Amphibious Architecture & Below Sea Level Settings: Creating Resilient Infrastructure to Respond to the Emerging Climatic Calamities in Kuttanads, India

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Abstract

The coastal regions have been the hub of various human activities, resulting in major cities developing along the seacoast of India. Kerala is an Indian southernmost state that was worst hit by disastrous floods in both 2018 and 2019. According to a forecast by the Indian Ministry of Earth Sciences, the calamity may be repeated every year in the future too, due to the changes in weather patterns; hence, there is a need for urgent mitigation in terms of flood and resilient infrastructure. This is a flood for which no law has been provided, since it is unprecedented. This paper discusses the feasibility of an amphibious structure-those that rise and fall with the water level-as a flood-resilient solution for Kerala's development plans.

The research adopted a mixed-method approach to understand the impact of repeated floods in Kuttanad, Kerala. It includes in-depth, qualitative case studies and interviews with residents that represent their adaptation strategies, infrastructure, and amphibious architecture, and a quantitative survey to assess the impacts of floods and response strategies targets government officials. The case study also presents India's first-ever floating house at Changanassery and some insight from its architect into amphibious design. This is also supported by the literature review, which has demonstrated amphibious architecture as a sustainable solution for flood-prone areas.

The research focuses on the compilation and analysis of various case studies from different parts of the world, drawing inferences related to safeguarding flood-prone communities and especially Kuttanad in Kerala. It also carries out in-depth examinations of amphibious homes to propose design guidelines. Further, it considers ways in which amphibious architecture responds effectively to Kuttanad's as well as India's very particular issues with flooding, enhancing its resilience and hence improving life for its residents.

Keywords: Floating Cities, Rising Sea Levels, Floods, Amphibious Architecture, Adaptive Architecture

Introduction

India is a peninsular country surrounded by the Arabian Sea, the Bay of Bengal, and the Indian Ocean, making flooding a grave concern. Flooding represents one of the most common natural catastrophes of the country; every year, it causes great losses to property and human lives. As shown in the Figure 01 and according to GSI, about 12.5% of the total area of the country is prone to floods. The major river systems, such as the Ganga, Brahmaputra, Godavari, and other rivers including their tributaries have posed a perennial threat in these regions, especially during monsoon rains which heighten flood conditions, particularly in the South and the East. Indeed, newer approaches towards the management of flood with recurrence of floods and rise in sea levels due to climatic changes assume significance, especially in coastal and riverine areas. It is no longer sufficient to merely construct embankments, coastal barriers, and other heavy engineering solutions. With the rise in global sea levels associated with climate change, there is a rising need for innovative and adaptive architectural designs that keep communities out of the reach of these swelling dangers. In this context, amphibious architecture emerges as one promising solution.

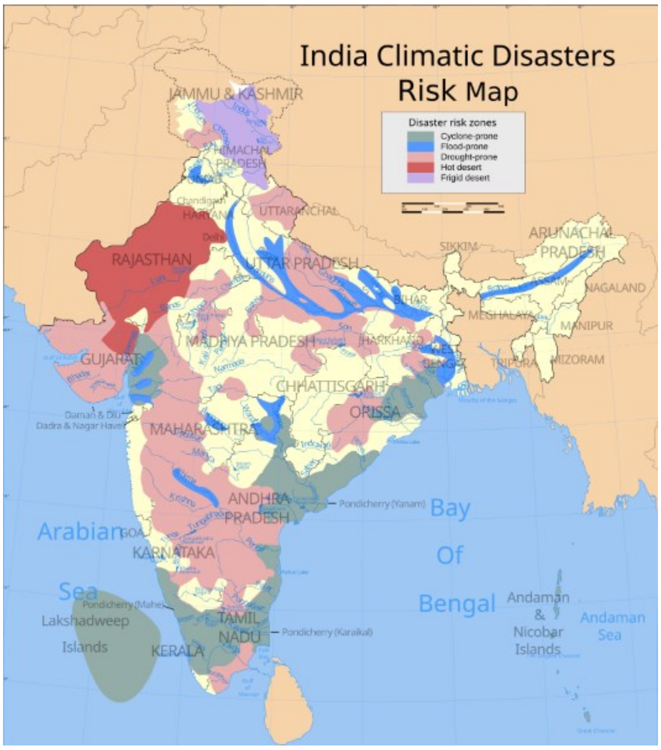


Fig. 01: Indian Climatic Disaster Risk Map
Source: https://en.m.wikipedia.org/wiki/File:India_climatic_disaster_risk_map_en.svg

Amphibious architecture is what works both out of water and during a flood: the structures adapt to the fluctuating water levels without structural damage. So-called buoyant foundations are provided with an anchoring system through the use of vertical guideposts, uprising and going down with water, while preventing these buildings from floating away or sustaining structural damage. Once the floodwaters recede, the building would return to its former position. Thus, the ability of structures to sit atop floodwaters and function cohesively makes this concept a workable solution for flood mitigation in at-risk communities.

The following rationale considers the rising need to build such resiliency in light of the widespread impacts that are now being levied by climate change globally within communities susceptible to flooding and on all coasts: Human endeavors, particularly those involving greenhouse gas emissions, have warmed the planet; to this, glacier melting, ice sheet discharges, and ocean expansion contribute significantly.

According to the Inter-governmental Panel on Climate change, there has been an increase of 1.5 degrees Fahrenheit in temperature over the past hundred years; this has numerous various serious implications for coasts worldwide. Climate-driven changes pose a heightened threat for Indian coastal cities, which hold large sections of its population. Research on sea-level rise and greenhouse gas emissions shows frightening trends, where a huge part of the Indian coastline may suffer extreme flooding within this century.

Therefore, as shown in the Fig 1, a state like Kerela falls into cyclone prone are with the extension of this flooding cycle in places like Kuttanad due to climate change. For instance, the building infrastructure has to be resilient enough to respond to such dynamics. Amphibious architecture remains one feasible sustainable solution to mitigate flood risks in areas below mean sea level.

In this context, this research investigates amphibious architecture as a sustainably adapted resilient solution to recurrent floods in below sea-level settings.. Its aim is to help improve the quality of life for its habitants in Kuttanad, Kerala, India.

Its objectives are:

1. To investigate the viability of amphibious architecture as a flood-resistive design in flood-prone regions.
2. To assess the effects of repeated flooding within Kuttanad, Kerala, and assess infrastructure resilience.
3. To develop design guidelines to produce amphibious structures suited to unique environmental challenges in Kuttanad.
4. To ascertain the potential contribution of amphibious architecture towards enhanced living conditions and the safety of communities within the flood-prone areas.

Theoretical Framework

Types of Water Related Buildings

Terp Dwelling:

A terp is a man-made mound of earth constructed to afford elevated and safe ground during floods. The first terps were built about 500 B.C. in the Netherlands, where tidal disruptions in the nearby rivers affected everyday life. These mounds, which were often rising to 15 meters, were built to keep residences dry and allow space for animals and food storage. Around 1000 A.D., the villagers began connecting these mounds with one another to form a dike system that would protect their fields from flooding. Terp houses still appear well above the ground to stay dry until the water is at its high point. Figure 2 shows example of a terp dwelling from Netherlands.

Fig. 2: Bridge House in Achterhoek, Netherlands
Source: https://123dv.nl/en/villa/bridgehouse/

Fig. 3: Sandy Orchid Lodge
Source: https://www.cobbrealestate.com/rentals/sandy-orchid-lodge

Static Dwelling:

One of the more general approaches to retrofitting against flooding is to elevate the home to the minimum BFE. If correctly elevated, only the largest floods would inundate the home's living space. There are two major techniques for elevating your house: 1. Elevating your home and constructing a new or extended foundation under it. 2. Leaving the structure of the house intact and creating within it an elevated floor or building a new second storey. Figure 3 shows example of a static dwelling from Texas.

Pile Dwellings:

Pile dwellings are a structure standing on columns or piles of concrete, steel, or wood above ground, usually seen at shallow waters and places that are easily affected by changing water levels. These are raised 8-15 feet off the ground. It protects against flooding. In Indonesia and Singapore, "kelongs" are good examples for fishing. Figure 4 shows example of a static dwelling around the Alps.

Fig. 4: Prehistoric Pile Dwelling around the Alps
Source: https://www.newlyswissed.com/unesco-world-heritage-sites-in-switzerland/

Fig. 5: House Boats of Kerela (Source:Author)

Timber piles, having served for over 6,000 years, offer a lightweight, renewable, and highly treatable and drive-able material. If underwater, they can last indefinitely; those above the waterline may last over a hundred years with proper maintenance. Concrete piles may be either pre-cast or cast in place and offer durability without the prospect of rust or decay at a lower cost than steel. Steel piles take up numerous forms of the cross-section and are much strong and adaptable. When submerged in water, they easily corrode and therefore not as durable compared to concrete. Due to their strength and adaptability, steel is still commonly used.

Houseboats

Houseboats came into being by the conversion of ships and fishing vessels into dwellings and therefore combined the concepts of land property with buoyant structures to support the pressure of water. Houseboats became part of American history in the early 1900s, with the first documented in Seattle in 1905, peaking at over 2,000 in the 1930s. During the 1940s, a shortage of housing in San Francisco saw laborers taking old fishing boats and decommissioned battleships and turning them into homes, many of which were moored in Sausalito Bay.

In India, houseboats are found in the backwaters-especially on Dal Lake in Srinagar and in Kerala. Figure 5 shows example of Houseboats of Kerala in India, used for carrying grains and spices have now become vehicles for leisure cruises. These boats, usually 60-70 feet long, were made from planks of wood tied with ropes and coconut fibers and covered with roofs of bamboo and palm leaves. Cashew nut oil was used for protecting the boats. Modern day floating homes built by firms such as Waterstudio and Aquatecture of the Netherlands have gained tremendous popularity in coastal regions around the world.

Amphibious Dwellings

Amphibious buildings utilize buoyancy in their foundation design to mitigate the impacts of flooding. Some of them have attached mechanical systems creating buoyancy that may allow the structure to temporarily rise with floodwaters and then smoothen out back to its original ground level as the water recedes.

Factor and Boiten define an amphibious building as one that will 'adapt' to a flood situation and float as water levels rise. English et al. define amphibious architecture as a flood mitigation strategy that allows an "otherwise-ordinary structure" to float on the surface of rising floodwater levels. Moon defines an amphibious house as one that lies on the ground or on a structure above water but floats during a flood as water levels rise. Prosun defines an amphibious house as a structure with a buoyant foundation, constructed on solid ground with capabilities of floating up with rising water levels. Barker and Coutts define an amphibious house as a building that rests on the ground when conditions are dry but rises in its dock and floats during a flood.

Fig. 6: Amphibious Dwelling , Maasbommel Project
Source: https://366solutions.com/13-/09-/2020/13-amphibious-housing-adapts-water-level/

Examples of amphibious houses can be identified in the Netherlands; one example is the Maasbommel water dwellings along the Maas River as shown in Figure 6. Amphibious architecture provides a flood mitigation strategy in concert with natural flood cycles of susceptible regions rather than attempting to stop it.

While there are a number of different means to deal with increased water levels, amphibious structures provide protection from flooding that is reliable and allows the community to resist calamities and get up and running much quicker rather than if their buildings were not resilient to flooding. Amphibious designs can let buildings "coexist" with floods in sensitive environments. The floodwater lifts the structure, using its power for the benefit of the building and averting major damage. Instead of building barriers to block the water, these methods absorb floodwater while protecting the building. The experimentation with the amphibious house is common in many parts of the world where flooding occurs regularly, but not in India.

For amphibious buildings, the usage of material and construction method lags far behind between developed and developing nations. The concept of design covers construction, land-use planning, selection of a site, policy-making, and resilience at community levels. Consideration is taken for the infrastructure needs such as the mechanical systems and utilities, system components, and also the codes and certifications that are required for amphibious structures. These factors make amphibious architecture an essential tool for enhancing resilience in flood-prone areas.

Designing an amphibious dwelling is based on a few main parameters that are essential to guarantee the safety, functionality, and resilience of the dwelling.

- **Capability of Floating*:*** The house must have the ability to float reliably during flooding events without compromising structural integrity.

- **Foundation:** The foundation must be designed to support the structure both on land and while floating, with buoyant properties that activate during rising water levels.
- **Floating Line:** This is the height at which the dwelling starts to float in relation to the level of the water.
- **Buoyant Foundation Height:** It must be buoyant enough to provide the height needed for the structure to remain well above the ground in case of a flood.
- **Structure Type:** The choice of materials and design should be suitable for both land-based living and aquatic conditions.
- **Road and Parking Conditions:** Access to roads and parking facilities should remain functional during flooding, taking into account the need for alternative transportation.
- **Utility Access:** Utilities such as water, electricity, and sewage systems must be able to function while the house is floating, ideally connected to municipal systems.
- **Fire Safety:** Fire safety measures must account for both land and floating scenarios.
- **Water Maintenance*:*** Proper drainage and water maintenance systems are needed to ensure that the structure remains stable and safe during and after flooding.

Types of Floating Foundations

Expanded Polystyrene Filled with Concrete (EPS): This type of foundation consists of an EPS foam core wrapped by concrete. It is very buoyant and unsinkable; therefore, this has a minimal draft, and it is well suited for shallower water conditions.

Concrete Hull: A concrete hull foundation consists of hollow, reinforced concrete boxes. The internal airspace provides buoyancy, supporting both the structure and the concrete itself. Concrete's resistance to corrosion and minimal condensation make this a durable option for long-term use in aquatic environments.

Pneumatic Stabilization Platform: This type of foundation is composed of multiple cylinders made from materials like steel, concrete, or plastic. The buoyancy is provided by air trapped in the cylinders, with water on the bottom side and a deck on the top. This design allows for stability and adaptability in varying water conditions.

Plastic Bottles: This eco-friendly foundation uses common 2-liter plastic bottles, which are inexpensive, resistant to saltwater, and widely available. The bottles are connected into hexagonal grids, stacked, and laminated to create a buoyant platform. A solid surface is then applied on top of the bottle-based flotation system to support the structure.

Each of these floating foundation types offers unique benefits, depending on the environment and design needs of the amphibious dwelling.

Review of Literature

Amphibious architecture is a futuristic concept proposing solutions for flood issues that come along with low-lying regions. Though it is a well-researched concept in many parts of the globe, especially in highly flood-prone countries like the Netherlands, in India itself, it has been applied on a very small scale. Traditionally, buildings are built on land and boats in water; however, amphibious design incorporates both-a structure needs to have its function on both land and in water. Ideas like these really open up wonderful possibilities for regions such as Kuttanad in India, which faces serious flooding year after year due to the area lying really low below sea level. Consequently, despite the promising applications, not many resources and studies on this subject exist; the famous ones include “Amphibious Housing in the Netherlands” and “Float: Building on Water to Address Urban Congestion and Climate Change."

Amphibious Housing in the Netherlands

The management of water in the Netherlands has a long history due to the peculiar geography of the place with polders, dikes, and canals that control the flow of water. Such adaptive resilient housing has been an immediate need felt as climate change and rise in sea levels have grown. Amphibious architecture thus successfully embeds water into urban design rather than fighting against it. In the last few years, a number of innovative building forms have emerged in the Netherlands, including floating homes, amphibious homes, and dike homes. The latter are to be adapted to the aquatic environment, and there are plans for dedicated amphibious quarters with their own infrastructure.

Some of the more well-known architects and urban planners that have contributed a great deal to the development of amphibious housing in the Netherlands include Nillesen and Singelenberg. Projects by Nillesen range in scope from single floating houses to major waterfront residential design developments, while Singelenberg has worked with the Water Living Program of the Steering Group for Housing Experiments in an effort to promote government-sponsored housing developments. Their collaboration thus represents the sustained efforts at addressing the housing challenges posed by climate change in the Netherlands.

The Massbommel Amphibious Project

Perhaps one of the latest and most significant examples of amphibious architecture in the Netherlands can be considered to be the Massbommel project along the Meuse River as shown in figure 7. The rural village lies outside the main flood protection systems, hence it is highly vulnerable to floods. In turn, the Dutch government sanctioned plans for 34 amphibious houses and 14 floating ones back in 2005. From designs by Factor Architecten and builders Dura Vermeer, these houses were to float on the water during high levels. The foundation of these houses will then be made with a concrete hull acting as a watertight basement.

The concrete hull weighs about 70 tons and is joined with six concrete piles, sunk deep into the ground. Under normal conditions, the houses would be on solid foundations but during floods rise along two mooring poles buried in the ground that would keep the houses stable, anchored to prevent drifting with strong currents that could further cause damage. Moreover, they are linked to one another, which lessens the stress of wave action and water movement on individual houses.

Fig. 7: Maasbommel Project
Source: https://www.factorarchitecten.nl/project/drijvende-woningen-maasbommel/

Construction and Functionality

Amphibious homes in Massbommel are designed with functionality and resilience in mind. Traditional in shape, the houses have provision for parking, gardens, and even access to roads, as any normal house would have during regular conditions. As figure 8 shows these amphibious homes has amphibious structure and mooring pole with base which has high buoancy. It is only in cases of flooding that the floating system is activated. As the water rises, so do the houses, kept steady by mooring poles. As figure 9 and 10 shows different conditions for these structure during normal water levels and during floods. The major load-carrying structure in these homes was prefabricated, and on site, a roof was put up in steel and wood and then clad with PVC. Regarding services, the facilities in these homes are no different from those in normal Dutch dwelling houses, having central heating, electricity, water, and sewage connections. The only difference is in flexible utility hookups for these utilities. The pipelines are designed to be able to stretch and continue working while there is flooding-so as to keep supplying homes with basic services even while floating .

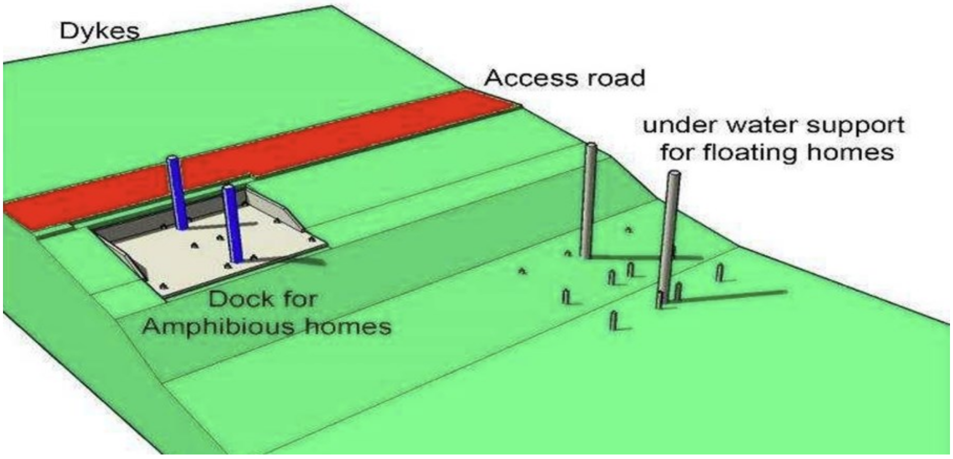


Fig. 8: Amphibious Structure dock and mooring pole
Source: https://www.factorarchitecten.nl/project/drijvende-woningen-maasbommel/

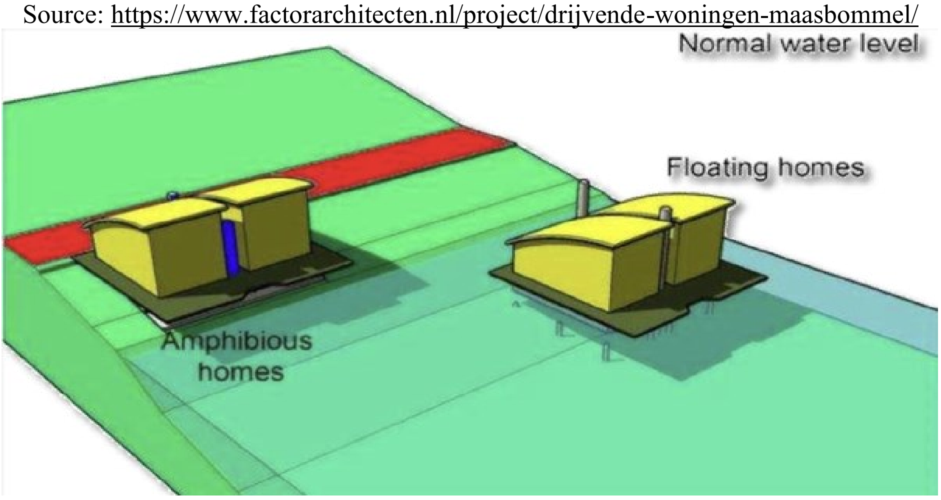


Fig. 9: Amphibious homes during normal water level
Source: https://www.factorarchitecten.nl/project/drijvende-woningen-maasbommel/

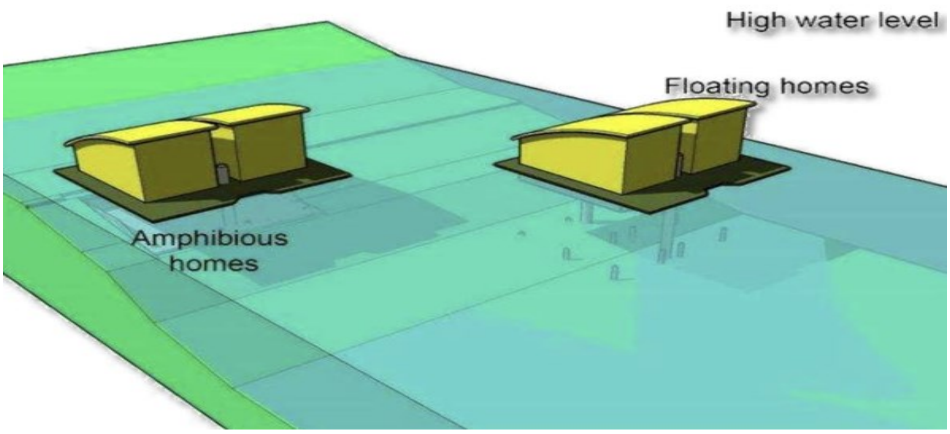


Fig. 10: Amphibious homes during flood conditions
Source: https://www.factorarchitecten.nl/project/drijvende-woningen-maasbommel/

Testing and Results

Amphibious houses in Massbommel have already been tested for some flood events, including that of 2011 when the water rose to over 7 meters.

The residents had received prior notification and had shifted their vehicles from the parking site. When the water reached its peak, the houses successfully floated; residents were able to reach them by boats. When the flood waters receded, the houses moved smoothly back into their original position without any structural damage or damage to the docking systems.

The Massbommel Project shows how amphibious architecture can be an effective solution for flood-prone regions. Since 2005, the floating and amphibious houses function very well, needing only slight maintenance. For this reason, these homes present a prospect for integrating amphibious architecture into urban and rural planning that can be one of the sustainable ways of living harmoniously with water.

A review of the amphibious architecture in the Netherlands provides valuable insight into how similar flooding problems elsewhere in regions like Kuttanad have been tackled. Its implementation in India could, thus, be the effective and practical long-term measure toward flood resilience by assuring the safety of a community while keeping it functional against rising waters.

Research Methodology

This study adopts an integrated qualitative-quantitative approach to explore the effects of recurring floods in Kuttanad, Kerala, on people's lives. Emphasis is placed on residents' adaptation to these circumstances, infrastructure adjustment, and how amphibious architecture could provide sustainable solutions. Primary data collection was carried out by author as qualitative interviews with people in flood-prone areas, living in architecturally advanced homes. An exploration by author was made into the experiences of the residents, the damage to homes and infrastructures, and the mitigation's that are made during floods. It also examines how technological advancements in architecture could potentially affect their resilience from the prevalent flooding that occurs two to three times a year.

Data Collection Methods

1. Direct Observation: This consisted of on-site monitoring and observation of new government construction projects. An observation guide, structured with both open-ended and specific questions, was used in the gathering of responses from informants as data sources relevant to the research.
2. Literature Review and Record Analysis: This is also known as a literature study, in which relevant theoretical data is gathered based on scientific resources-both published and unpublished. Data gathering sources included books on both physical and digital platforms, online research papers, and journals.
3. Documentation: Data was obtained from archival records of documents, books, and written accounts of expert opinions and debates. The information in the field data was recorded by writing down all the information related to the study.
4. Interviews: Personal interviews with informants were undertaken, including residents of Kuttanad and areas around the region, government officials who had experience in the response against flood situations, architects, and construction workers involved in designing new structures. It gave an opportunity for the researcher to interact directly with the respondents face to face and extract information through direct and indirect questioning.

Fig. 11: government officials
Source: Author

A quantitative survey was carried out by the author with officials in government in order to gather data on flood impact and response strategies. Figure 11 shows an anteraction between government officials and author during the interviews. Questions were asked to the government officials to get the precise data regarding the local losses during the floods. The research also includes a living case study of the first floating house in India, which is located in Changanassery, Kerala. Its architect was interviewed in the process, with the view of gaining insight into critical design considerations for amphibious houses. Besides fieldwork, the research also heavily relies on an extensive literature review of books, articles, reports, and case studies. The resultant reviews have been used to inform the case studies and provide the grounding for a questionnaire on specific research questions and analysis. The mixed-method approach therefore offers comprehensive insights into the scope and potential of amphibious architecture in flood-prone settings.

Case Studies

Introduction to Case Studies

Kuttanad is a region in the state of Kerala, India. It lies below sea level and often faces serious flooding. Kerala, despite having a high Physical Quality of Life Index, good governance, social equity, and spiritual harmony, was struck by one of the most disastrous floods in August 2018. Figure 12 and 13 shows comparision between the satellite image of Kerela of before floods and after floods. The flood, considered as the worst in nearly a century, transformed the face of the landscape into scars and caused devastation to biodiversity, infrastructure, and livelihoods in an unparalleled manner. Over 483 lives were lost, while incalculable losses were reported to livestock, homes, roads, and bridges. The agriculture losses considerably affected the farmers' livelihood, and the tourism sector also was severely affected which is one of the major contributors to the state's economy. The total estimated loss was about Rs 40,000 crore. International attention was attracted by the flood when United Nations, Asian Development Bank and the World Bank showed its response.

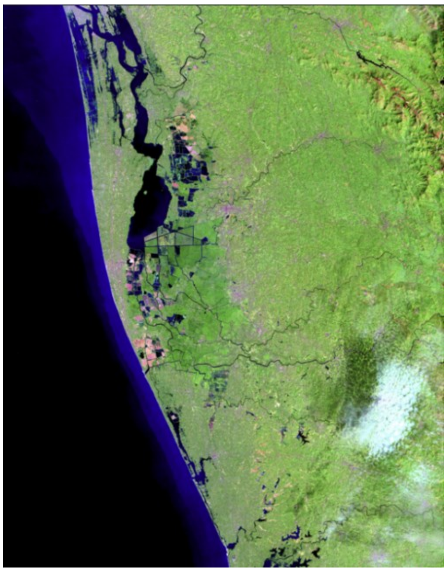


Fig. 12: Satellite image of Kerela
February 6, 2018, *Source: NASA*

Fig. 13: Satellite image of Kerela
August 22, 2018, *Source: NASA*

Recovery from this calamity is believed to take a number of years, with the after-effects of the flood likely to impact the state for 5 to 10 years. The calamity brought out the vulnerability of Kerala in terms of natural hazards such as floods, droughts, landslides, coastal erosion, and lightning-all worsened due to climate change. Due to the geographical variation in Kerala, the state commonly faces all these natural threats, especially the areas with reclaimed land below sea level, such as Kuttanad, and the regions with steep slopes in the Western Ghats, which are prone to landslides. Apart from that, coastal erosion, slight earthquakes, and lightning strikes also contribute to the complication of the environmental problems in the region. This flood has really brought to the forefront the requirement for Kerala to rethink its development strategy and implement long-term disaster management measures. A survey conducted on the inhabitants in Kuttanad revealed that a majority thought that lack of proper implementation of technology is one of the reasons for the aggravation of flood destruction.

Fig. 14: Damage during Kerela floods, 2018
Source: Kerela Disaster Management

Fig. 15: Damage during Kerela floods, 2018
Source: Kerela Disaster Management

While Kuttanad is well-recognized for its houseboats and floating structures, few residents were informed about amphibious architecture as a possible solution. The amphibious architecture lets the structures float during flood conditions and relapses into their earlier positions once the water level goes down. Many residents of Kuttanad were found receptive to this concept after explanation and said they would like to use the technology due to its potential to minimize the damage caused by floods. However, the high cost of such building structures is another serious hindrance factor in their widespread adoption. Despite that fact, the study "highlights amphibious architecture as one viable flood-resistant solution for the region;

however, it would need more investment and technological support to make it possible to broaden its reach in the general population.".

Case Study 1: VSK Model House

The flood-prone state of Kerala has received a flooding new answer from the Gopala Krishnan VSK Model House. The unassuming house at an area of 1,600 square feet floats on the waters when floods hit Kerala. Mr Gopala Krishnan himself built this house, which is unconventional, and prevents the entry of stones, bricks, and cement into the construction, basically adhering to the environmental recommendations of the Gadgil report. Figure 16 shows an interaction between Gopala Krishnan and author while conducting the research. Figure 17 shows the floating house. His design came out of the need for a flood-resistant design after massive flooding was experienced within the state; hence, the house that rises with the water and has the least environmental impact was born.

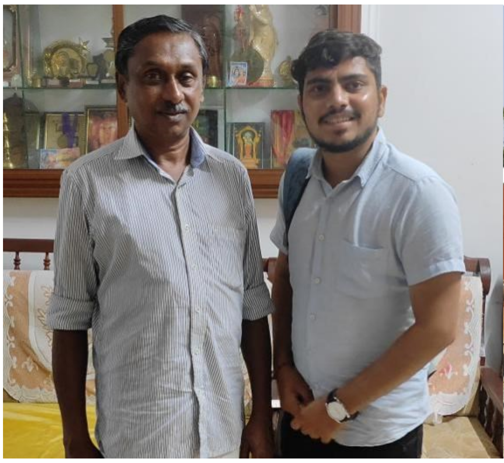


Fig. 16: Gopala Krishnan (Left), Author (Right)
Source: Author

Fig. 17: VSK Modal Floating House
Source: Vastushilpi Kannan

This floating house is capable of rising several feet with water. This, it does with air tanks embedded in the foundation raise the house as water increases pressure on the tanks. Interestingly, the house weighing roughly 6 tons floats easily. According to Gopala Krishnan, construction cost is around 30% less when compared to conventional cement-based homes and can be built within a total budget ranging between Rs 15-20 lakh.

This floating home was built with durable materials, so it can be considered as an eco-friendly and flood-resistant house. The house in Chanaganessery, Vazhappally, has all modern amenities, including three bedrooms, a kitchen, and toilets attached to each of the bedrooms with space on the terrace for further expansion. Gopala Krishnan has registered a patent for his floating house technology, besides he has put into place homes that are resistant to earthquakes and strong coastal waves. In front of his house, there is shown a model of the house with reduced dimensions, where visitors can see for themselves the innovative technology. This case study will be discussed further.

Case Study 2: Water Dwelling, Ijburg (Netherlands)

The Ijburg, between Zeeburger Island and Haven Island, on the IJ Lake, is a typical example of Dutch floating architecture on floodlands. Figure 18 shows Water dwellings of Ijburg built in 2001, this new quarter on Amsterdam's east side has grown to house over 15,500 residents. Figure 19 shows overall plan of the water dwellinggs. The first island in the chain of islands constituting Ijburg is Steigereiland. It was created with two inland waterway neighborhoods, comprising floating houses along with houses on platforms. These houses are actually prefabricated and built more than 30 miles from the site. Carefully constructed were the footings, wherein the structure's walls and floors concurrently poured with concrete created a smooth, watertight foundation. The walls were of different thicknesses depending on which would bear the weight of furniture and the inhabitants alike. Once attached to the foundation, the nearly completed dwellings were transported to Ijburg. This technique gave high accuracy in construction and was found resilient enough to face the problem of water level rise; therefore, Ijburg became a model for modern amphibious architecture in an urban context.

Fig. 18: Water Dwellings Ijburg
Source: archdaily

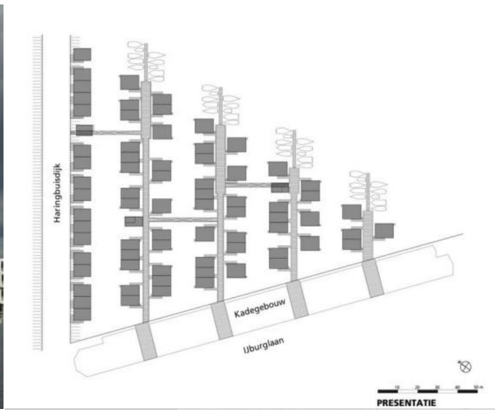


Fig. 19: Overall Plan, Water Dwellings Ijburg

Case Study 3: The Float House, New Orleans (USA)

New Orleans Float House is a prefabricated, inexpensive house type for the flooded areas. Figure 20 shows the float house of New Orleans. The needs and budgets of the local households were met with the flooded area in mind. This house was designed by the students and faculty at UCLA along with the architects from Maynes and Morphosis. It follows the traditional shotgun style houses in New Orleans. The house was built on a foundation of expanded polystyrene foam sprayed with glass fiber-reinforced concrete, incorporating a front porch that allows easy accessibility for elderly and disabled individuals, maintaining the cultural charm of the town. A 4-foot foundation also houses the electrical and plumbing systems; the house is able to float during floods. It is one of the major steps toward affordable resilient housing in the most vulnerable communities.

Fig. 20: The Float House, New Orleans
Source: archdaily)

Findings

The 2018 Kerala floods were the worst ever recorded in the history of the region. The calamity came with severe impacts on human life and infrastructure. Between August 7th and 20th, the floods killed 504 people and directly affected 23 million others. Economic losses were estimated at $2.85 billion, hence the third costliest flood in India. Further, more than 110,000 houses were damaged or destroyed, while over 60,000 hectares of agricultural land were affected and considerable livestock were lost. Flooding damaged over 130 bridges and a combined total of 83,000 km of roads, leaving many communities isolated.

Satellite images on the 21st of August 2018 had indicated a 90% increase in water cover in the areas affected by the flooding. In many places, such as Kuttanad and the Kole lands of Thrissur, water reached up to 5 to 10 meters high. The discharge of floodwater in Kuttanad was obstructed due to heavy rainfall, the opening of shutters from upstream dams, and high tidal action in the Arabian Sea. Field observations indicated that the embankment breakages around Vembanad Lake further worsened the flooding with the inflow of lake water into paddy fields and residential areas.

A significant factor here was the sudden release from dams across the state. Changes in land-use patterns, such as deforestation and encroachment in catchment areas, over the past two to three decades have given a greater dimension to the scale of this disaster. Landslides, silt deposition, and soil erosion further reduced the effective storage capacities of the dams, increasing the magnitude of the flood. These findings point out the immediate need for better flood management and land-use practices in the region.

Impact of floods

The state of Kerala stands second only to Tamil Nadu in terms of urban development with an urbanization rate of 47% (Census 2011). As far as the quality of its housing is concerned, Kerala boasts of a very good stock of buildings: 83.5% of them are pucca, 12.7% semi-pucca, and only 2.6% kutcha. As many as 66% of its dwellings were rated as excellent, 28% rated as habitable, and only 5% rated as deteriorating. Moreover, 94% have electricity in their houses, and 95% have latrines, out of which 93% from rural households have latrines on their premises. The main sources of water are wells, at 62%, and tap water, at 30%. Kerala has quite a low poverty rate, with less than 12% of the population living below the poverty line.On the other hand, human settlements experienced high destruction during the 2018 Kerala Monsoon Floods in both the urban and rural settings. As depicted in Table 1 about 22,132 houses were completely destroyed while 104,636 were partially damaged. The kutcha houses, being fragile in nature, accounted for 30% of the severely and 20% of the marginally damaged ones. The destruction was witnessed to range from tribal hamlets, riverside villages, to peri-urban areas. Consequently, the elderly, disabled, female-headed households, and ST/SCs were especially constrained in reconstructing houses.

Table 1: Housing damages
Source: Kerela Disaster Management

	Fully damaged			Partially damaged			Total
	Kutcha	*Pucca*	*Total (A)*	*Kutcha*	*Pucca*	*Total (B)*	(A+B)
District	Units	Units	Units	Units	Units	Units	Units
Alappuzha	2,830	2,056	4886	4,519	17,517	22,036	26,922
Ernakulam	6	3,619	3625	8	23,110	23,118	26,743
Idukki	632	1,716	2348	1,437	3,920	5,357	7,705
Kannur	0	11	11	113	397	510	521
Kasaragod	0	0	0	0	26	26	26
Kollam	49	7	56	414	80	494	550
Kottayam	95	946	1031	1,737	9,582	11,319	12,360
Kozhikode	118	237	355	1,126	4,726	5,852	6,207
Malappuram	784	296	1080	2,824	2,734	5,558	6,638
Palakkad	539	231	770	2,265	971	3,235	4,005
Pathanamthitta	463	669	1132	2,052	9,233	11,285	12,417
Thiruvananthapuram	16	73	89	107	546	653	742
Thrissur	916	4,412	5328	2,184	10,561	12,745	18,073
Wayanad	514	897	1411	1,494	3,606	5,100	6,511
Sub-total	**6,962**	**15,170**	**22,132**	**20,280**	**87,009**	**107,288**	**129,420**

Table 2: Cost for Repair of partially damaged and Reconstruction of the Fully Damaged Houses
Source: Kerela Disaster Management

District	Fully Damaged		Partially Damaged		Total		
	Number of units	INR million	Number of units	INR million	Number of units	INR million	USD million
Alappuzha	4,886	2,201	22,036	2,183	26,922	4,384	62.63
Ernakulam	3,625	1,884	23,118	2,404	26,743	4,288	61.26
Idukki	2,348	1,145	5,357	523	7,705	1,668	23.83
Kannur	11	6	510	50	521	56	0.8
Kasaragod	0	0	26	3	26	3	0.04
Kollam	56	23	494	41	550	65	0.92
Kottayam	1,041	530	11,319	1,135	12,360	1,665	23.79
Kozhikode	355	170	5,852	582	6,207	752	10.74
Malappuram	1,080	468	5,558	510	6,638	978	13.97
Palakkad	770	336	3,235	282	4,005	618	8.83
Pathanamthitta	1,132	533	11,285	1,124	12,417	1,657	23.68
Thiruvananthapuram	89	44	653	65	742	110	1.57
Thrissur	5,328	2,661	12,745	1,273	18,073	3,934	56.2
Wayanad	1,411	672	5,100	495	6,511	1,167	16.67
Total	**22,132**	**10,673.20**	**107,288**	**10,671.24**	**129,420**	**21,344.44**	**304.92**

Table 3: Relocation - Total cost of basic services, land required for relocation, cost of land acquisition, and transition shelters arrangements
Source: Kerela Disaster Management

District	Cost of Basic Services	Area of land required	Cost of land acquisition	Cost of transition shelters	Total Cost of Land for Relocation	
	INR million	Acre	INR million	INR million	INR million	USD million
Alappuzha	166.03	30.2	755.08	49.15	970.25	13.9
Ernakulam	113.13	17.39	434.76	28.3	576.19	8.2
Idukki	76.29	12.77	319.24	20.78	416.31	5.9
Kannur	0.34	0.05	1.32	0.09	1.75	0
Kasaragod	-	-	-	-	-	0
Kollam	1.98	0.39	9.65	0.63	12.26	0.2
Kottayam	32.94	5.22	130.44	8.49	171.87	2.5
Kozhikode	11.64	1.98	49.61	3.23	64.48	0.9
Malappuram	37.46	7.06	176.4	11.48	225.34	3.2
Palakkad	26.61	4.98	124.57	8.11	159.29	2.3
Pathanamthitta	37.54	6.54	163.39	10.64	211.57	3
Thiruvananthapuram	2.85	0.46	11.62	0.76	15.23	0.2
Thrissur	170.63	27.73	693.36	45.13	909.12	13
Wayanad	46.49	8	199.88	13.01	259.38	3.7
Total	**723.94**	**122.77**	**3,069.32**	**199.78**	**3,993.04**	**57.0**

Table 4: Total Cost of Housing Reconstruction
Source: Kerela Disaster Management

District	Reconstruction and Repair Cost	Relocation Cost	Total Cost	
	INR million	INR million	INR million	USD million
Alappuzha	4,384.41	970.25	5,354.66	76.5
Ernakulam	4,288.36	576.19	4,864.55	69.49
Idukki	1,667.76	416.31	2,084.07	29.77
Kannur	56.05	1.75	57.8	0.83
Kasaragod	2.7	0	2.7	0.04
Kollam	64.68	12.26	76.94	1.1
Kottayam	1,665.41	171.87	1,837.27	26.25
Kozhikode	752.02	64.48	816.51	11.66
Malappuram	977.78	225.34	1,203.11	17.19
Palakkad	617.81	159.29	777.1	11.1
Pathanamthitta	1,657.47	211.57	1,869.04	26.7
Thiruvananthapuram	109.7	15.23	124.94	1.78
Thrissur	3,933.70	909.12	4,842.83	69.18
Wayanad	1,166.58	259.38	1,425.97	20.37
Total	**21,344.44**	**3,993.04**	**25,337.48**	**361.96**

Even structural damage occurred in buildings with a structured foundation, such as RC-framed structures with cement-mortared masonry. As depicted in table Extensive collateral damage has been caused to many structural components, including electrical systems, plumbing, flooring, doors, windows, and compound walls. The total estimated damage and loss is Rs. 26,718 crores, as depicted in table 2,3 and 4 while the recovery needed was estimated at Rs 31,000 crores. Infrastructure sectors affected included transportation, water and sanitation, electricity, and irrigation. But notably, the long-term economic loss was huge, as nearly 2.6% of the GSDP of Kerala was lost owing to flood-related damage, accompanied by wage and livelihood losses. Figure 21 shows share of disaster recovery needs across different sectors.

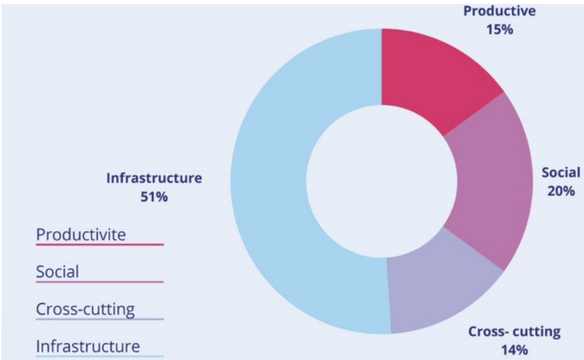


Fig. 21: Share of disaster recovery needs across different sectors
Source: Author

Findings from the Case study of VSK Modal House

This case study explained a new technique that was used to make a floating house flood-proof. It consisted of four pistons made of steel buried 25 feet underground at each corner of the house. These were concealed and could be both seen outside as well as inside the house to give the building the structural support without touching the hard ground. The pistons work with an air tank such that the house rises with a flood. As and when the water rises, so does the house with the air tank; when the water goes down, the house retreats to its old position. Figure 22 shows the conceptual section of the house. According to Acharya, the model will manage to keep the house stable and unmoving at the time of flooding, without lateral shifting.

As depicted in schematic section in figure 23, the pistons are adjustable and extend up to 15 feet above ground, which is the desired height for the house to move securely up to 10 feet. To extend the height of the pistons, their strength and length must be increased in proportion. Dirt, pebbles, tiles, cement, and wood are some of the traditional materials that are not used in this construction. Instead, it is mainly GI pipes in structure, while multi-wood sheets make up the walls, with a gap of 1.5-inch between them for cooling. The basement is also covered with multi-wood sheets, making the air tank not very prominent. The mini house itself is made from aluminum sheets, while the roofing material is flexible and one is left to one's choice.

Such a flood-resistant house may cost around Rs 1,600 per sft if high-quality GI pipes are used. The building activity related to a 1,300-sft house required four months for completion with a small group of specialized workers. Four welders along with a few carpenters were required continuously for welding, carpentry, wiring, and plumbing works. Figure 24 shows all the materials used and mechanism of the house. Acharya points out that it can adopt all types of soils, ranging from loose sand to hard rock, and hence is particularly suited to low-lying areas like Kuttanad where both waterlogging and flooding prevail. The model house, called the "extra height home," has its housing elevated on multiple pistons to bear upwards. This would serve to enhance resilience in flood-prone regions.

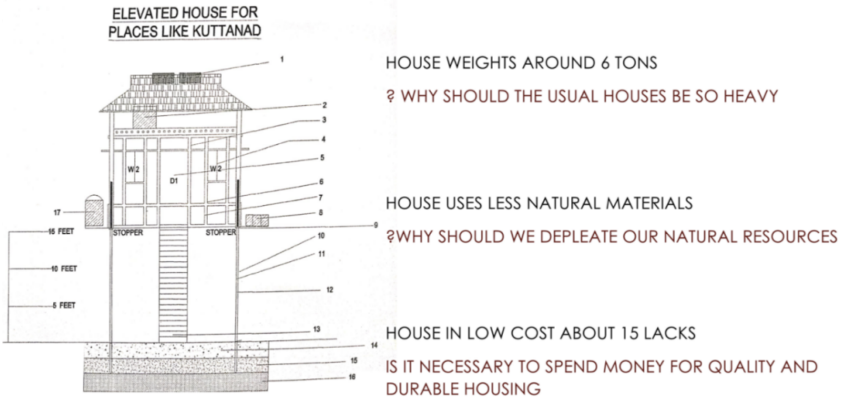
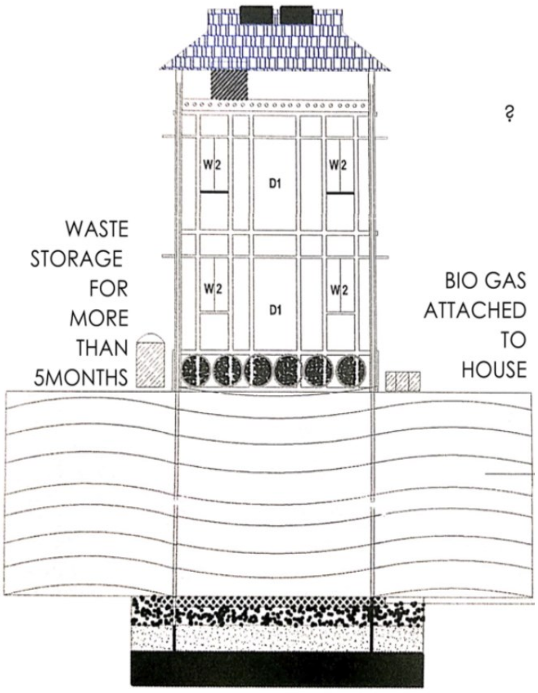


Fig. 22: Conceptual Section (*Source: Vastushilpi Kanan)*



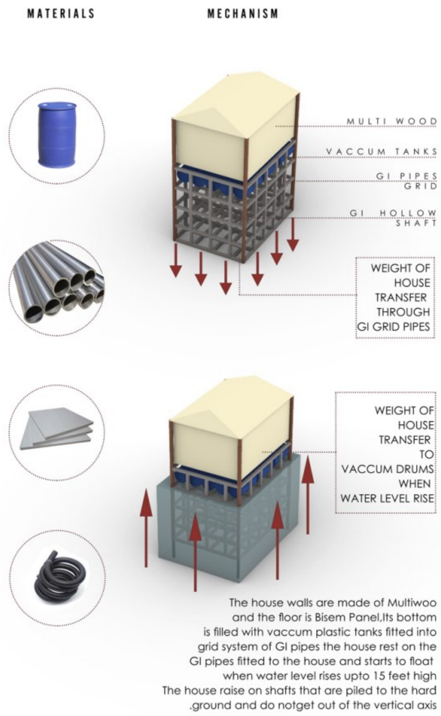


Fig. 23: Schematic Section
Source: Vastushilpi Kanan

Fig. 24: Materials & Mechanism of VSK Model House

Features:

1. Complete security from flood and rainstorm.
2. Construction cost of these houses/building will be less than that of concrete houses/building.
3. It is possible to complete the construction by less than half the time for constructing concrete houses/building.
4. Weigh less than that of concrete houses/building.
5. It has more life than that of concrete houses/building.
6. Width of the wall will be approximately 5 1/2 inches.
7. Similar to concrete houses/building these houses/ building are also resistant to wind and earthquakes.
8. These houses does not require materials such as rocks, soil, sand, blocks/bricks, cement, wood etc. Hence ensures environmental protection.
9. Even if the soil below the house gets fully eroded, it does not go down or get slanted.
10. As the flood water rises the house/building lifts up and rises to the surface of water.
11. When the flood recedes, the house/building comes down and fixes at the original position. (maximum 2 inches difference)
12. No matter how long the house/building is at the water surface, no damage will happen to it.
13. These types of houses/buildings can be made in any model and in any area (sqft).
14. These houses/buildings can also be constructed on seashores with specific changes.
15. It can reduce future damages and relief cost.
16. These houses/buildings can be built in any type of land as a low budget house/building.
17. Interior of this house/building is relatively less warmer compared to ordinary houses/buildings.
18. Toilet can be used during flood as the septic tank also rises with the house/building.
19. Normal life is possible during the flood by the installation of water tank, R.O System and solar panel on the terrace. It ensures the availability of pure water and electricity everyday & even during flood.
20. Any luxury facilities like tile, cupboard, gypsum, Air Conditioner etc. can be used

Conclusion

The emerging evidence of rising sea levels coupled with extreme rainfall events and recurrent floods demands a different kind of resilient infrastructure that are rooted in local traditions for India. Amphibious architecture has been explored as a sustainable and adaptive solution to address the peculiar environment of Kuttanad, which lies below sea level, to mitigate the impacts of flooding and thus improve the quality of life of its residents.

Amphibious constructions, in turn, rely on the vernacular architecture design principles in offering effective alternative options to conventional flood defenses through locally sourced materials, community-led designs, and flexibility within a natural environment.. The discussion on case studies involved India's first floating house in Changanassery and continued with similar examples from across the world-from the Netherlands to New Orleans, Sausalito in California, and Bangladesh-proving the viability of amphibious architecture over traditional elevation-based flood defenses. The VSK MODAL house in Kuttanad represents the best model wherein low cost, sustainability, and locally sourced materials provide all resilience against flood with least dependence on state support.

Therefore, the research was able to achieve its objectives: assessing the repeated impacts of flooding, testing the feasibility of the amphibious design, and providing guidelines fitted for environmental and cultural landscape conditions in Kuttanad. Amphibious structures not only enhance flood resilience but also present a viable way to live in harmony with natural water cycles, ensuring that communities can sustain their way of life without displacement.

Embracing amphibious architecture which honors the resilience embedded in vernacular architecture can transform India’s approach to water-based living, fostering a shift from seeing rising waters as threats to adapting to these changes with resilience and confidence. Adding such amphibious designs into development plans allows for sustainable living that adapts easily with floods and solidifies the stability of the community. Amphibious architecture is creating an attainable solution for adaptive and sustainable quarters within a country like India, facing unforeseeable increase in climatic uncertainty in the future. This design can redefine our relationship with water and assembles an existent resilient future in harmony with the rhythms of nature.

References

Anjali K. A., Asla, B. N. B., Adhila. F, Mufassil, & Yunus, N. (2020) Amphibious House: International Journal of Innovative Research in Science, Engineering and Technology

Balkrishnan.D. (2018) Field Visit to Flood affected areas By Kudumbashree Mission Report: State Poverty Eradication Mission.

Barker, R. & Coutts, R. (2016) *Aquatecture: Buildings and Cities Designed to Live and Work with Water*; RIBA Publishing: London, UK

Department Related Parliament standing committee on Home Affairs (2018) The Cyclone Ockhi- Its Impact on Fishermen and damage caused by it: Rajya Sabha Secretariat, New Delhi.

English, E. & Klink, N. (2023) Thriving with Water: Developments in Amphibious Architecture in North America

English, E. (2009) November. Amphibious foundations and the buoyant foundation project: Innovative strategies for flood resilient housing. In *International Conference on Urban Flood Management sponsored by UNESCO-IHP and COST Action C* (Vol. 22, pp. 25-27).

Factor, A. & Boiten, R.I. (2018) Project Review: Floating Homes 'De Gouden Kust' Maasbommel, The Netherlands.

Georgieva, Y. (2013) Prevention of floods vs. living with them. Strategies for the JRDNA. (2018) Kerela floods and landslides 2018 Joint rapid damage and needs assessment report September 2018: World Bank group, Asian Development Bank.

Kuriokose. S. (2018), Kerala Floods 2018 - A Study on the Emergency Supply Chain Logistics in Kuttanad, Alapuzzha Vol. 1: TATA Institute of Social Sciences.

Modi, A., Nair, T.B., Remya, P.G., Harikumar, R., Srinivas, K. & Srinivas, G. (2021) The role of anomalous oceanic features on enhancing flooding duration in Kuttanad region, Kerala (India). *Journal of Earth System Science*, *130*(2), pp.111.

Mohan.S ,Velayudhan. M & Geevan C. P. (2019) Marginalization in Catastrophe: Rainfall, Landslides and Deluge in Kerala, 2018: Centre for Social Studies and Culture (CSSC)

Mutia, I. (2012) Living on the Water: Spatial Planning Experiences from The Netherlands and Indonesia. In *Paper presented at the 1st Biennale International Conference on Indonesian Architecture and Planning (ICIAP) Universitas Gadjah Mada Yogyakarta*.

Moon, C. A. (2015) Study on the floating house for new resilient living. *J. Korean Hous. Assoc.*

Nekooie, M.I.M.M.A. & Ismail, Z.B. (2012)Amphibious House, a Novel Practice as a Flood Mitigation Strategy in South-East Asia: Public Policy and Administration Research

Nekooie, M.I.M.M.A. & Ismail, Z.B. (2012) Amphibious House, a Novel Practice as a Flood Mitigation Strategy in South-East Asia

Prosun, P. (2011) LIFT House: An Amphibious Strategy for Sustainable and Affordable Housing for the Urban Poor in Flood-Prone Bangladesh.

Ropel-Morski, Z., English, E. & Turner, S. (2015) Amphibious Housing: An Innovative Approach to Seasonal Flood Mitigation for Vulnerable First Nations Communities. In *Proceedings of the International Conference on Amphibious Architecture, Design and Engineering, Bangkok, Thailand August 26–29 2015*.

Sanil Kumar, V., Sajiv Philip, C. & Balakrishnan Nair, T.N. (2010) Waves in shallow water off west coast of India during the onset of summer monsoon. In *Annales Geophysicae* (Vol. 28, No. 3, pp. 817-824). Göttingen, Germany: Copernicus Publications.

Sara. A. (2020) A Research Proposal: Amphibious architecture in the context of Kerala Floods: Deakin University.

Siromony. S. M. V, Oommen. O, Mathai .S J, Muhammed .A, Rawther. M, Varghese .T, & Shij. B. S. (2018) Kerela Flood 2018 The disaster of the century: Rajiv Gandhi Institute of Development Studies.

Upadhyay A. K., Pal P. B. (2019) Aquatecture Practices in India: School of Architecture, Dr. K.N. Modi University, Newai, Rajasthan, India

Vijayan. S. P. (2018) Rebuild Kerala Development Program: A Resilient Recovery Policy Framework and Action Plan for Shaping Kerala's Resilient, Risk-Informed Development and Recovery from 2018 Floods: Rebuild Kerela Initiative