sea level (Syahputra, 2022). Out of a total of approximately 82,190 villages and urban wards, 65% are in coastal areas (Ledoh et al., 2019). The high concentration of population in these regions increases the potential risks to the social and economic life of coastal communities. Semarang City, situated as a central hub along the main corridor of the northern coast of Java with a coastline of about 36.63 km, has rapidly developed as a major city with diverse industrial, trade, and service activities. This rapid urban growth has led to a significant increase in the population of Semarang's coastal areas (see Fig. 1.)

This condition has led to the emergence of classic environmental challenges in Semarang, notably tidal flooding (locally known as banjir rob) and land subsidence, both of which are being exacerbated by climate change (Walsilah & Syahid, 2023). Tidal flooding, which frequently affects Semarang's coastal areas, is triggered by a combination of meteorological factors, lunar cycles, land subsidence, and global warming, as reported by researchers from BRIN (National Research and Innovation Agency of Indonesia) (Stywan, 2022). A study by Wu et al. (2022) using Interferometric Synthetic Aperture Radar (InSAR) technology identified Semarang as the city with the second-highest rate of land subsidence in the world, averaging 3.96 cm per year (Megarani, 2022). In particular, the northern part of Semarang has experienced significant land subsidence, ranging from 8.23 to 15.8 cm per year (Saffana et al., 2023).

Based on disaster risk assessment data, approximately 1,346 hectares of coastal areas in North Semarang are affected by year-round tidal flooding. Nearly 95% of these areas are densely populated residential zones, categorized as high-risk in terms of hazard exposure, social vulnerability, disaster risk potential, and environmental degradation (BPBD, 2023). Tambak Lorok in Semarang is a notable example of a coastal settlement affected by these conditions. In this area, land subsidence is estimated to reach 9- 10 cm per year (Ayu, 2022), driven by coastal soil characteristics, structural load from buildings, and intensive extraction of deep groundwater (Megarani, 2022).The recurring and expanding tidal floods have resulted in severe physical damage, socioeconomic disruptions, and a decline in the overall quality of life for affected communities (Asrofi, 2024).

The built environment plays a crucial role in addressing these challenges, as it contributes to land conservation while safeguarding human well-being by implementing resilience and adaptation strategies that go beyond conventional approaches (Rosso et al., 2020). One architectural approach gaining recognition in the context of climate change adaptation in coastal regions is floating architecture. This approach offers a solution that is not only innovative but also sustainable and resilient, beneficial to both the environment and the economy in the long term (Kartheekeyan et al., 2024). Within the framework of resilience oriented urban planning, floating housing is considered one of the most promising future strategies to address the risks associated with coastal flooding and sea level rise.

Fig. 1. Spatial Context of Tambak Lorok in North Semarang, Central Java
(Source: www.arcgis.com, 2025)

Based on previous studies by Wijayanto (2024) and Septian (2022), research in the Tambak Lorok area has predominantly emphasized technical approaches, such as the effectiveness of sea dikes, pumping systems, land reclamation, and physical building structures. However, these approaches are considered insufficient to address the need for long-term adaptation. On the other hand, floating housing as an alternative adaptive solution has received relatively little attention. Previous studies on floating architecture have, in fact, highlighted its potential as an adaptive solution to climate change challenges in coastal areas. For instance, Rosso et al. (2020) examined the typology of amphibious and floating houses with a focus on construction and thermal-energy performance through annual dynamic energy simulations. Similarly, Kartheekeyan et al. (2024) explored the potential of floating architecture and the blue economy strategies pioneered by the UAE in addressing energy challenges. In Southeast Asia, Nguyen et al. (2022) developed architectural design guidelines for sustainable floating housing and settlements in Vietnam, emphasizing the integration of local context, affordability, and resilience to the impacts of climate change. Nevertheless, most of these studies remain focused on technical-conceptual aspects or building prototypes and are mostly conducted in contexts outside of Indonesia. Studies that specifically examine floating architectural design strategies for housing in Indonesian coastal areas particularly those highly vulnerable to the combined impacts of tidal flooding, land subsidence, and sea level rise, such as in Tambak Lorok, Semarang is still very limited.

Therefore, this study addresses the gap by focusing primarily on the physical dimension of coastal resilience based on the Climate Disaster Resilience Index (CDRI) framework. The research identifies contextual issues, explores adaptive floating architectural concepts, and proposes design guidelines. Floating architecture strategies are formulated as they offer adaptive solutions to flooding by providing flexibility to fluctuating water levels while minimizing the impacts of land subsidence, which is difficult to control. Unlike conventional strategies such as seawall construction, which tend to be static and add structural loads to vulnerable coastal soils, floating housing can reduce vertical pressure on the land. Furthermore, this approach provides opportunities for creating safer living spaces for fishing communities without severing their connection to coastal ecosystems and marine-based economic activities. Thus, this study is expected to contribute both conceptually and practically to the planning of more resilient urban coastal areas.

LITERATURE REVIEW

Index & Coastal Vulnerability Indicators

Coastal vulnerability is influenced by the ability of individuals and communities to prepare for, withstand, and recover from impacts (Noor & Maulud, 2022). According to the study by Arbon et al. (2016) in Almutairi et al. (2020), one method to reduce the vulnerability of coastal communities and infrastructure is by enhancing coastal resilience. Coastal resilience, as defined by Masselink & Lazarus (2019) and Almutairi et al. (2020), refers to the capacity of a coastal system whether geomorphic, ecological, socio-economic, or a combination of these to recover from major shocks or disturbances.

Awareness of the need to develop methodologies and techniques for assessing coastal resilience has grown alongside the evolution of the concept (Cutter, 2016; Mulligan et al., 2016 in Imani et al., 2022). Although the concept of resilience has been widely studied, there remain no consistent characteristics or standard metrics for evaluating resilience to disasters across specific populations or regions (Imani et al., 2022). One conceptual framework for assessing the physical resilience of an area is the Climate Disaster Resilience Index (CDRI). This framework was developed to evaluate community resilience to climate-related disasters (Shaw et al., 2009 in Almutairi et al., 2020). According to Almutairi (2020), CDRI analysis provides critical information that can guide strategic planning and policy development. The CDRI comprises five key dimensions: physical, social, economic, institutional, and natural environment (Imani et al., 2022; Almutairi et al., 2020). In the context of this research, the focus is directed toward the physical dimension, particularly on the sub-indicators of housing and land use, which represent micro-scale indicators within the spatial and structural context of coastal areas. These two indicators are employed as conceptual instruments to formulate floating housing design strategies that align with the physical and spatial conditions of densely populated coastal settlements.

Floating Architecture

One adaptive micro-scale approach in coastal housing design is floating architecture, namely buildings designed to float on the water surface and adjust to changes in water elevation. This approach has increasingly been adopted as an alternative solution for areas affected by tidal flooding and land scarcity, due to its flexibility and minimal intervention in the seabed ecosystem (Kartheekeyan et al., 2024; Ratodi, 2023). Floating foundations provide stability while allowing structures to rise and fall in response to water level fluctuations (Lin et al., 2019). Rosso et al. (2020) highlighted that floating houses offer adaptive capacity to water dynamics, while also creating opportunities to enhance thermal performance and energy efficiency through annual simulations. This study demonstrates that floating design strategies serve not only as a physical response to flooding but also as a means of improving the energy sustainability of buildings. In the Southeast Asian context, Nguyen et al. (2022) developed sustainable floating architectural design guidelines in Vietnam, emphasizing three key aspects: affordability, integration of local context, and climate resilience. Affordability ensures that the solution is accessible to low-income communities; integration of local context emphasizes the use of local materials and alignment with the lifestyle of coastal communities; while climate resilience refers to the capacity of structures to withstand sea-level rise, storms, and changes in rainfall patterns. Beyond being a spatial solution, floating architecture is also linked to the development of the blue economy. Kartheekeyan et al. (2024) showed how floating typologies can be utilized not only for housing but also to support productive functions such as fisheries, tourism, and renewable energy. This opens opportunities for integrating living spaces with sustainable economic spaces.

METHODS

This study employs a qualitative descriptive approach to understand and explain how the concept of architectural resilience, specifically in the form of floating architecture, can be applied in urban settings, particularly in coastal areas. Data was collected through field observation, document analysis, audiovisual materials, and a review of relevant journal articles.

The first stage involved identifying key issues related to coastal resilience, with a specific focus on the Tambak Lorok area in Semarang City. This was carried out through the examination of official documents from relevant institutions, a review of previous academic studies, and field observations to gain an understanding of the current conditions in flood-prone areas affected by tidal inundation. In the second stage, a literature review was conducted on scholarly works related to floating architectural resilience to extract key elements applicable to the identified issues. These aspects were then developed in the third stage into design guidelines that can serve as a reference for planning in coastal areas vulnerable to tidal flooding. The aim is to support the creation of a more adaptive, resilient, and sustainable built environment. The design guidelines that were developed were then further refined into a prototype, which was presented to Tambak Lorok residents to gather feedback on the aspects contained in the guidelines. In this way, the design guidelines that have been created can be applied and accepted by the Tambak Lorok community (see Fig. 2).

This research focuses on architectural resilience in coastal areas affected by tidal flooding, with an emphasis on exploring floating architecture as an adaptive strategy to mitigate the impacts of climate change and rising sea levels. The scope of the study includes identifying environmental vulnerability issues in the study area, analyzing spatial and social contexts, and formulating conceptual design guidelines for use in coastal development planning. The literature review was limited to journals, books, and documents relevant to the context of tidal flooding and architectural adaptation in coastal areas with similar characteristics. The research locus is in the coastal area of Tambak Lorok, Tanjung Mas Subdistrict, North Semarang District, Central Java, selected due to its high vulnerability to tidal flooding, dense settlement patterns, and complex socio-economic conditions, making it a relevant case study for the application of adaptive floating architecture.

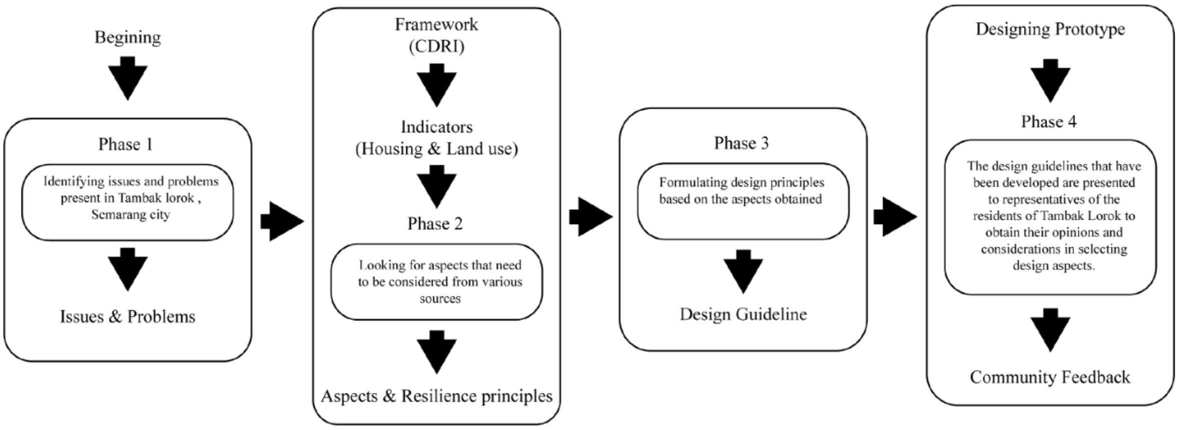

Fig. 2. Methodology Research
(Source: Author, 2025)

RESULTS AND DISCUSSION

Study Area & Environmental Issue

Tambak Lorok is one of the coastal settlement areas in Semarang City that has historically developed as a traditional fishing village. The village is located along the coast of the Java Sea, on the northern outskirts of Semarang City. Tambak Lorok is part of the Tanjung Mas Urban Village and the North Semarang Subdistrict (Nugraha & Dwiyanto, 2023; Anita, 2020). The total area is 46.8 hectares, with a residential area covering 32.4 hectares (Ayu, 2022; Anita, 2020). Tambak Lorok is classified as a slum settlement with a population density ratio of more than 750 people per hectare and 970 poor households (Ayu, 2022). The spatial condition of Tambak Lorok is divided into five neighborhoods: RW 12, RW 13, RW 14, RW 15, and RW 16 (Rais & Hariyanto, 2021; Isrofi & Gunawan, 2025) (see Figure 4.). Most residents of Tambak Lorok work as fishermen who depend on natural resources (Ramadhika, 2019; Nugraha & Dwiyanto, 2023) (see Fig. 3 & 4). The proximity of residential areas to water bodies is a key factor for their livelihood, as it provides easy access to the sea, ports, and distribution of catch results.

Fig. 3. Tambak Lorok Fishermen Village Pier
(Source: Author, 2025)

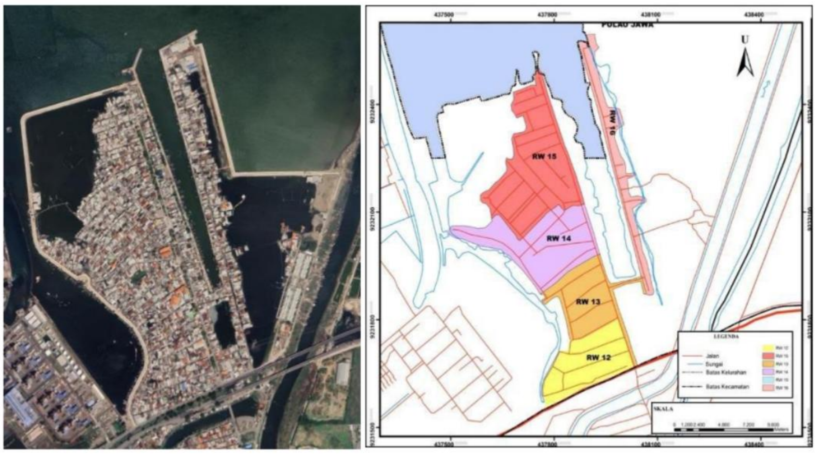

Fig. 4. Existing Spatial of Tambak Lorok
(Source: Google Maps ; Indrianingrum et al., 2019)

Geographically, Tambak Lorok is bordered by the Java Sea to the north, Yos Sudarso Arterial Road to the south, PT Indonesia Power PLTGU to the west, and the Banger River to the east. It is in a lowland area consisting of coastal plains (Garang Delta) with a land slope of 0-2%, making the area vulnerable to tidal flooding from sea tides (Nugraha & Dwiyanto, 2023; Iskandar et al., 2022). The area also experiences significant land subsidence of 9-10 cm per year (Ayu, 2022) as well as the impacts of global climate change causing rising sea levels (Isrofi & Gunawan, 2025). Additionally, according to research by Ruslana et al. (2021), between 2005 and 2021, flood events were caused by extreme daily rainfall exceeding the upper limit of 89 mm/day. Accordingly, the overall issues in Tambak Lorok are summarized in Table 1.

Table 1. Findings on Environmental Issues in Tambak Lorok
(Source: Author, 2025)

Issues	
Source	Statement
Nugraha & Dwiyanto, 2023 ; Iskandar et al., 2022	Tidal Flooding from Sea Tides
Ayu, 2022	Land Subsidence
Isrofi & Gunawan, 2025	Sea Level Rise
Ruslana et al (2021)	Extreme Rainfall
Ayu, 2022 ; Anita, 2020	Population Density

In response to the high geographical vulnerability and disaster risks, policy interventions and spatial planning programs have been directed to reduce risks while improving the quality of coastal settlement environments. Since 2015, the government, through the Ministry of Public Works and Housing (PUPR), has planned the Arrangement of Fishermen Settlements and Waterfront Areas in 11 locations across Indonesia, including the fishing village of Tambak Lorok. This program aims to reduce the risk of tidal flooding and to develop coastal settlements based on the fishery economy. Additionally, Tambak Lorok is a priority area in government programs such as Kampung Bahari and KOTAKU (Cities Without Slums), which aim to reduce slum areas while also promoting tourism potential in Semarang City (Anita, 2020). Through these programs, the government targets the provision of decent housing supported by Public Infrastructure and Facilities (PSU) while still considering sustainable development aspects (Anita, 2020). Apart from these policies, the Semarang City Government, through Semarang City Regional Regulation Number 5 of 2021 concerning the City Spatial Planning for 2011-2031, encourages spatial planning adjustments that are more adaptive to environmental changes in line with increasing tidal flood risks. One of the primary focuses is the development and enhancement of infrastructure (Wijayanto, 2024).

Fig. 5. Coastal Settlement Area of Tambak Lorok
(Source: Author, 2025)

Settlements in Tambak Lorok generally share similar characteristics in terms of building materials. Most houses are permanent structures built with elevated continuous foundations, red brick walls, ceramic tile flooring, and asbestos roofing materials (Septian, 2022) (see Fig. 5). During tidal flooding, inundation can persist for hours or even days due to poor drainage systems (Isrofi & Gunawan, 2025). This condition is further influenced by tidal fluctuations and rainfall, disrupting the daily activities of coastal communities. The saline content of tidal water can damage ceramic floors, accelerate the deterioration of brick walls, and cause corrosion of structural metal elements. As a form of adaptation, residents independently implement structural strategies by raising the floor level and elevating the building structure by more than one meter above street level to avoid inundation and minimize damage during flooding events (Septian, 2022).

Resilient Measures

Coastal area resilience to climate change and hydrometeorological disasters has evolved from hard infrastructure approaches to adaptive design-based approaches. Based on the mapping of vulnerability issues and literature synthesis, the resilient floating housing design approach in the Tambak Lorok area focuses on strengthening adaptive housing and land use aspects to risks of tidal flooding, land subsidence, rising sea levels, and high rainfall. This approach emphasizes responses to vulnerable infrastructure, microclimate conditions, dependence on conventional energy, limited early warning systems, disrupted utilities, dense spatial conditions, limited land availability, and prolonged flooding.

In formulating resilient floating housing design guidelines, a synthesis was carried out from previous academic findings that highlight adaptation strategies in coastal environments identified as having similar issues to the conditions in Tambak Lorok, thereby producing resilience principles. The mapping of contextual issues in Tambak Lorok against resilience principles from the literature was used as an initial framework in developing the design guidelines (see Table 2).

Table 2. Resilience Principles of Coastal Floating Housing
(Source: Author, 2025)

Resilience Principles		
Source	**Issue**	**Statement**
Rosso et al., 2020	Tidal Flooding from Sea Tides Sea Level Rise Extreme Rainfall Population Density	Able to adapt flexibly to changing environmental conditions Energy performance reduction
Kartheekeyan et al., 2024	Sea Level Rise Population Density	Adaptation to sea level fluctuations. The use of materials that can be reused and recycled for as long as possible A stable floating system to ensure that buildings can withstand wind, waves, and operational loads. Floating houses integrating renewable energy sources for self-sufficient power generation and carbon emission reduction.
Bariroh & Surtikanti, 2024	Tidal Flooding from Sea Tides Sea Level Rise Extreme Rainfall Land Subsidence	Floating housing is designed with flexibility to adapt to sea level fluctuations, ensuring the continuity of residential functions
Bradecki & Konsek, 2020	Tidal Flooding from Sea Tides Sea Level Rise Extreme Rainfall Population Density	Adaptive to climate change and sea level rise with floating house systems designed to withstand flooding. Floating houses utilizing renewable energy, water treatment systems, and rainwater storage to support the ecological resilience of cities. Flexible, modular, and low-cost materials for housing in flood-prone areas.
Sumayya et al., 2021	Sea Level Rise Population Density	Ensuring the structural resilience of the floating house by balancing the building's weight with the buoyant force of water in situations of flooding, waves, and strong winds. Adaptive to environmental changes and adjusted to the size and proportion of the building mass. Considering water depth in the implementation of floating houses to ensure safety during tidal fluctuations, while considering the use of lightweight materials.
Nguyen, 2022	Population Density	Floating houses need to focus on waste management, sanitation, the use of renewable energy, and strong structures capable of withstanding sea level rise, wind, and flooding. Cost-effective floating houses should utilize innovative technologies and materials while also considering the sustainable livelihoods of local communities.
Sharma & Rahi, 2021	Tidal Flooding from Sea Tides Sea Level Rise	Floating houses applying Archimedes' principle using pontoons and lightweight materials to remain stable against dead loads, live loads, wind, and waves. Floating houses that are adaptive to environmental changes as a solution to sea level rise, flooding, and water intrusion risks.

		Floating houses that are affordable in terms of cost and safety.
Calcagni et al., 2025	Tidal Flooding from Sea Tides Sea Level Rise Population Density Land Subsidence	Floating urban areas adapt to the water cycle through the integration of water landscapes, such as green spaces, coastal ecosystems, and flood disaster mitigation. Floating infrastructure with modular, flexible systems that can be relocated at any time and supported by non-permanent foundations.
Mahmoud et al., 2024	Tidal Flooding from Sea Tides Sea Level Rise Land Subsidence	Buildings are designed with floating foundations that rise and fall with the water surface, enabling adaptation to sea level rise. Use of local, recycled, and bio-composite materials that are more resistant to humidity and flooding. Floating housing integrated with landscape design as an early warning system. Housing designed in a modular way to allow easy relocation, assembly, or disassembly, reducing economic losses during floods. Floating housing proposed to integrate vertical gardens and food production areas to enhance community resilience.
Anwar et al., 2022	Tidal Flooding from Sea Tides Sea Level Rise Extreme Rainfall	Housing adaptation through building structures by developing flood-resistant houses, implemented using floating houses that follow tidal fluctuations and are easily movable.
Plasencia, 2024	Tidal Flooding from Sea Tides Sea Level Rise Population Density	Using flood strategies (floating design) Adaptation through modularization Low-impact materials
El-Shihy, 2024	Sea Level Rise	Designing buildings that are adaptive to water fluctuations, integrating natural ecosystems, applying renewable energy, and implementing sustainable water systems to manage waste and sanitation without polluting aquatic ecosystems. Utilizing the principle of buoyancy (Archimedes) with lightweight materials. Incorporating mooring and anchoring systems, or raft-type housing. Easily movable, such as modular structures and rafts. Affordable and inclusive for middle-income communities.

Design Guideline

Based on Table 2, the resilience principles derived from various journal sources are grouped according to the closeness of their discussions, resulting in aspects such as adaptability to water fluctuations, adaptability to environmental changes, structure, materials, modular systems, sanitation, and energy. These aspects are then examined using the CDRI indicators of housing and land use in the discussion.

For the housing indicator, the structural aspect discusses residential designs that can adapt to sea level rise, remain flexible so that the house functions can continue, withstand flooding and water intrusion, and adapt to changing environmental conditions. This can be achieved by using floating foundations as platforms that follow sea level fluctuations, such as raft house concepts or flood strategies including dry flood proofing or wet flood proofing. The material aspect emphasizes the use of durable and reusable materials, preferably lightweight to ensure buoyancy and stability against dead loads, live loads, wind, and waves. Such materials may include EPS, composites, or bamboo. Materials should also ideally be prefabricated modules to facilitate construction, while promoting the use of local, recycled, and bio-composite materials that are more resistant to humidity and flooding. Selected materials must also minimize environmental impact while being flexible, modular, and affordable. The modular system allows relocation at any time through non-permanent foundations and is designed to be easily moved, assembled, and dismantled to reduce losses during flooding. Sanitation requires a focus on proper waste management to prevent pollution. The energy aspect is optimized by employing renewable sources such as tidal, ocean thermal, wave, and wind power. For water management, wastewater treatment and rainwater harvesting systems are also necessary.

The land use indicator includes aspects of adaptability to water fluctuations, in which the design is integrated with natural ecosystems and renewable energy. Adaptability to environmental changes is reflected in the ability to adjust building mass and proportions, adapt to the water cycle, and integrate water landscapes, coastal ecosystems, and flood-mitigation measures. Finally, the modular system enables expansion or reduction in accordance with population dynamics.

Table 3. presents guidelines that can be applied in the design of floating architecture in the Tambak Lorok area. Adaptive capacity to water fluctuations addresses issues of sea-level rise and the potential for tidal flooding in Tambak Lorok. Land subsidence can be managed through adaptability to environmental changes, achieved by selecting appropriate structures and materials, as well as implementing integrated sanitation and waste management systems to prevent further subsidence. Extreme rainfall can be mitigated by adapting to the water cycle and integrating with natural coastal ecosystems, alongside the use of rainwater harvesting systems to improve energy efficiency. Population density issues can be resolved through modular and prefabricated systems, which allow expansion or reduction according to the existing population, as well as enabling rapid assembly and disassembly.

Table 3. Architectural Guidelines

Architectural Guidelines Housing
Structure • Housing is designed to adapt to fluctuations in sea level. • Flexible design ensures that the functions of the house can continue to operate. • Able to address rising sea levels, flooding, and saltwater intrusion. • Capable of adapting to changing environmental conditions. • Buildings are designed with floating foundations that can follow the rise and fall of sea levels. • May apply the concept of raft houses. • Flood-resistant structure (floating structure and stilt structure)
Materials • Utilizes durable, reusable materials. • Lightweight materials for stability against dead loads, live loads, wind, and waves (e.g., EPS, composites, bamboo). • Prefabricated materials to simplify the construction process. • Local, recycled, and bio-composite materials that are more resistant to humidity and flooding. • Low-impact materials (causing minimal environmental damage). • Flexible, modular, and affordable materials.
Modular System • Employs a modular system with non-permanent foundations, allowing relocation when necessary. • Designed to be easily moved, assembled, and dismantled to reduce loss during floods.

Sanitation • Emphasis on waste management and sanitation systems.
Energy • Efficient use of energy. • Utilization of renewable energy sources such as tidal, ocean thermal, wave energy, and wind power. • Application of wastewater treatment systems and rainwater harvesting.
Land Use
Energy • The design integrates with natural ecosystems and renewable energy sources.
Modular System • Adjustable in terms of building mass, proportion, and scale. • Expandable or reducible according to population needs.

Community Feedback

Based on the architectural guidelines in Table 3, prototype scenarios were formulated to derive aspects of structure, material, modular system, sanitation, and energy in relation to the preferences of the residents of Tambak Lorok. Feedback from the residents revealed that they tend to prefer floating house structures and stilt house structures over raft houses, as they consider bamboo when used in water not only heavy but also less durable, especially in the open-water conditions of Tambak Lorok. The impact is that bamboo deteriorates rapidly, with an estimated lifespan of only 1.5–2 years, due to the presence of marine termites that can create holes within just three months, as well as barnacles that cause the bamboo to rot. In addition, bamboo is highly vulnerable to tidal flooding (rob). Consequently, bamboo structures and materials are deemed unsuitable for residential use but may still be used for small huts as resting places for workers in the fishponds. Hence, bamboo is perceived as an inefficient material because it requires frequent replacement within a short period and is considered relatively costly.

For floating house structures, residents prefer to use HDPE floating cubes because they are easier to arrange, can be configured more compactly, and have better material thickness. In contrast, HDPE plastic drums are considered thinner and, when assembled, still leave gaps between them. It was emphasized that for floating structures, in addition to the configuration, material thickness is crucial, as the sea around Tambak Lorok is highly susceptible to marine pests. It was further suggested that after installing the HDPE floating cubes, they should be coated with anti-fouling paint to improve their durability and longevity. For the wall materials, residents prefer to use EPS (Expanded Polystyrene) or water-resistant gypsum rather than plywood, as these are stronger, lighter, and more resistant to water exposure. Plywood is considered less durable against rain and vulnerable when in direct contact with water. For the roofing, residents often use asbestos sheets, but these are frequently damaged during tidal flooding. Therefore, they prefer galvalume sheets, which are lightweight and can be painted and coated with sand to enhance their durability.

For stilt house structures, residents prefer reinforced concrete piles despite being more expensive, as they are more durable and offer stronger support compared to bamboo, which cannot remain straight, or timber, which decays and shrinks more quickly especially when using low-quality wood. For the wall materials, residents favor EPS, water-resistant gypsum, and lightweight timber over plywood because these materials are stronger, reduce the structural load, are more resilient in water-exposed environments, and allow for easier adaptation to raise the houses in response to land subsidence. For the roofing, residents again prefer galvalume sheets for their lightweight and durable properties, along with other environmentally friendly materials that can help reduce heat.

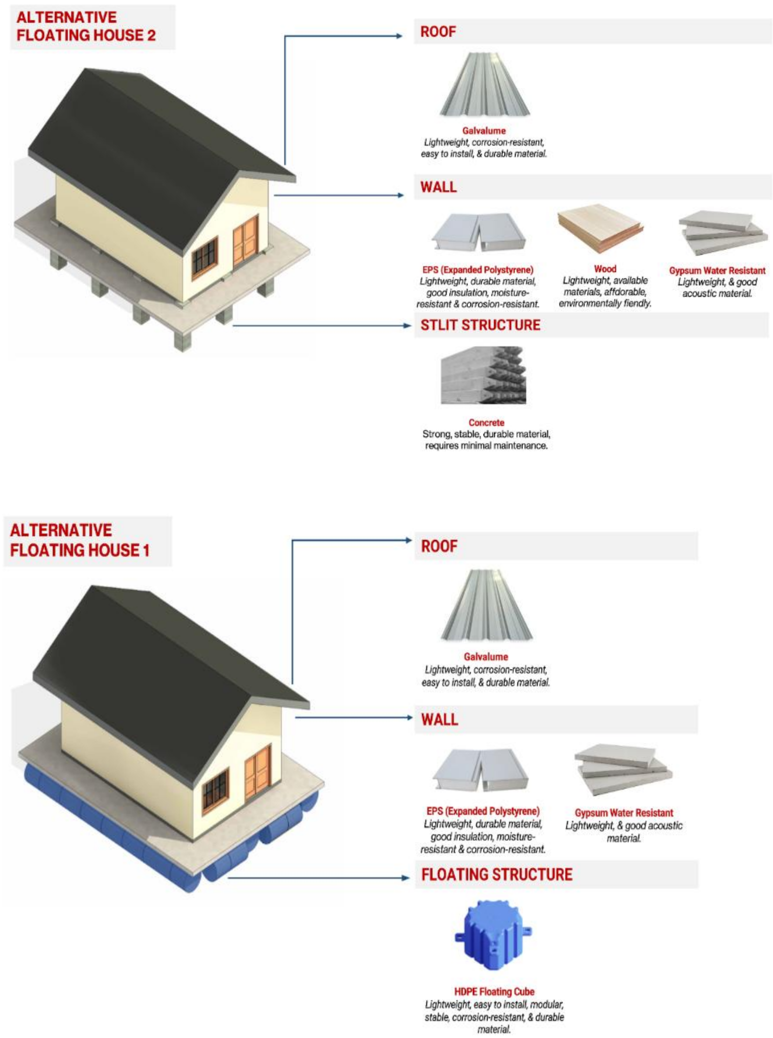

Fig. 6. Alternative Floating House
(Source: Author, 2025)

Regarding residents' preferences for floating house structures and stilt house structures, there are similarities in the aspects of modular systems, sanitation, and energy. In terms of the modular system, they prefer linear module configurations arranged along circulation pathways, with the possibility of adding units on the right and left sides, maintaining spacing between houses as plot boundaries, and providing areas for boat parking, compared to square modular platform configurations that are interconnected with flexible mobility. For waste management, residents prefer a collective waste collection system, as they believe individual household systems would lead to poor compliance. A collective approach allows waste to be sorted into organic and inorganic waste by the women's community group (PKK) in Tambak Lorok, while plastic waste can be repurposed by local fuel and oil vendors. The remaining waste is collected by municipal workers with a monthly contribution from residents. For sewage systems, residents also prefer a collective system, as it is seen as more efficient and convenient, with options such as biofilter septic tanks or innovative pneumatic tube systems. For the energy aspect, residents prefer the development of renewable solar energy, supported by the high solar potential due to the coastal location. Solar panels can serve as an alternative power source during outages and for night-time lighting. Portable wind turbines are considered less effective because strong and consistent winds are not always available.

Overall, residents are highly receptive to both proposed prototype concepts floating houses structures and stilt houses structures with some adjustments to incorporate local wisdom specific to Tambak Lorok (see Fig. 6). Residents also suggested that the construction of the houses should be carried out gradually, and that the housing could be integrated with additional functions, such as aquaculture facilities or even tourism-oriented housing development, as a means of generating additional income.

CONCLUSION

This study formulates comprehensive design guidelines for resilient floating housing to address the pressing challenges in Tambak Lorok, a coastal settlement highly vulnerable to tidal flooding, land subsidence, sea-level rise, extreme rainfall, and high population density. The findings demonstrate that floating housing offers a flexible and adaptive alternative to conventional strategies such as seawalls. Unlike static infrastructure, floating housing can adapt to water level fluctuations, reduce structural stress on coastal soils, and expand or contract through modular systems to accommodate population dynamics. This novelty lies in the integration of sustainable materials, energy-efficient technologies, and spatial modularization as a long-term adaptive strategy for coastal resilience.

The proposed design principles highlight structural adaptation through floating foundations such as raft systems, the use of lightweight and environmentally friendly materials, and the application of renewable energy-based utility systems for wastewater and rainwater management. Modular spatial configurations further ensure adaptability to population size and evolving community needs. Collectively, these strategies reinforce the potential of floating architecture as a practical and sustainable option for vulnerable coastal communities.

Nevertheless, the study remains primarily conceptual and has not been technically validated or implemented in practice. Socio-cultural aspects and participatory design processes have not yet been fully addressed, which may affect community acceptance and long-term sustainability. Therefore, further research is required to conduct prototype testing, structural and material performance simulations, and energy efficiency evaluations. Additionally, participatory methods should be integrated into future studies to ensure inclusivity, relevance, and cultural sensitivity. Finally, the scalability and replicability of modular floating systems across other coastal urban contexts, such as Demak or Jakarta Bay, should be explored to strengthen their applicability. By advancing in these directions, floating housing can evolve from a conceptual framework into an adaptive, inclusive, and sustainable strategy for resilient coastal planning.

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REFERENCES

Almutairi, A., Mourshed, M., & Ameen, R.F.M. (2020). Coastal Community Resilience Frameworks for Disaster Risk Management. *Natural Hazards, 101*, 595-630. doi.org/10.1007/s11069-020-03875-3

Anita, J. (2020). Perencanaan Kampung Bahari Sebagai Upaya Keberlanjutan,Perkampungan Nelayan Tambak Lorok, Semarang. *Jurnal Arsitektur TERRACOTTA*, *1*(3), 171-179. doi.org/10.26760/terracotta.v1i3.4102

Anwar, Y., Setyasih, I., & Oktoberdinata, D. (2022). Adaptation strategy community from exposure floods lake in the face of floods in Semayang Village, East Kalimantan, Indonesia. *IOP Conference Series Earth and Environmental Science*, *986*. 1-9. doi:10.1088/1755-1315/986/1/012053

Asrofi, A., Giyarsih, S.R., & Hadmoko, D.S. (2024). The Impact of Tidal Floods on Poor Households in the Sayung Coast, Demak Regency, Indonesia. *Indonesian Journal of Geography*, 56(3), 457-465. doi.org/10.22146/ijg.94063

Ayu, A.A.N., & Indrawati. (2022). Evaluasi Lanskap Kampung Nelayan Tambak Lorok Sebagai Kampung Wisata Bahari. *Prosiding (SIAR) Seminar Ilmiah Arsitektur*, 482-491. proceedings.ums.ac.id/siar/article/view/1026

Bariroh, G., & Surtikanti, H. K. (2024). Strategi Masyarakat Pesisir Margolinduk dalam Penanganan Banjir Rob Serta Implikasi Terhadap Sikap Peduli Lingkungan. Applied Environmental Science, 1(2), 69-86. https://doi.org/10.61511/aes.v1i1.2024.303

BPBD. (2023). *Dokumen Kajian Risiko Bencana Kota Semarang Provinsi Jawa Tengah*. bpbd.semarangkota.go.id/storage/file/UErWSIuK20250203005912.pdf

Bradecki, T., & Konsek, P. (2020). Examples and Concepts of Floating Architecture in the Face of Climate Change - The Example of Szczecin. *IOP Conf. Series: Materials Science and Engineering, 960*, 1-8. doi.org/10.1088/1757-899X

Calcagni, L., Ruggiero, A., & Battisti, A. (2025). Resilient Waterfront Futures: Mapping Vulnerabilities and Designing Floating Urban Models for Flood Adaptation on the Tiber Delta. *Land*, *14*(1). 1-22. doi.org/10.3390/land14010087

El-Shihy, A & Ezquiaga, J.M. (2019). Architectural Design Concept and Guidelines for Floating Structures for Tackling Sea Level Rise Impacts on Abu-Qir. *Alexandria Engineering Journal*, *58.* 507-518. doi.org/10.1016/j.aej.2019.05.003

Imani, M., Lo, S.L., Fakour, H., Kuo, C.Y., & Mobasser, S. (2022). Conceptual Framework for Disaster Management in Coastal Cities Using Climate Change Resilience and Coping Ability. *Atmosphere*, *13*(16), 1-21. doi.org/10.3390/atmos13010016

Indrianingrum, L., Azman, M.N.A., & Downing, K. (2019). Layout Tambaklorok Fisherman Village of Low-Income Housing: A Case Study of the Central Java, Indonesia. *International Journal of Innovation, Creativity and Change, 7*(6), 162-178. ijicc.net/images/vol7iss6/7610_Indrianingum_2019_E_R.pdf

Iskandar, P., Rukayah, R.S., & Atik, S. (2022). Morfologi Dari Kampung Nelayan Menjadi Kampung Bahari. *Jurnal Arsitektur ARCADE*, *6*(2), 190-198. DOI:10.31848/arcade.v6i2.970

Islam M.T., Hossain M.M., Ha-Mim N.M., Hossain M.Z., & Sikder S.K. (2025) Climate change impacts on shoreline migration and community livelihood resilience: evidence from coastal Bangladesh. *Frontiers in Sustainability*, *5*. 1-13. Doi.org/10.3389/frsus.2024.1525483

Isrofi, M.H.A., & Gunawan. (2025). Studi Ketahanan Sosial Masyarakat Tambak Lorok dalam Menghadapi Bencana Rob. *Langgas: Jurnal Studi Pembangunan*, *4*(1), 50-61. doi.org/10.32734/ljsp.v4i1.20803

Kartheekeyan, K., Baig, A., & Mahanta, N.R. (2024). Exploring the Potential of Floating Architecture & its Energy Challenges in the UAE. *International Conference on Sustainable Technologies in Civil and Environmental Engineering, 559*, 1-11. doi.org/10.1051/e3sconf/202455903012

Kirby, J.A., Masselink, G., Essex, S., Poate, T., & Scott, T. (2021). Coastal adaptation to climate change through zonation: A review of coastal change management areas (CCMAs) in England. *Ocean and Coastal Managemen*, *215*, 1-14. doi.org/10.1016/j.ocecoaman.2021.105950

Ledoh, L.Y., Satria, A., & Hidayat, R. (2019). Livelihoods Vulnerability of Communities in Coastal City to Climate Variability (Case Study in Kupang City). *Journal of Natural Resources and Environmental Management*, *9*(3). 758-770. doi.org/10.29244/jpsl.9.3.758-770

Lin, H., Lee, K. S., & Chen, T. (2019). Floating Buildings and Sustainable Water-Based Urbanization. *Sustainable Cities and Society*, 48. https://doi.org/10.1016/j.scs.2019.101556

Masselink, G., & Lazardus, E.D. (2019). Defining Coastal Resilience. *Water*, *11*, 1-21. doi.org/10.3390/w11122587

Mahmoud, R.S., Dagher, S.A., Youssef, P. (2024). Flooded architecture as an adaptation tool for climate change impact a case study of possible interpretation in Egypt. *Innovative Infrastructure Solutions*, *9*(158). 01-09. doi.org/10.1007/s41062-024-01474-w

Megarani, A. (2022, October 05). Semarang memiliki laju penurunan tanah tertinggi kedua di dunia. Jenis tanah, beban bangunan, dan penggunaan air tanah dalam dikatakan ahli, jadi sumber penyebab utama. ekuatorial. ekuatorial.com/2022/10/menggali-penyebab-banjir-rob-di-semarang/

Nguyen, T.T.T. (2022). Architectural Design Guideline for Sustainable Floating Houses and Floating Settlements in Vietnam. *WCFS2020*, 461-474. DOI:10.1007/978-981-16-2256-4_28

Nguyen, T.H.H., Wang, G., Chen, W., Yu, J., Liu, R., Huang, X., Jiang, X., Bui, V.V., Le, D.N., & Phung, V.P. (2025). Risk Assessment and Management Strategy of Coastal Erosion in the Red River Delta, Vietnam. *Land, 14*, 1-35. doi.org/10.3390/land14061247

Nugraha, M.S., & Dwiyanto, A. (2023). Tinjauan Konsep Keberlanjutan Pada Kawasan Permukiman Kampung Nelayan Tambak Lorok Dalam Program Kampung Wisata Bahari. *Jurnal Arsitektur ARCADE*, *7*(3), 504-509. scribd.com/document/840884335/3285-19757-1-PB

Noor, N. M., & Abdul Maulud, K. N. (2022). Coastal Vulnerability: A Brief Review on Integrated Assessment in Southeast Asia. *Journal of Marine Science and Engineering*, 10(5), 595. https://doi.org/10.3390/jmse10050595

Ohenhen, L.O., Shirzaei, M., Ojha, C., Sherpa, S.F., & Nicholls R.J. (2023) Disappearing cities on US coasts. *Nature*, *627*. 108-129. doi.org/10.1038/s41586-024-07038-3

Plasencia, J. (2024). Floating Urbanization Resilient Architecture for Climate Change (Master's thesis, Virginia Polytechnic Institute and State University). *Virginia Tech Libraries*. https://hdl.handle.net/10919/119340

Rais, M., & Hariyanto. (2021). Strategi Pengembangan Wisata dengan Pendekatan Konsep Urban Community Based Tourism (UCBT) di Kawasan Teridentifikasi Kumuh Kampung Bahari Tambak Lorok Kota Semarang. *Geo Image (Spatial-Ecological-Regional*), *10* (2), 95-106. journal.unnes.ac.id/sju/geoimage/article/view/48974

Ramadhika, M. (2019). Tipologi Ruang Interaksi di Permukiman Nelayan Tambak Lorok Kota Semarang. *Jurnal Proyek Teknik Sipil*, *2*(2). 01-06. doi.org/10.14710/potensi.2019.5781

Ratodi, M. (2023). Exploring the Potential and Challenges of Floating Architecture for Sustainable Urban Development in Indonesian Rivers A Qualitative Study. *Rivers Studies*, *1*(1). 1-18. researchgate.net/publication/370765163_Exploring_the_Potential_and_Challenges_of_Floating_Architecture_for_Sustainable_Urban_Development_in_Indonesian_Rivers_A_Qualitative_Study

Rodrigues, E.A., Carvalho, A.R.d., Ferreira, M.L., Victor, R.A.B.M., Luca, E.F.d., Rocha, G.C.d., Carvalho, B.R.d., Bustillos, J.O.W.V., Sodre, M.G., Oliveira, M.C., Jurema, B., & Andrade, D.A.D. (2024) Beyond the Rising Tide: Towards Effective Climate Policy in Coastal Urban Centers. *Land*, *13*. 1-14. doi.org/10.3390/land13122071

Rosso, F., Mannucci, S., Ferrero M., & Cecere, C. (2020). Adapting Toward Resilience: Analysis of The Construction Features and Dynamic Energy Performance of Amphibious and Floating Houses. *Tecnologies Engineering Materials Architecture*, 6(1), 31-40. https://doi.org/10.30682/tema0601c

Ruslana, Z.N., Sulistyowati, Umaroh, Prihatin, R.S., & Ana, S.E. (2021). Pengaruh CENS-CT Terhadap Curah Hujan Ekstrim Pemicu Banjir Di Kota Semarang Tanggal 6 Dan 7 Februari 2021. *Jurnal Mereorologi dan Geofisika*, *23*(2), 63-74. doi.org/10.31172/jmg.v23i2.761

Saffana, K., Putra, F.G., Pandani, A.A., & Poerbo, H.W. (2023). Resilient Urban Design Approach for Coastal Settlement (Case Study: Kampung Bahari Tambak Lorok, Semarang). *TATA LOKA*, *25*(3). 204-216. doi.org/10.14710/tataloka.25.3.204-216

Septian, L. H., Abadi, A. A., & Nurdini, A. (2022). Strategi Adaptasi Bermukim dalam Merespon Banjir Rob di Tambak Lorok, Semarang. *Review of Urbanism and Architectural Studies*, *20*(2), 144–155. doi.org/10.21776/ub.ruas.2022.020.02.13

Sharma, P., & Rahi, T. (2021). Implementation of Floating Building for the Areas with the Rising Sea Level Problems. *International Research Journal of Engineering and Technology (IRJET), 9*(4), 591-604. doi.org/10.22214/ijraset.2021.33692

Styawan, A. (2022, June 03). 4 Penyebab Banjir Rob Semarang, Siklus Bulan hingga Badai. CNN Indonesia. cnnindonesia.com/teknologi/20220602182348-199-804098/4-penyebab-banjir-rob-semarang-siklus-bulan-hingga-badai

Sumayya, R.K., Vishal, B.V., Mamatha, P.G., & Shiva Shankar, K.M. (2021). Analysis, Design and Performance Evaluation of Floating Building Using FEA. *International Research Journal of Engineering and Technology (IRJET), 8*(8), 3774-33783. irjet.net/archives/V8/i8/IRJET-V8I8429.pdf

Syahputra, A. (2022, Augusst 29). Loss and Damage Akibat Dampak Perubahan Iklim di Sektor Pesisir. LCDI. lcdi-indonesia.id/2022/08/29/loss-and-damage-akibatdampak-perubahan-iklim-di-sektor-pesisir/

Warsilah, H & Syahid, C.N. (2023) Climate Change, Community Response and Resilience. Climate Change, Community Response, and Resilience. 345-360. doi.org/10.1016/B978-0-443-18707-0.00018-7

Wijayanto, R. S & Marlina, N. (2024). Evaluasi Kebijakan Penanganan Rob Di Semarang Utara Tahun 2022-2023. *Jurnal Kajian Politik Dan Pemerintahan*, *13*(4), 343–363. Ejournal3.undip.ac.id/index.php/jpgs/article/view/47309/32106