Envisaging the scope of amphibious architecture in below sea level regions of Kuttanad

Nikhila Nelson

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ENVISAGING THE SCOPE OF FLOATING ARCHITECTURE IN BELOW SEA LEVEL REGIONS OF KUTTANAD

Dissertation submitted in partial fulfillment of the requirement

for the eighth semester of the Degree of

BACHELOR OF ARCHITECTURE

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college seal

DISSERTATION

January 2019- June2019

Guided by:

Prof. PARVATHY SAGAR
Department of architecture,
TKM College of Engineering, Kollam

Submitted by:

NIKHILA NELSON

Department of Architecture

Thangal Kunju Musaliar College Of Engineering
Kollam - 691005, Kerala

UNIVERSITY OF KERALA
May 2019

Thangal Kunju Musaliar College Of Engineering

Kollam - 691005, Kerala

Department of Architecture

CERTIFICATE

Certified that this is a bonafide record of the
dissertation submitted by
NIKHILA NELSON
during the period of January 2019 to May 2019
in partial fulfillment of the requirements for the
Eighth semester, Degree of
BACHELOR OF ARCHITECTURE
of the University of Kerala

Guided by: *Submitted by:*

Prof. PARVATHY SAGAR
Department of architecture,
TKM College of Engineering, Kollam

NIKHILA NELSON

Valued by

External examiner *Internal examiner*

DECLARATION

I hereby declare that dissertation named ENVISAGING THE SCOPE OF FLOATING ARCHITECTURE IN REGIONS OF BELOW SEA LEVEL KUTTANAD, submitted to the Department of Architecture, TKM College of Engineering, is a record of an original work done by me, under the guidance of Prof. PARVATHY SAGAR, Department of Architecture TKMCE.

The information and given data in this report is authentic to the best of my knowledge and is not submitted in any other university or institution for the award or any degree or fellowship.

Kollam **NIKHILA NELSON**
10.06.2019

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ABSTRACT

For centuries, Kuttanad has been the focus in agriculture as it is the only place in India where paddy farming is done below sea level and also gained the fame "Rice bowl of Kerala" for the past years. However, over the recent years, the situation has changed and frequent floods with high intensity are occurring and successive damage episodes are happening. The people of Kuttanad are now facing huge difficulties during floods especially the recurring damages happening to their properties and moving to some other safe places for shelter. Since Kuttanad is one of the most vulnerable area for flood, proper technologies should be implemented here to provide flood proof, safe and affordable structures for all residents of Kuttanad especially because majority of them are farmers and belong to Below Poverty Line.

This report will explore and documents the various ways of protecting and creating a sustainable living environment for residents in Kuttanad with the help of floating architecture. This dissertation will answer the questions like "How can a structure sits in ground can survive during floods?" In this dissertation, I focus on Amphibious architecture, which is the technique to provide houses for flood residents functioning both in land and water. Amphibious Architecture is cost effective and safe alternative for permanent static elevation with improved recovery from the disaster and it is achieved by buoyant foundations.

In order to ensure the well-being of the inhabitants, number of case studies are analyzed and interacted with the residents of Kuttanad itself, for the purpose of identifying key features that will facilitate the construction of amphibious houses in Kuttanad. This report is a response to design challenges raised by recent disastrous flood happened in 2018.

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CHAPTER 1 **INTRODUCTION**

1.1 INTRODUCTION

Kuttanad, which is known as the rice bowl of Kerala, is a region that has a deltaic trough-like formation which is the resultant of the convergence of four major rivers- the Meenachil, the Manimala, the Pampa and the Achenkovil, which drain into the Arabian Sea through the Vembanad Lake, is heavily prone to flooding. There are huge losses for the people residing here every year who are almost 70% below poverty line. The scale of this disaster is very huge in Kuttanad which is having lots of paddy cultivation and the only place where farming is done below sea level. There are huge farms and since they are lying below sea level, the damages are caused easily on monsoons and everything is being damaged by flood which occur suddenly. With the occurring of flood, the residents are capable of adapting to the flood when the intensity is small, even though it is difficult. But with the increase in the intensity of flood, the residents are forced to move to other places or relief camps for shelter as their houses and neighborhood will be drowned. During the last recent floods of 2018, approximately 170,000 residents were moved to the relief camps. As the farms and houses drown completely in water during floods, the lives of people are much miserable and all activities will go down and freeze during this time and after the flood there are huge losses to their properties and is such a pathetic situation. The process and is continuing every year but still there are no effective schemes adopted to tackle this issue so far. A new residence for people in Kuttanad should be designed to withstand the rising water and frequent floods. Those residents should be safe, flood proof, eliminating the rebuild process after flood and thereby provide healthier and stable family. So it is high time to make a change in this scenario in this century of technologies and innovations. Floating architecture is one of the solution to this problem. Though it is not a new concept in the world of architecture, it is still not adopted in Kuttanad where it can have application and possibility.

Floating architecture is the field of architecture which deals with the architecture consisting of a floatation system at its base, to allow it to float on water. As a mean of flood resilience, amphibious architecture which is a part of floating architecture is to be adopted. Amphibious architecture adapts to dry and wet conditions without causing any damage during or after flood. Amphibious architecture refers to buildings that sit on dry land like ordinary buildings, except when there is a flood. During flood or if there is a rise in the water level, they are capable of rising and floating on the water surface until the floodwater recedes. The development of an amphibious community is a long time strategy that will minimize the potential risk of flooding in Kuttanad residences. A buoyancy system beneath the house displaces water to provide flotation as needed, and a vertical guidance system allows the rising and falling house to return to exactly the same place upon descent. This is a proven strategy that has already been applied successfully in the Netherlands since 2005 and in rural Louisiana for about forty years. Amphibious construction is an adaptive flood risk reduction strategy that works in synchrony with a flood prone region’s natural cycles of flooding, rather than attempting to obstruct them. The solution will also include waterproof material and protection of vital utilities, design of buoyant foundation, vertical guidance pole attached to the foundation, which provides resistance from lateral force caused by wind and water. Thus when this technology is found to be suitable for applying in regions of Kuttanad, then it will be of greater boon to Kuttanad when implemented.

1.2 AIM

The overall aim is to analyze the potentialities associated with floating architecture which invariably will be the solution to rising water level and flood issues occurring continuously in Kuttanad region which is lying below sea level.

1.3 OBJECTIVES

- To study the main principle behind floating architecture.
- To study and identify the problems of Kuttanad region and lives of people residing there.
- To study the design parameters of floating buildings.
- To discover whether floating architecture is suitable for Kuttanad.
- To throw some light on improving the lives of Kuttanad people.
- To provide proper ideas of housing for people in Kuttanad.

- To find sustainable and affordable way of achieving floating architecture in Kuttanad
- To study whether floating architecture can be helpful for agriculture in the flood seasons.

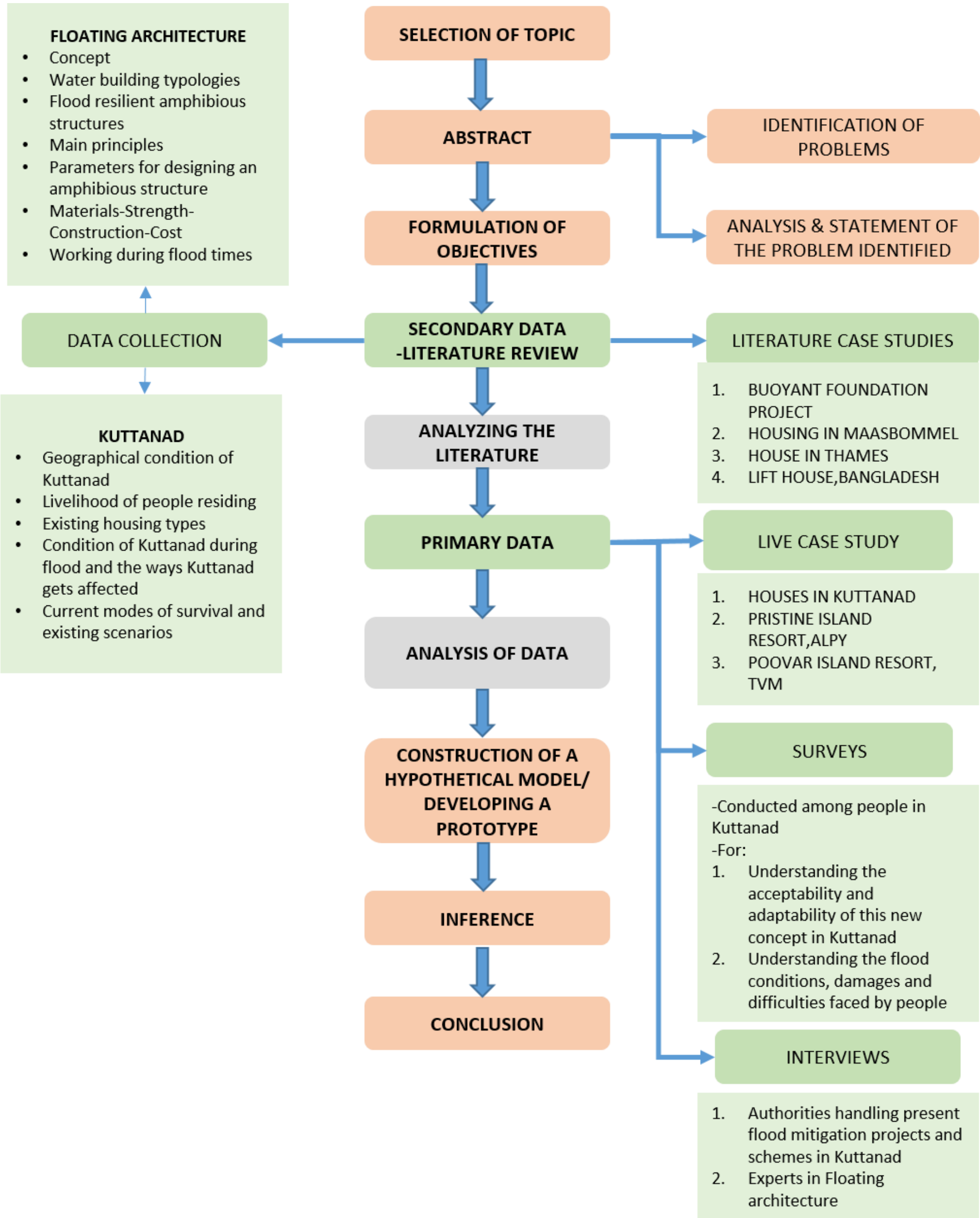
1.4 SCOPE

- The scope of this study is to realize the problems of Kuttanad and different types of floating architecture that is practiced and their benefits and how it can be helpful in flood resiliency.

1.5 LIMITATION

- The study part is limited to the study of amphibious architecture and its feasibility only in Kuttanad regions.

1.6 METHODOLOGY



CHAPTER 2 **LITERATURE REVIEW**

2.1 FLOATING ARCHITECTURE

2.1.1 Basic principles of floatation

Archimedes' principle: A body floating or submerged in a fluid is buoyed (lifted) upward by a force equal to the weight of the fluid that would be the volume displaced by the fluid. This force is known as the buoyant force.

The point through which the buoyant force acts is called the *center of buoyancy*; it is located at the center of gravity of the displaced volume of fluid.

Fig1 (a) shows a floating body in equilibrium, with its *center of gravity (CG)* located directly above the *center of buoyancy (CB)*.

If the CG is to the right of the line of action of the buoyant force when the body is rotated slightly counter clockwise as in fig1 (b), the floating body is stable.

If instead the CG is to the left of the line of action of the buoyant force as in fig1 (c), the floating body is unstable. This differentiation between stability and non-stability can also be made by referring to the point of intersection of the vertical axis (A-A) and the line of action of the buoyant force (B-B).This point of intersection is known as the *metacenter (me)*.

It is clear from observing figs1 (b) and (c) that a floating body is stable if its CG is below the *me* and unstable if its CG is above the *me.*

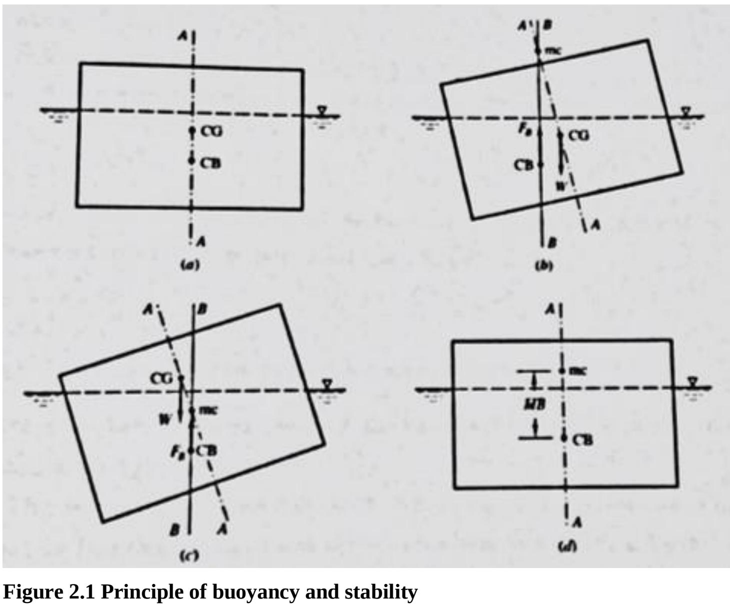


Figure 2.1 Principle of buoyancy and stability

For stable equilibrium, in case of a floating body, *metacentre* lies above the centre of gravity. For unstable floating body, the metacenter lies below the centre of gravity, and for neutral equilibrium, *me* and CG coincides. *Metacentric height*, in relation to a floating building, means the distance between the centre of gravity and the metacenter.

The determination as to whether the CG is below or above the *me* (and therefore stable or unstable respectively) can be made more quantitatively by using the following equation to determine the distance from the CB to the *me*;

$$MB = I/V_d$$

where I=moment of inertia and V_d=Volume of water displaced.

Once distance MB is determined, the body can be judged to be stable if the me is above the

body's CG or unstable if it is below the CG.

2.1.2 **Water building typologies**

According to the foundations and the relationship to the water, water dwellings can be categorized into terp dwellings, static elevation, pile dwellings, amphibious dwellings and floating dwellings. Some types have been used for centuries while others are relatively new technique, such as the amphibious house. However in the event of rising water levels, each type has proven resilience.

2.1.2.1 **Terp dwellings**

A terp is an artificial earthwork mound created to provide safe ground in the event of a rise in water levels. The first terps were built in the Netherlands during 500 B.C where tides from the nearby rivers affected daily routines. The terps were built up to 15 meters high and was intended to keep a house dry and provide enough space for cattle and food storage. Around 1000 A.D the inhabitants began to connect these mounds to prevent the sea from flooding their lands, commencing the formation of a permanent dyke system. The terp dwelling

Figure 2.2 Bridge house in Achterhoek, Netherlands

is connected to the land and remains dry until a maximum water level has been reached. Although it feels safer and more secure than a floating dwelling. But is not safe because there are no means of escape during extreme and unexpected high water levels. Today few modern terps can be found throughout Europe one such example is the Bridge House in Achterhoek, Netherlands. The landscape architect removed the top layer of the soil throughout the property in order to make the soil less fertile for the replanting of indigenous trees. The soil was then reused to form a raised area beneath the house in the event of high water levels, resulting in a traditional Dutch terp dwelling.

2.1.2.2 **Static elevation**

Figure 2.3 Static elevation

One of the most common methods is elevating a house to a required or desired Base Flood Elevation (BFE). When a house is properly elevated, the living area will be above all. Several elevation techniques are available. In general, they involve two technique as discussed below

(1) Lifting the house and building a new or extending the existing foundation below it.

(2) Leaving the house in place and either building an elevated floor within the house or adding a new upper story

2.1.2.3 **Pile dwelling**

Figure 2.4 Pile dwelling

Pile dwellings are a type of housing built on top of concrete, steel or wooden poles and can be found in shallow water, coastal areas, or lakes where changes in the water level can be predicted. This type of dwelling typically rests 8-15 feet from the ground and has been used throughout the world as means of protection from water. In Indonesia, Singapore, and other countries these housing are called as "kelong" which are built for fishing. The "Nipa hut" is the primary type of housing found in the Philippines and a similar stilt house structure is also popular in Papua New Guinea. Thai stilt houses are often built above freshwater and the "Palafito" is found in the tropical river valleys of South America.

Timber pilings have been used for 6,000 years and continue to be one of the leading types of driven piles. Timber is often used in pile foundations because it is a readily available and renewable resource. Because it is light in weight, timber is also more easily handled, driven and cut than other types of piles. According to the Federal Highway Administration, timber pile foundation underwater will last indefinitely and timber piles partially above water can last up to 100 years or longer if they are properly prepared and treated.

Concrete piles can be pre-cast or cast-in-place, and they can be reinforced, pre-stressed or plain. They do not corrode like steel piles or decay like wood piles. concrete is more readily available than steel. Pre-cast concrete piles are shaped and molded according to shape, length and size prior to being driven into the ground. Cast-in-place piles are poured into holes in the ground where a rod has been previously driven and removed.

Steel pilings can be formed into many different shapes but the most common steel pile types have rolled circular, X-shaped or H-shaped cross sections. They are very strong and are great for driving especially in firm soil and can be easily cut off and can also be easily joined by welding. Although steel pilings can last up to 100 years, they are prone to corrosion, especially when submerged in water.

2.1.2.4 **Houseboats**

Houseboats began with the conversion of ships and fishing vessels into livable environments. These types of houses resemble a land based property in its design and construction yet are buoyant enough to withstand the forces of water. In India houseboats are common on the backwaters of Kerala, on Dal Lake near Srinagar.

Figure 2.5 Houseboats in Kerala

House boats in Kerala are huge slow moving barges used for leisure trips. They are used to carry rice and spices from different places in early times. These house boats are considered as a convenient means of transportation. It is about 60 to 70 feet long and about 15 feet wide at the middle. The hull is made of wooden planks that are held tightly by ropes and coconut fiber. The roof is made up of bamboo poles and palm leaves. The exterior of the boat is painted with protective cashew nut oil coat. The need for housing brought many workers to transform old fishing boats into residential dwellings.

Some of the more modern examples of floating homes are those built by Dutch architects including Waterstudio, Aquatecture, Factor Architecten and Architectenbureau Marlies Rohmer. The trend to build residences on water has attracted many homebuyers in coastal countries.

2.1.2.5 **Amphibious Dwelling**

Figure 2.6 Amphibious dwelling

Amphibious housing is a dwelling type that sits on land but is capable of floating. During a sudden rise in water a house will be lifted by the water provided either by pontoons or a hollow basement in order to ensure it remains dry and will then return to the ground as the water recedes. By sliding along two vertical mooring poles that are driven deep into the ground the houses are capable of rising vertically while restricting horizontal movements on the water. Although the amphibious house resembles a houseboat there are some essential differences between the two types. The hollow basement of an amphibious house is exposed when there is no water forcing designers to conceal the base in the ground or in water.

The second difference is the distribution of forces in the base. When the property is sitting on land it lacks the even upward force of the water which it experiences when it floats making the basement larger than that of the barge of a houseboat. The biggest difference between houseboats and amphibious homes is their connection to land. Typically amphibious homes are designed where water levels are moderate but are rarely prone to extreme flooding therefore all utility services can be connected to the municipal pipes whereas houseboats must contain all utilities within the structure. Examples of these houses can be found throughout the Netherlands most notably the Maasbommel water dwelling situated along the River Maas.

2.1.3 Flood resilient amphibious construction

Amphibious architecture is a flood mitigation strategy that works in synchrony with a flood prone regions' natural cycles of flooding, rather than attempting to obstruct them. Although there are many types of strategies to defend against rising water levels, amphibious buildings are a proven flood protection strategy that gives a community defense against and improves its ability to recover from disaster. In environmentally sensitive locations, amphibious construction "lives with" the flooding, using the floodwater itself as the active agent to elevate a building. Rather than creating barriers, amphibious strategies accept the presence of floodwater but prevent it from causing significant damage to the building.

Amphibious structures are unlike floating units such as a houseboat. These houses usually sit on the ground like any ordinary house, but when inundated rises up to a predefined height and sinks back to its original position after the water recedes. Movement is defined by the help of vertical guiding poles. Here the main working principle is that a lightweight superstructure sits on a buoyant base similar to a ship's hull which is watertight, lightweight and strong.

Experiment with amphibious houses is common in countries with flooding problem, though not in India. There is striking contrast between developed and developing countries for the choice of material and construction technology. In Netherlands, USA and Australia, the buoyant base is made of extended polystyrene (EPS) and autoclaved aerated concrete (AAC) of density 881 kg/m3 and 600-700 kg/m3 respectively i.e. lighter than water. Sometimes high performance reinforced cement concrete (RCC) tanks is used for basement of buildings which float permanently in deep water. Though RCC is heavier than water, these structures manage to float with some part submerged due to buoyancy void. The lighter bases are always above the water level and hence known to ‘dry-proofing’ while the RCC tanks uses ‘wet-proofing’ concept. On the contrary, in developing countries of Bangladesh and Ghana, cheaper materials are used which requires less technical infrastructure.

Amphibious design also includes the concepts of land use planning, site selection, policy considerations and community resilience issues such as the place of amphibious buildings in multiple-lines-of-defense systems. Amphibious engineering addresses issues such as infrastructure, mechanical systems and utilities, system components and selection criteria, and codification and certification concerns.

Amphibious construction is not a new concept: for over forty years, residents of Old River Landing, Louisiana, have been retrofitting their fishing camps with expanded polystyrene(EPS) buoyancy blocks and sliding sleeves fitted around steel guidance posts embedded in the the ground. This configuration allows the houses to rise with the floodwater, mitigating the damage caused by the seasonal flooding of the nearby Mississippi River. Amphibious prototypes have been built in UK, Bangladesh, US and Thailand and new projects are under development in France and Canada. Most recent examples of amphibious buildings around the world are found in new construction where they predominantly serve moderate to high income populations in industrialized countries. However, amphibious architecture has much to offer to rural and low income populations in developing countries as well, either by inclusion in new low-cost housing projects or as a retrofit solution to increase resilience in flood-prone regions.

2.1.4 Parameters for designing an amphibious structure

There are certain criteria to be followed to design an amphibious house to be livable, functional and enjoyable. These house must be a valuable replacement for normal home. The home must be adaptable and flexible. This home should replace the existing home and as well as it should also able to float with the climate change. To make them float during flood condition and make it recedes carefully after the flood is a challenging process for the architects to design. In order to fulfill this role as a functioning and desirable amphibious home certain criteria has been identified: Capability to float, float line, buoyant foundation height calculation, Structure type and utility access.

2.1.4.1 Capability of floating

Figure 2.7 Foundation block of Maasbommel project

The most critical design guidance factor which decide whether the home will actually will be able to float during flooding conditions. As seen in the previous examples with the supports of the mooring poles and the simple calculation of the buoyant foundation the house can make to float during flood. If the total weight of the entire home including the dead and live load of the house should be less than the volume of the water then the house can float. The buoyant foundation should also be water tight so that it won’t develop any cracks. A water tight walls and floor should be taken into consideration so that the structure stands independently without any extra support. Light weight building materials should be used to make the building equivalent to the volume of the water.

2.1.4.2 Foundation

Foundation is the important part of the structure to support the light weight structure and to float during flooding condition. Deep foundation are the structural component that transfer loads into deeper layer of earth material than a shallow foundation. Deep foundation includes pile foundation with driven pile, drilled shafts, and micro piles and grouted in place piles. Structure design engineers are responsible for calculating the pile design load and for providing other structural detail. With the site seismicity and the factored load the structural engineer should calculate and derive the foundation technique and material for the proposed site condition.

2.1.4.3 Float line

The float line is the line that denotes when the building will begin to float. According to buoyant principle, if an object displaces a volume of water which weights a greater than the object then it will float. Likewise if an object displace a volume of water that weighs less than the object then the structure will not float. The building will have a static square or rectangular foundation the volume of water can be altered only by the height of the building. This means that if the sea level rises the water volumes also expands, so if the sea level rises the structure with less weight than the sea water will float. The float line is to be designed for 5 feet below the pier if the water level rises and the grade becomes steeper it will not because the pier will be completely inundates at that points.

The basic equation for Archimedes force is as follows:

$$\mathbf{U = G / (A \times P)}$$

Where: U is the vertical drop below the water line (m) G is the dead load of the total building construction (kN) A is the area of the floating body (m^2) P is the density of water (kN/m^3)

2.1.4.4 Buoyant foundation height calculation

The Archimedes principle states that “the buoyant force of the submerged object is equal to the weight of the fluid that is displaced by the object.” The depth of the foundation were calculated by finding the dead load and live load of the entire structure. The weight of the structure per square foot should be divided by the weight of the water which equals the depth of house will be submerged when floating.

$$\text{Depth of the house submerged} = \frac{\text{the total weight of structure per sq.ft}}{\text{The weight of the water}}$$

2.1.4.5 Structure type

To make the structure float the selected material should be of light weight material. The foundation is made up of a strong concrete hull or of any other material and the structure above the foundation which will float should be made up of light weight material. These material should also be water proof material and should promote insulation and other passive heating and cooling technique to be sustainable structure. A future measure to reduce the weight of the building is developed by light weight wood framing doors and windows.

2.1.4.6 Road and parking condition

A separate parking garage for the cars can be constructed for the residents. The parking place can be provided near the house as in Maasbommel project or the parking lots can be provided in place for all the houses in community. Residents can park their vehicles in the parking garage and take bicycles or motorcycle to their dwellings. The parking space can be differentiated from the other place by the use of material and with a level difference. During flood condition these vehicles can be taken from the parking lots and placed in some safer place. The residents can use boats can their transport or during emergency conditions. The aluminum can be used for the pedestrian walkway. The aluminum is low in maintenance and does not become slippery in case of rain. The aluminum panel can easily be removed in case of any maintenance problem.

2.1.4.7 Utility access

The utility access is a difficult criteria in designing an amphibious building or floating building. All the utility services should be provided for these amphibious house also like any other normal residential house on land. The utilities will use this forced access point into the home to run water, sewage and electricity. This is a necessary step because modern practice of burying utilities will not be adequate for life on the water. It is crucial that things such as height, utility access points, float lines, foot prints and other items are uniform across the development are to be considered and also an easy installation, flexible connection should be provided. As in Netherland the service pipeline can be long and flexible fixed from the land to the amphibious house so that when the structure rise with the flood water these long pipeline will also rise with the dwelling. These pipeline will be long during normal condition when the structure rests on the land but during flooding condition they will be suitable for the length. Another type of pipeline can also be provided for floating and amphibious dwelling. It includes the pipeline will break by itself when the structure starts to rise and when the building recedes the connection can be fixed by an easy installation method.The lighting and meter boxes can be placed above the entrance or in the entrance bridge so that they are not fluctuated because of water. The cables behind the meter box are umbilical and will vertical stretch as the house moves. The pipes passing to this meter boards and distribution boards can be preferably metal pipes, ductile iron or coated steel can be used.

2.1.4.8 **Fire safety**

Amphibious homes should also be provided with the normal fire safety norms as the normal residents. A minimum width of 10 feet walkway should be provided in the Community Street or corridor for the fire fighters and also for people rushing out from the home. The fire hose may be short to reach all the residents in the community so a dry hose may run underneath the platform or garden near the structure. It can also be adjacent to the other cables and pipe of the utility service. In case of fire the fire brigade places a pump wagon on the mainland to fill the water in the dry hose. Each residents should have a point where a fire hose can be connected.

2.1.4.9 **Water maintenance**

The salt water will erode the structure and also moving water can accumulate sludge and other waste particle. With the year passes by a thick layer of sludge or waste materials can accumulate and also will damage the utility connection to the building and also erode the steel in foundation and walls. The house should be protected with good material that will prevent the materials from corrosion because of water. After the flood when the dwelling recedes down the flood water will bring any particles when it returns. It should be checked and maintain that no particle gets stuck in the dock portion of the structure. If anything get struck then there will be a problem in smooth motion of the structure. Minimum height should be maintain from the water level because when the water level is low the dwelling will get stuck in the mud.

2.1.5 **Types of floating foundations**

A number of companies construct floating foundations using a variety of materials and methods. Durability, cost and buoyancy are the key metrics that guided the invention of current technologies, and will guide the development of future technologies. Early Dutch houseboats used wood and steel hulls because they co-opted contemporary shipbuilding technologies for residential purposes.

However, due to maintenance issues and the desire for more stability and comfort, newer houseboats typically use a hollow reinforced concrete box called a concrete caisson. This foundation lies mostly underwater, while the rest of the structure floats above. The environment within the concrete box is similar to a basement and can function as additional mechanical storage or living space.

This foundation typology has transcended houseboats and many floating buildings use them because of their durability and affordability. For floating buildings, water depth is the main obstacle to using a concrete caisson foundation. Since many of these buildings are manufactured offsite in dry docks, the building's foundation cannot exceed the depth of the waterways it must traverse; and the heavier the building the deeper the caisson. If it does exceed this dimension, it can be hauled over land, but this adds significant costs to the project.

An alternative to concrete caissons are flat buoyant foundations made from a hybrid of different materials; the combination must be waterproof, durable, buoyant, and strong enough to support the building. Unlike concrete caissons, these foundations are solid; they also draw less water making them optimal for shallow water sites. Since they sit higher in the water, they also tend to be less steady than the previous style, but engineers can account for this in the foundation's design.

The different types of floatation foundations are as listed below:

1. Expanded Poly Styrene(EPS) with concrete filling
2. Concrete hull
3. Pneumatic stabilizing platforms
4. Plastic water bottles

2.1.5.1 Expanded Polystyrene (EPS) with concrete filling

This system is based on a core of polystyrene foam EPS and a concrete shell. This system gives the possibility to build on water and results in less draught so it can be used in more shallow waters. On top of these advantages the system is also unsinkable.Regarding the environment the EPS (also known as Styrofoam) is a non-toxic and totally inert. EPS doesnot decompose and it provides therefore lifetime durability. The moisture pickup over 30 years is measured at a maximum of 5-6%. The material is 100% recyclable. EPS is waterproof and doesnot leachout or degenerate. Concrete is extremely long lasting therefore its carbon footprint is reduced over time. EPS is 96% air. It can create foundation from 10 sqm to several thousand sqms. They are unsinkable and conform to the strictest requirements.The lightweight construction gives Flexbase floating platforms a considerable buoyancy and therefore also a large load bearing capacity. This system gives the possibility to construct on water at any sheltered location.

Two existing references of EPS construction are the floating pavilion in Rotterdam and the floating greenhouse in Naaldwijk, Netherlands.

Figure 2.9 Floating pavilion in Rotterdam

Figure 2.8 Floating greenhouse in Naaldwijk, Netherlands.

2.1.5.2 Concrete hull

The hull is made from concrete which means there is no rusting and condensation is minimal. These are hollow boxes of reinforced concrete, with enough buoyancy from the interior airspace to support the concrete as well as the structure. Its designs include shock-absorbing connectors, incorporated structural cleats and pile rings, because the structures are monolithic and sealed, they cannot take on water and are unsinkable unless broken. Ferro cement is cheap. They'd be fairly easy to connect to one another and small ones could be easily built on board. This is the most promising technology for protected waters.

Figure 2.10 Concrete hull

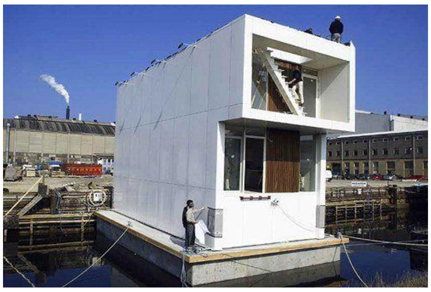


Figure 2.11 Concrete hull used in floating building

2.1.5.3 Pneumatic Stabilizing Platforms

A Pneumatic Stabilizing Platforms consists of multiple cylinders, made of steel or concrete or plastic. The air, which is enclosed in the cylinder by the deck on the top side and on bottom side by the water gives the platform its buoyancy.

A disadvantage with open containers is that as depth increases, the air is compressed and displacement goes down.

This floatation is cheap to manufacture and can be stacked for easy transport.

Figure 2.12 Steel platform pontoon

2.1.5.4 Plastic bottles

It utilizes plastic 2 ltr beverage bottles, which are extremely common, incredibly cheap and resistant to seawater. These bottles can be banded together into hexagonal grids of 7 bottles each. The grids are then stacked and layered to form a buoyant lattice. Some sort of rigid surface then needs to be placed on top of the floatation.

Figure 2.13 Plastic bottles used for foundation

2.1.6 Materials for superstructure

2.1.6.1 Timber work

Advantages

- Heat retaining
- Soundproof
- Moisture proof
- Rot proof
- Fire proof
- Termite proof
- Windproof
- Healthy and environment friendly

Disadvantages

- Timbers tend to silver or look old if left natural and unpainted.
- Timber maintenance can seem to be higher than other building materials.

2.1.6.2 **Light weight steel**

Advantages

- The strength-weight ratio of steel is highest in all materials, so it can be used to build large span space
- Has good performances to withstand strong winds
- The unique intensity and toughness of steel makes lightweight steel structure houses have better resistance to natural disaster
- Having a greater flexibility in architectural design, structural reconstruction can be easily carried out and non- load bearing walls can be removed, replaced, reconstructed easily
- All steel products are recyclable and the coefficient of recovery can come to 66%, which is the highest in all artificial materials. Also steel can be recycled without degradation.
- Steel can be processed into many prefabricated parts and standard and traditional parts inorder to reduce the waste of construction site and save the cost of the project

2.1.6.3 **GFRC (Glass Fiber Reinforced Concrete)**

Glass fiber reinforced concrete is an engineered material that contains cement, polymers, and glass fibers that are ingrained in the cementitious matrix. The properties are influenced by the glass contents, mix design, and production process. GFRC is mainly used for external applications since it increases its load-bearing capacity. It produces an extremely lightweight yet durable material.

Advantages

- GFRC concrete can be cast in thinner sections and is therefore as much as 75% lighter than similar pieces cast with traditional concrete.
- GFRC is light weight allowing for lighter foundation and reduces shipping costs

- High strength can be obtained by using GFRC, being tough and resistant to cracking. It has a high ratio of strength-to-weight.
- Since GFRC is internally reinforced, other types of reinforcement are not necessary that may be complicated for complicated molds
- Since the materials have a fiber coating, they are unaffected by the environmental effects, corrosion attacks, and other harmful effects.
- It is sustainable because it is uses less cement than equivalent concrete and also often uses significant quantities of recycled materials so GFRC is qualified as sustainable

Disadvantages

- Lack of expertise in the existing contractors
- Extensive planning during design phase needed
- Requirement of Free Space and Equipment Area during construction
- Price advantage only when done on scale

2.1.6.4 **Ferro cement**

Ferro cement is the method of applying a mixture of cement, sand and water in layers on wire mesh and steel reinforcement. It is light in weight than the concrete and also it is waterproof due to its cement content and application methods. Metals commonly used is iron or some type of steel. It is used to construct relatively thin, hard, strong surfaces and structures in many shapes such as hulls for boats, shell roofs and water tanks.

Ferro cement is a high versatile form of reinforced cement. It is a type of thin reinforced concrete construction in which large amount of small diameter wire meshes are uniformly placed throughout the cross section. Mesh can be a metal or any other suitable material. Mortar is used instead of concrete Portland cement. Its strength depends on two factor cement mortar mix and the quality of the reinforcing material.

Advantages

- Basic raw materials are readily available in most countries.
- Fabricated into any desired shape.
- Low labour skill required.
- Ease of construction, low weight and long lifetime.
- Low construction material cost.
- Better resistance against earthquake.

Disadvantages

- Structures made of it can be punctured by collision with pointed objects.
- Corrosion of the reinforcing materials due to the incomplete coverage of metal by mortar.
- It is difficult to fasten to Ferrocement with bolts, screws, welding and nail etc.
- Large no of labors required.
- Cost of semi-skilled and unskilled labors is high.
- Tying rods and mesh together is especially tedious and time consuming.

2.1.6.5 **EPS (Expanded Poly Styrene)**

Expanded Polystyrene (EPS) or Extruded Polystyrene (XPS) is a Geofoam that is manufactured into a large lightweight blocks. The blocks varies in size but are mostly in 2m x 0.75m x 0.75m. These geofoam is a light weight void fill. It is used in many applications such as light weight fill, green roof fill, compressible inclusions, and thermal insulation and sometimes it is used in drainage also.

EPS panel is used in prefabricated structure for walls, roofs, and foundations. EPS insulated panels offer an innovative option related to construction as well as maintenance as compared to traditional constructions.

Advantages

- Prefabricated EPS panel do not required skilled labour to erect the structure. Building can be erected with local support with minimum training and as a result it save the labour cost as well.
- Minimum maintenance
- Design flexibility is a attractive advantage in prefabricated construction and panels are available in different thickness.
- Low density but it gives high strength.
- A cubic meter of EPC with a density of 16 kg/m3 has a buoyancy of 984kg.
- Long-term R-Value (“R” is the resistance to heat flow)
- Energy efficiency
- Constant thermal resistance
- Measurable energy savings
- Low cost
- Dimensional stability
- Chemical inertness

Disadvantages

- Geofoam should be treated to resist insect infestation. Insects like ants can burrow into the geofoam and will weaken the material.
- Not extensively in use in Kerala

2.2 KUTTANAD

2.2.1 Introduction

Kuttanad is a region in South Central Kerala which is popularly known as the 'Rice bowl of Kerala', because of its extensive paddy lands and wealth of paddy crops. This region which lies at the heart of the backwaters in Alappuzha district is fringed with coconut palms and water bodies and mainly crisscrossing canals. It is one of the major tourist destinations of Kerala. It is a vast area of partly reclaimed land, covered with the bright green paddy fields, separated

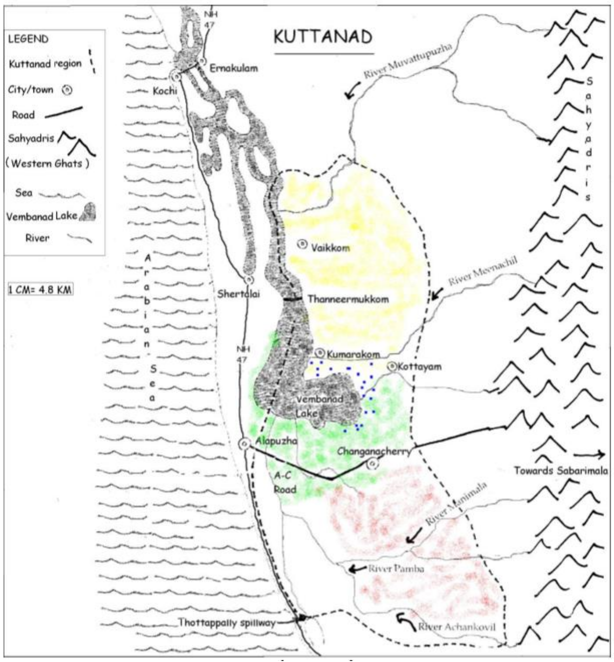


Figure 2.14 Map of Kuttanad region

Figure 2.15 Aerial view of Pallathuruthy bridge, Kuttanad

by dykes. The unique feature about paddy cultivation in Kuttanad is that the level of water is a few feet higher than the level of the surrounding land. It's the area with the lowest altitude in India, and one of the few places in the world where farming is carried out upto 2 meters below sea level.

Figure 2.16 Aerial view of AC road in Kuttanad

The major occupation in Kuttanad is farming, rice being the stable crop. Large farming areas near the Vembanad Lake were actually reclaimed from the lake. Kuttanad, the largest wetland eco-system in the Indian west coast, is a marshy delta lying below the mean sea level and fed by four major rivers in its southern part viz, Pampa, Achenkovil, Manimala and Meenachil and receives inflows from two major rivers in its northern part ie, Muvattupuzha and Periyar rivers. This unique eco-system supports a high density of population by allowing a multiplicity of livelihoods based on inland marine, fisheries, rice, coconut, several allied enterprises and the water tourism.

2.2.2 Geographical conditions of Kuttanad

Kuttanad has very peculiar geographical characteristics and configuration. Lying between latitudes 9^0 8’ and 9^0 52’ and longitudes 76^0 16’ and 76^0 44’, the present Kuttanad covers an area of 1157 square kilometers spread over the districts of Alappuzha, Pathanamthitta and Kottayam. It is one of the places in the world which is lying below the sea level and the only place where farming is done below sea level. This low lying Kuttanad is 0.6 to 2.2 m below mean sea level. Because of this reason, the level of salinity of water and soil here is very high. Aerial view of Kuttanad presents a picture of patches of land mass, floating over a conglomeration of rivers, rivulets, canals and waterways. The deltaic formation at the confluence of four rivers- Meenachil, Manimala, Pampa and Achencovil- which enter Kuttanad at different points together with the low-lying areas in and around Vembanad lake contribute to this unique geography in no small measure. These rivers drain into the Arabian sea through the Vembanad lake. An intricacy of canals, rivulets and waterways interconnect these rivers and consequently it is almost impossible to trace separately any of these rivers in the region. The geographic area has a concave relief and slopes towards northwest and reaches below sea level towards west where it joins Vembanad Lake- a Ramsar site. Most of the vast expanse in this region is lying below sea level, water logged almost throughout the year, subjected to continued flood submergence and saline water intrusion during the summer months.

The Vembanad lake extends from Alleppey in the south to the Cochin Harbor in the north where it opens into the Arabian Sea. Water in this lake is a mixture of saline water from the Arabian Sea and fresh water from the river system. Cursory evidence suggests that the whole of Kuttanad region was reclaimed from Vembanad lake over a period of time. Geologically, Kuttanad region can be categorized as a recent sedimentary formation.

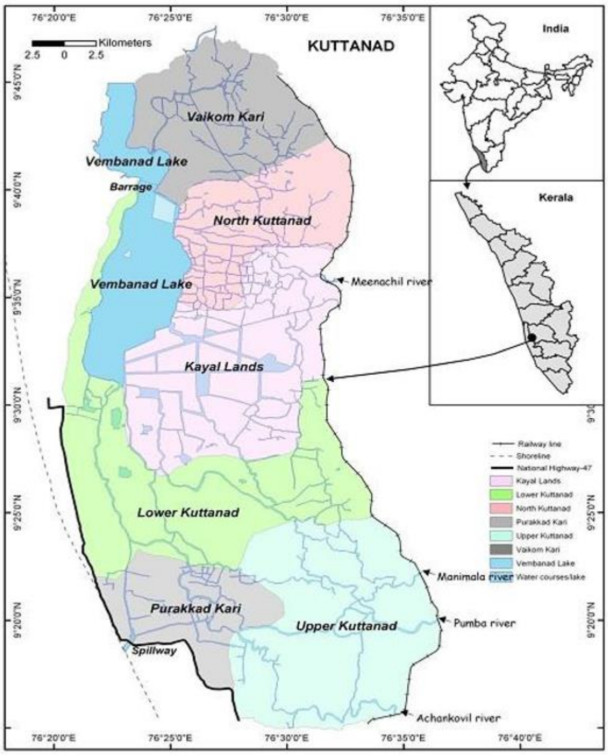


Figure 2.17 Classification of Kuttanad region

On the basis of geographical characteristics and continuity with Vembanad Lake, people generally demarcate the region into Upper Kuttanad, Lower Kuttanad and North Kuttanad. What shapes this perception is the people's closer relationship with land and water, mode of transportation, isolation from the rest of the region and the resulting cultural identity.

Based on the soils, geomorphology and salinity intrusion, Kuttanad is subdivided into six agro-ecological zones (Fig.13) viz., (i) Upper Kuttanad (ii) Kayal lands (iii) Vaikom Kari (iv) Lower Kuttanad (v) North Kuttanad and (vi) Purakkad Kari

Heterogeneity can be observed in Kuttanad with respect to some aspects like incidence of flood submergence, degree of salinity and configuration of agriculture. The havoc caused by flood is more serious in the lower reaches of Kuttanad. Degree of salinity is least in upper Kuttanad and increases down stream and the ones contiguous to the Lake are most vulnerable. Different soil types that exist along the river system have given rise to variation in some agricultural practices. The soil is silty clay which is highly impervious facilitating paddy cultivation but is extremely acidic in reaction due to microbial oxidation of organic matter resulting in iron / aluminum toxicity.

2.2.3 Livelihood of Kuttanad

Figure 2.18 People working in paddy fields

Kuttanad is a unique heritage of humanity with natural beauty and enterprising people. This region has high density of population due to the kayal reclamation for paddy cultivation. Kuttanad has always been dependent on agriculture with its peculiar geographical and topographical features. Hence the proportion of people dependent upon agriculture is naturally high. The literacy level of Kuttanad is 93 percent, slightly higher than the state average. Given the absence of alternative employment opportunities, people irrespective of literacy level, depended upon paddy cultivation. Among the poorer sections, the wages paid in kind, in the form of paddy for various activities related to paddy cultivation acted as a protection from starvation. However, since the late 70s the situation underwent a remarkable change with the availability of rice and wheat through the public distribution system at subsidized rates. The land reforms made most of the tenants proud owners of small pieces of land.

Kuttand cultivation has been highly labour intensive even from the very early days. The kayal reclamations in Kuttanad provide a striking contrast to the reclamations carried in European countries like Holland and Denmark in which the labour played a more significant and vital role than in the former. The cultivation operations in the reclaimed lands also required the service of huge army of labourers.

Figure 2.19 People engaged in agricultual activities

The agricultural workers form the backbone of Kuttanad cultivation. The entire labour was hired, mainly because the work involved was arduous and had to be carried out in the most unhygienic conditions with considerable risk to life even. Labourers and their entire family work for the landlord as permanent farm servants. Each landlord used to have one head labourer who was mainly responsible for the conduct of the cultivation. Besides managing the operations, he has to keep constant vigil, day and night, against breaches of bunds.

2.2.4 **Condition of Kuttanad during floodtime**

This section deals with problems of Kuttanad during flood times. The prime factor influencing the environment of Kuttanad is water. Management of water in different seasons holds the key to the environmental balance of Kuttanad. During the two monsoons the excess discharge of water from the four rivers to the Vembanad Lake causes floods in the entire Kuttanad region. However, as the level of sea is also high, the pressure of sea water does not allow automatic flow of flood water into the sea. Instead, the sea water may also enter Kuttanad adding to other flood hazards.

Flood causes untold misery to the life of the people. The floods cause breaching of bunds, which in turn, destroys the standing crops. When water level rises above the normal level, it causes great hardship to the people. During floods, the water transport will be suspended. Floods also cause heavy loss of property. The fruits and vegetables generally grown in the kitchen garden and home yard would be destroyed completely by floods. During floods, the main roads connecting upper Kuttanad with lower Kuttanad i.e., Thiruvalla with Thakazhy and Changanachery with Alappuzha will be partly under water, with bus services and postal services suspended for days. The occurrence of flood has become frequent in recent years15. Several measures have been taken to prevent flooding of the region. The Thottappally spill way was designed to deviate the flood waters from Kuttanad. Unfortunately, it was not recognised that river system in Kuttanad was directly connected to the reservoir at Thottappally. By the time the need for a leading channel to the reservoir was realised, the construction of the spillway was over.

Figure 2.20 Aerial view of flood affected Kuttanad in 2018 floods

Figure 2.21 House submerged in floodwaters

While floods cause untold miseries, it is not without some beneficial impact. In the past, cultivation in Kuttanad was almost dependent on natural fertility of the soil. The silt carried by the flood water had contributed to the fertility of the soil, since the efforts to divert the water before reaching Kuttanad have not been fruitful. Informed people of Kuttanad are of the opinion that fertility have already come down and they are forced to use more and more chemical fertilizers to compensate the loss of fertility. Another aspect to be noted in this context is that the construction of permanent bunds has not been a solution to the floods in Kuttanad. In their anxiety to encourage farmers to grow a second crop, successive governments have been liberally financing the construction of permanent bunds around the paddy fields. Since 1971, the Kerala Land Development Corporation has completed 908 kilometres of bunds in Kuttanad, costing nearly Rs. 24 crores. In addition, there has been private construction of bunds by individual farmers. The expectation that the Thottappally spill way and Thanneermukkom bunds would solve the flood problem in Kuttanad hasbeen belied. The fact is that, out of the forty five padasekharams where breaching of bunds occurred during 1979, forty two had permanent bunds constructed by the Kerala Land Development Corporation, couldn't withstand the floods.

Figure 2.22 Flood affected single storeyed house with water marks showing the water level it reached

Figure 2.23 Two storeyed house with water level of about 80 cm

Figure 2.24 House on the edge of paddy field

Figure 2.23 View of floodwaters from the first floor of a house

Figure 2.26 Adversely flood affected single storeyed house

Figure 2.27 Flood affected elevated house with almost drowned ground floor

Figure 2.28 Flood waters on the compound only

Figure 2.29 Minimum flood water level

Figure 2.30 House adversly affected by the flood

Figure 2.31 Road and house drowned in floodwaters

Figure 2.32 Interiors filled with floodwaters

Figure 2.33 People moving to safer places to escape from flood

Figure 2.34 Boats as the only means of transportation during floods

CHAPTER 3 **CASESTUDIES**

3.1 LITERATURE CASESTUDIES:

3.1.1 Shotgun house, New Orleans

3.1.1.1 Project brief

Location:	*New Orleans*
Completion year:	*2006*
Architect:	*Elizabeth English*
Water type:	*Salt water*
House type:	*Amphibious*
Area:	*700 sqft*

Figure 3.1 Shotgun house with buoyant foundation

3.1.1.2 Introduction

Shotgun House was constructed as part of the Buoyant Foundation Project. The Buoyant Foundation Project (BFP) is a non-profitable research program organized by Dr. Elizabeth English in 2006. It was the first step to apply amphibious foundation to the existing residence in New Orleans to prevent flooding. The typical style of house in south of New Orleans is called as shotgun house consist of a narrow rectangular frame. To test the buoyant test the house has been fitted with amphibious sub frame. In this project, amphibious foundation is retrofitted into the existing residence so as to float during flood conditions. As it retains the original residence, it is cheaper compared to the complete amphibious construction and maybe suitable for Kuttanad region as the whole new construction of houses in Kuttanad is a very difficult process and also the cost can be reduced on application of this technique and this one does not depends on the geographical area.

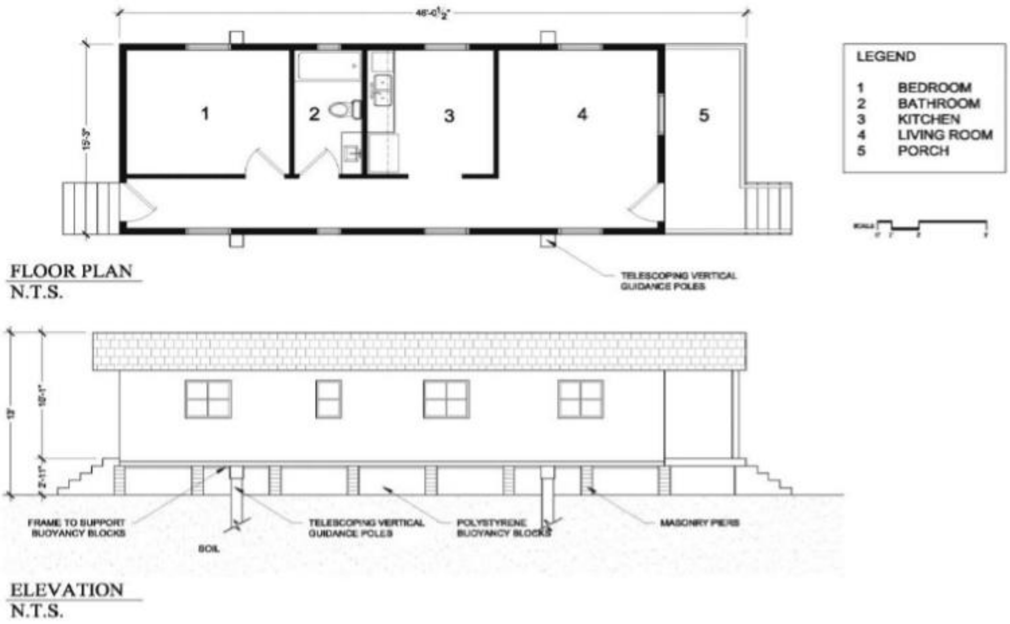


Figure 3.2 BFP floor plan and elevation

3.1.1.3 **Foundation**

The shotgun house has been fitted with amphibious sub frame. It is attached to the underside of the house and support the floating blocks made of Expanded Polystyrene Foam (EPS). The sub frame is attached to the vertical guidance pole found in the corner of the house which project outside from the ground to resists the lateral force by wind and flowing water. When flood occurs the floating blocks will lift the house with the block. The vertical poles will protect the house to go to other place because of flood water.

3.1.1.4 **Construction**

The construction and the fitting process of the house is simple and basically works like a floating dock. The process begins with drilling a pole into the ground and inserting the vertical poles. A steel frame is constructed by using the c channel. The house is then moved 4 to 5 feet to modify the plumbing and utility lines. The plumbing and utility is made in two methods

(1) Self-sealing 'break away' connection that disconnect gas and sewer line when house starts to rise due to flood water
(2) long, coiled lines that can stretch along with the house.

EPS blocks are connected to the sub frame and then the frame is connected to the house. The house is then lowered where it rests on 3 to 4 feet from ground. Most of the materials are lightweight materials. So it can be installed by two persons itself without any machineries.

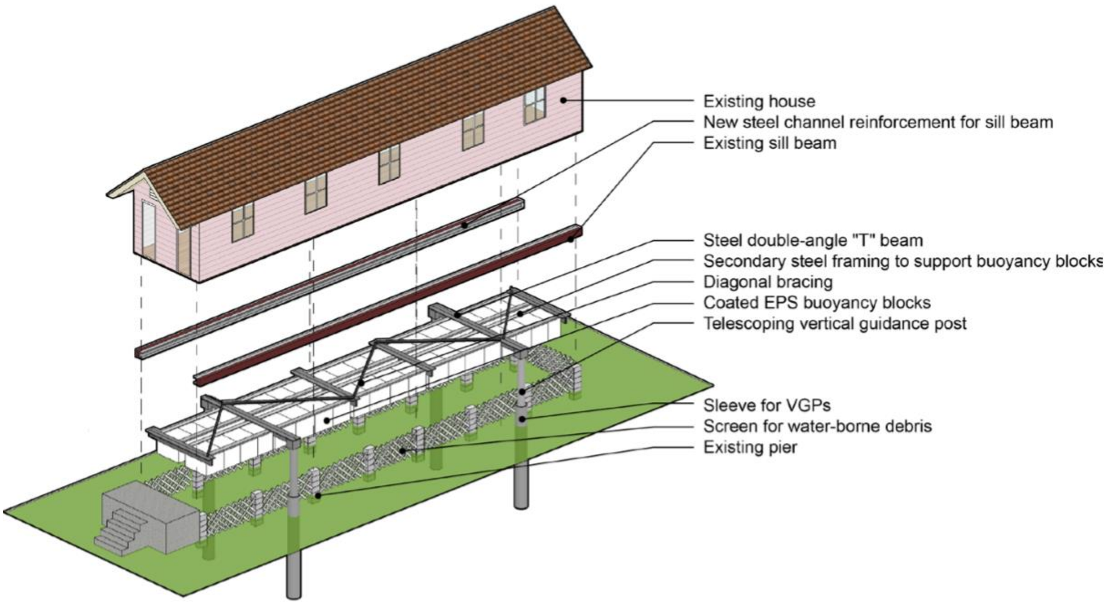


Figure 3.3 Buoyant foundation materials

3.1.1.5 **Condition during flood**

When flooding occurs, the flotation blocks lift the house, with the structural subframe transferring the forces between the house, blocks and poles. The vertical guidance poles keep the house from going anywhere except straight up and down on top of the water. After the buoyant foundation is in place, the house remains supported on its original piers except when flooding occurs.

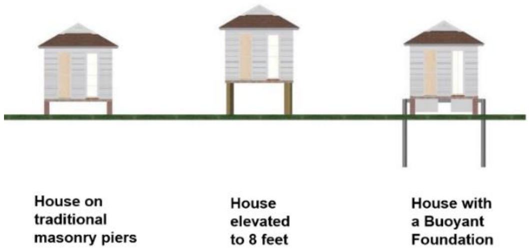


Figure 3.4 Comparison during three conditions

Figure 3.5 Houses during normal condition

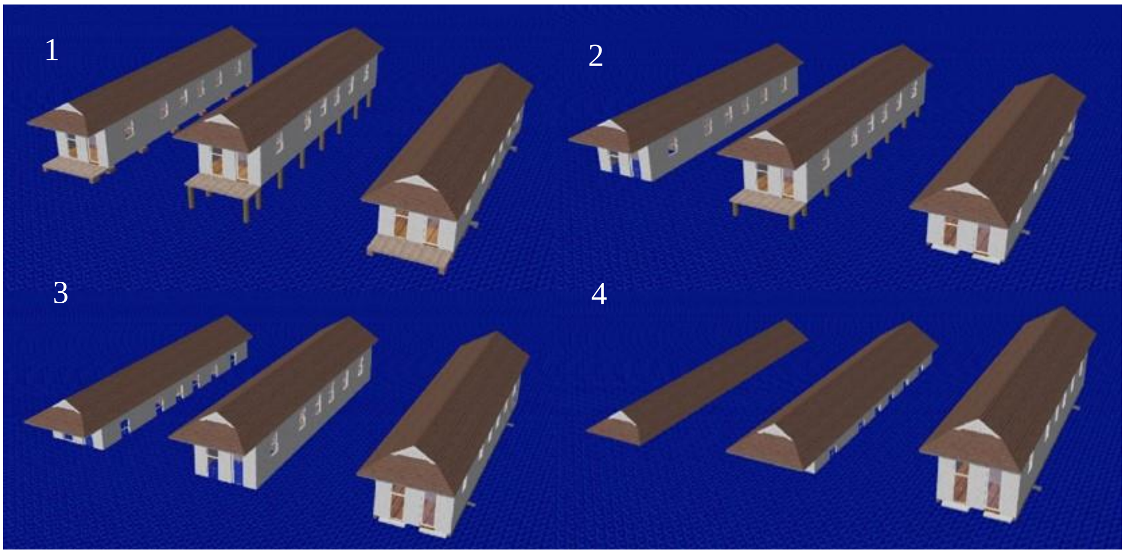


Figure 3.6 Different stages during flood condition

3.1.1.6 **Conclusion**

The finished prototype successfully demonstrates the ability of an existing residence to rise and fall with the water and thus ensure the protection of the inhabitants and their belongings. The buoyant bases allow the residents of New Orleans to protect and preserve their existing vernacular homes and maintain neighborhood character. This approach to flood mitigation is considerably less expensive ($20-25k US) than permanent static elevation ($40-60k US). They alleviate any long-term deterioration of protection resulting from soil subsidence and elevated sea level from global warming, something that permanent static elevation cannot avoid. The house is not permanently elevated and it is therefore less vulnerable to hurricane wind damage. The Buoyant Foundation Project promotes restoration rather than demolition and proves community resilience in extreme weather events and rising water levels.

3.1.2 **Housing in Maasbommel, Netherlands**

3.1.2.1 **Project brief**

Location:	*Along the banks of Maas river*
Completion year:	*2005*
Architect:	*Dura vermeer, Factor Architecten, Boiten*
Water type:	*Freshwater*
House type:	*Amphibious*
Area:	*2865 sqf*

Figure 3.7 Aerial view of Maasbommel project, 2005

3.1.2.2 **Introduction**

Figure 3.8 Maasbommel houses

The Netherlands is a country with a long history of mitigating flood damage and adapting to flood risk. With 60% of the country below sea level, the development and implementation of flood resilient infrastructure has become an important part of the dutch culture. The flood threat in the Netherlands is not only related to rising sea-levels. Rivers also pose a risk of flooding. This risk is increased by climate change as it causes more frequent and extreme rainfall.

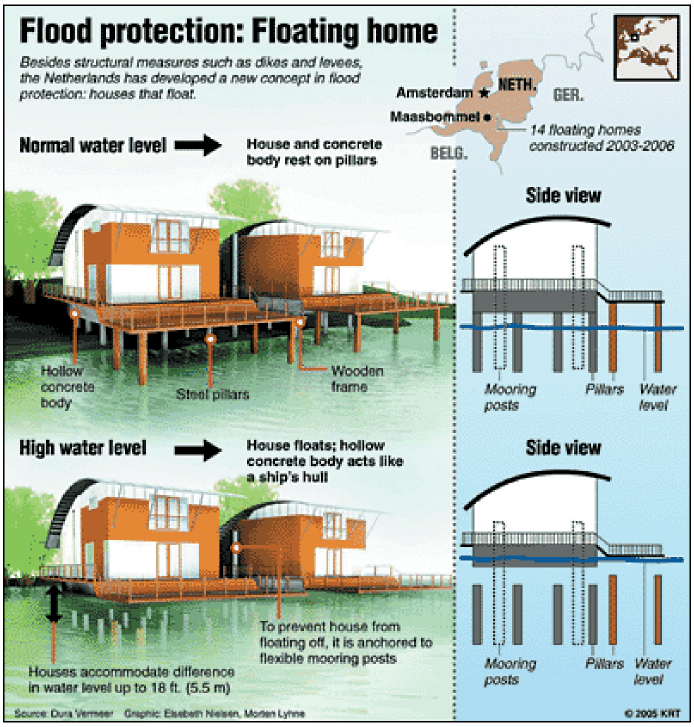


Figure 3.9 Visualization of Maasbommel housing

The program "Ruimte voor de Rivier" (room for the river), implemented in 1997, included the development of natural flood areas, where water could be temporarily stored in case of rising water levels. This had large consequences for the urban development of these areas as development of permanent construction was no longer allowed. One of these locations, Maasbommel (on the Maas river), became the site where the first amphibious houses were realized in 2005 (specifically 32 real amphibious houses plus 14 floating house were realized). Amphibious architecture, structures designed to function both on land and water, is a response to the risk of floods in low lying areas such as the Netherlands. The amphibious houses are constructed along the Maasbommel River and are able to rise with incoming water and return to their original locations on the ground when the water recedes. Although the technology of amphibious houses proved itself during a flood in 2011, the concept is only moderately adopted in the Netherlands. In 2012 the total number of "water houses", which is the definition under which amphibious houses fall, was estimated at a several hundred in the Netherlands.

3.1.2.3 **Geographical conditions of Netherlands**

Netherlands is a country with 60% of the country lying below sea level and situated between sea and rivers. Netherland is located on the delta and experience flooding from rivers and from ocean storms. Most communities in Netherland are protected with dykes, levees and flood gates. But some rural villages are located outside of these flood protection structures. One of those rural village is Massbommel located along Meuse River.

Figure 3.10 Part of Netherlands at flood risk shown in blue colour

Figure 3.11 River Maas when flooded in 1995

The earliest inhabitants of the river area, between the lower Rhine and the Maas Rivers, began settling on elevated former river channels called creek ridges. These river channels are separated by the lower laying areas called “komgronden” (roughly translated: bowl-grounds) which flooded during the winter but were used for cattle grazing during the summer season. By the 10th century, the population was increasing and more land was required for agriculture and livestock. The land near the rivers was drained for the purpose of cultivating, leading to the subsidence of the land and hence more susceptible to flooding. In order to protect themselves from flooding, the people constructed dikes thatdiverted floodwater from the upper sections of the river around their cultivated land.

3.1.2.4 **Foundation**

The common way to achieve the floating concept is making a hull and building a light weight house on top of it. This concept is used in all houseboats where a steel or a timber hull will be used as a basis to build a house. A concrete hull which act as a basement is adapted in these houses. Watertight 23 centimeter thick concrete hull was prefabricated and later moved to its location. The weight of concrete hull was about 70 tons and the timber house was about 22 tons. The concrete hull is resting on six concrete foundation pile.

The houses are built on top concrete basements that double as a buoyant foundation, making it a water tight hollow space used for resident occupancy and flotation. The concrete basements are constructed on site and reinforced with steel rebar. The concrete is poured in detached pairs with each basement weighing in at 70 tons. Two fifteen-foot steel vertical guidance posts are driven through the concrete slab and into the banks of the river. When the guidance posts are in place, the concrete basements

Figure 3.12 Prefabrication of concrete hull on site and placed into the dock of amphibious homes

are hoisted into position and the wood-frame houses are constructed overtop of them. Each pair is placed onto a concrete slab or on concrete piles. The concrete slab is used for amphibious houses that typically rest on dry land. At a low water level, the houses rest upon a foundation of concrete. The concrete piles are used as a base to rest upon at a low water level for floating houses that typically reside in water year-round. To keep the houses as light as possible the framework consists of timber. The houses are joined by a steel bracing that straps two steel plates to the corners of each of the concrete basements. These steel braces will allow both houses to rise and fall with the water at the same rate. The roof is assembled on site and hoisted overtop the pre-fabricated timber frame house. When water levels are high, the houses can reach a maximum height of 18 feet by sliding along the two vertical guidance posts. The vertical guidance posts restrict lateral movements from currents and waves, ensuring that the houses will not float away in the event of high tides.

3.1.2.5 **Construction**

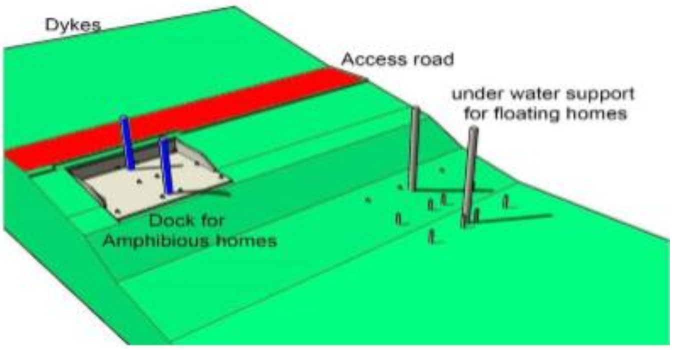


Figure 3.13 Amphibious structure dock and mooring piles

The 32 amphibious homes are under normal circumstances rest on concrete foundation and also starts floating when the water level rises and also during flooding. The advantage of these homes is that they are more or less like ordinary homes with parking space, a garden and access from road. The inhabitant feel that the house is floating only during flood conditions. Two houses are kept in place by the support of two mooring poles.

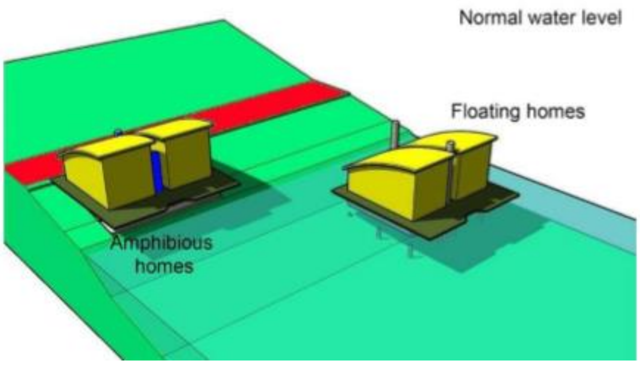


Figure 3.14 Amphibious homes during normal condition

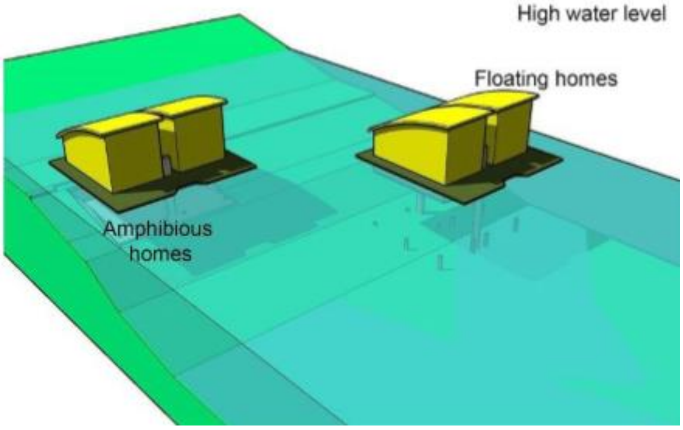


Figure 3.16 Amphibious homes durng flood conditions

These steel columns are driven deep into the ground. Even in the extreme flood condition the structure will be in place and can withstand the current of flowing water with help of these steel column. These steel column are connected by steel framework. The houses connected also limits the waves on the structure. Two houses weights around 200 tons. As the water level rises the houses will rise along with the mooring poles. The amphibious will be lifted out of their docks, and that will be filled with water. A constant descent should be maintain after the flood, for that the docks should be maintain obstacle free at all time. If anything got struck underneath the house as the water withdraws, there will be problem in constant descent of the structure. The

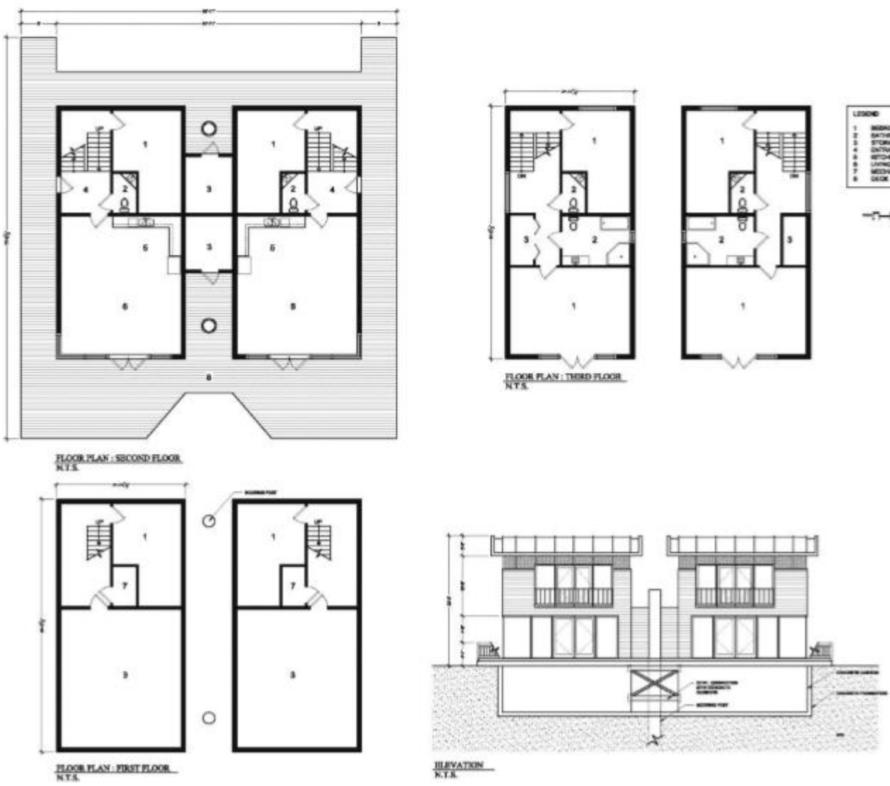


Figure 3.15 Maasbommel house- floor plan and elevation

basis of structure of the house is to provide a light weight structure on top of concrete box. The basic timber structure was prefabricated and then assembled in the site. The roof was made up of steel and wood and then covered with PVC roofing in site and then lifted up to the structure. The arched roof lower towards the dyke side and rising towards the east, provide good view from living room and master bedroom looking towards the lake.

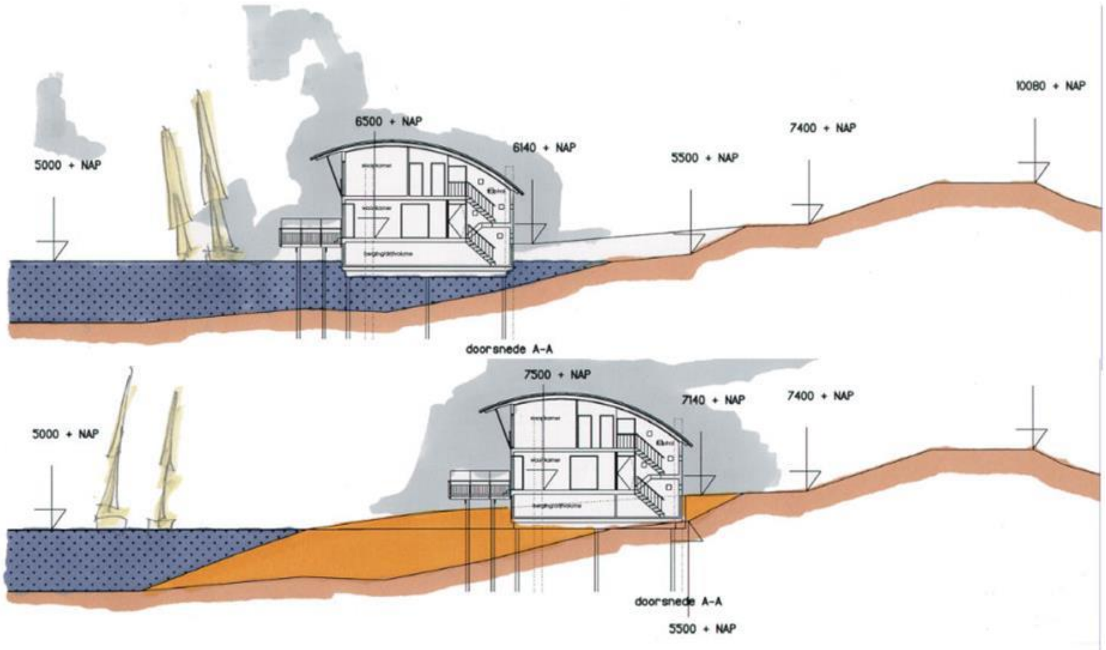


Figure 3.17 Section of Maasbommel floating house

3.1.2.6 **Services**

Figure 3.18 Flexible connection between two houses

The house gets all the facilities like other houses in Netherland. The house is heated by the central heating system with natural gas. It has connection with water, sewage, electricity and gases network like all other houses. The only difference is the connection between the house and the pipeline on the land. Between each pair of houses there is a connection from the dock to sides of the houses. The length was this connection is oversized for normal condition but it will remain connected in the flooding condition. The flexible pipelines are made for both amphibious and floating houses.

3.1.2.7 Flood condition

From 12th to 14th January these structures had final test. The water level rose above 7mts since 1995, that area flooded. Warning has been given to estate owner a day before. All cars were removed from the parking lot and owners were known about the situation. When they woke up on next morning they found that they were not connected to dry condition to land. The inhabitants used boats to get to the land. There seems a minor discomfort as these problem occur once in twelve year. When the amphibious homes descents to its original position everything went well. Nothing got stuck in the docks and the structure came back to its original position.

Figure 3.20 Normal condition

Figure 3.19 Flood condition

3.1.2.8 Conclusion

The concept of floating has proved in various places in small scale test, the Massbommel design, where 14 houses are floating continuously from 2005 and 32 Amphibious homes during flood on 2011 has proved to meet the requirement of the floating structure. Of course both the houses required regular maintenance, but there was no alteration was done since the construction. The owner of the house expressed their views in various interviews. There were no reports of uncomfortable due to waves by the water. The Massbommel project provides extraordinary way to live on and near the water.

3.1.3 House in Thames, UK

3.1.3.1 Project brief

Location: *Along the banks of Thames river*

Completion year: *2015*

Architect: *Baca architects*

Water type: *Freshwater*

House type: *Amphibious*

Area: *2050 sqft*

Figure 3.21 House in Thames

3.1.3.2 Introduction

This UK's first amphibious house is located adjacent to the River Thames in Marlow. Based on the practices pioneering non-defensive approach to make space for water within the built environment - the house marks a valuable and critical contribution to both architectural design and flood resilience discourse.

The 250 tonne house, which sits on the ground within a purpose made dock, is able to rise upto 2.7m when a flood occurs, buoyed by the flood water; whilst remaining connected to all utilities through flexible servicing. Built on the banks of the River

Thames in Buckinghamshire, the house is the first to secure Planning, Building Regulations and to be constructed in the United Kingdom.

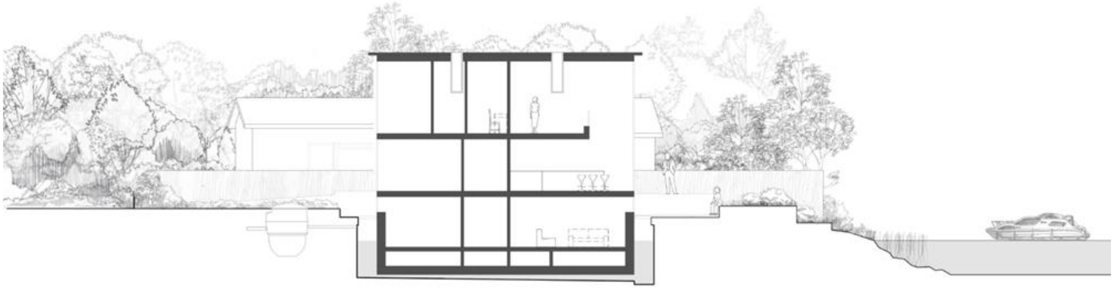


Figure 3.22 Section of Thames house

Figure 3.23 Site plan

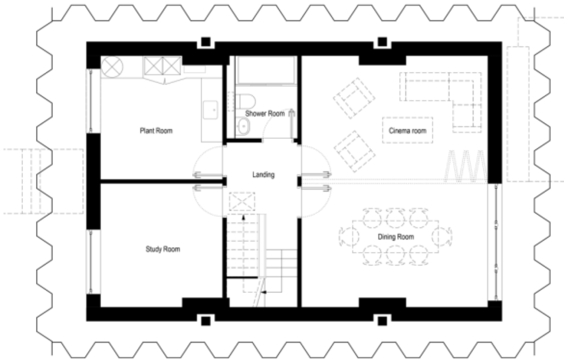


Figure 3.24 Basement plan

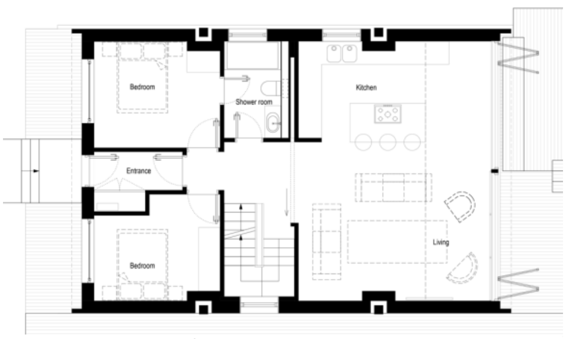


Figure 3.25 Ground floor plan

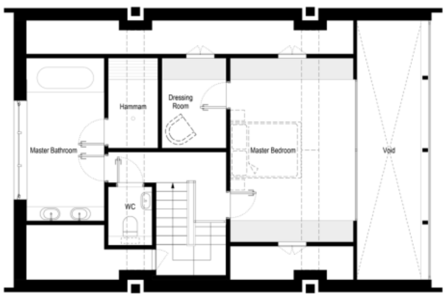


Figure 3.26 First floor plan

3.1.3.3 Foundation

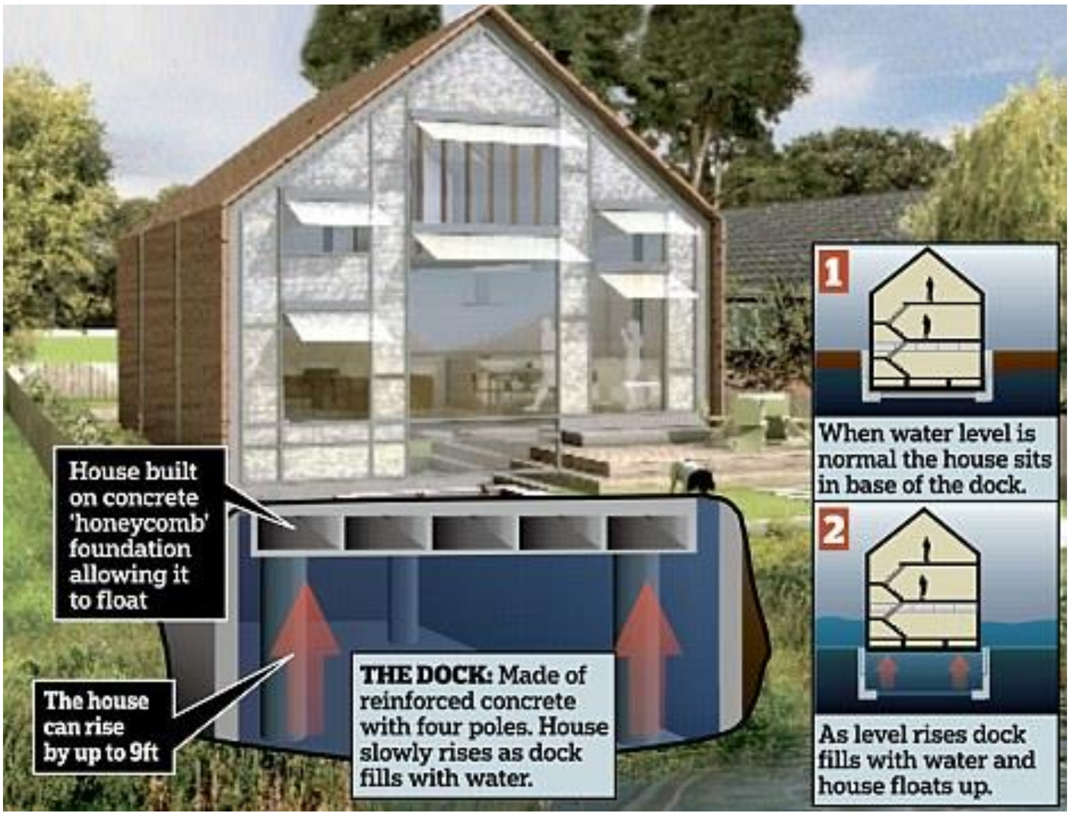


Figure 3.27 Foundation dock

3.1.3.4 Construction

The house uses technology from marine and bridge construction as well as conventional building to create an elegant solution to flooding that is also attractive and complimentary to the setting. The flotation attributes, including the guide-posts, slide-gear and flexible services are expressed in the architecture as is the industrial weather screen skin. The triple height glazed facade allows views of the river from all floors. The northern elevation provides a simple complement to neighbouring houses.

The unique 225sqm house, which is located just 10m from the river’s edge and within a Planning Conservation Area the house, also provides an intelligent and contextual response to its setting. The design was tailored to overcome the challenges of having no vehicular access to the site, limited space to work and needing all plant and materials to be brought across the river via a lightweight chain ferry. This pioneering prototype house passed a full float test before client occupation.

The dwelling is set between four galvanized steel columns termed 'dolphins'. A bespoke running mechanism is fixed between the house and guide posts to facilitate smooth vertical movement as the house rises and falls. The dolphins hold the house true and level against the river current during a flood.

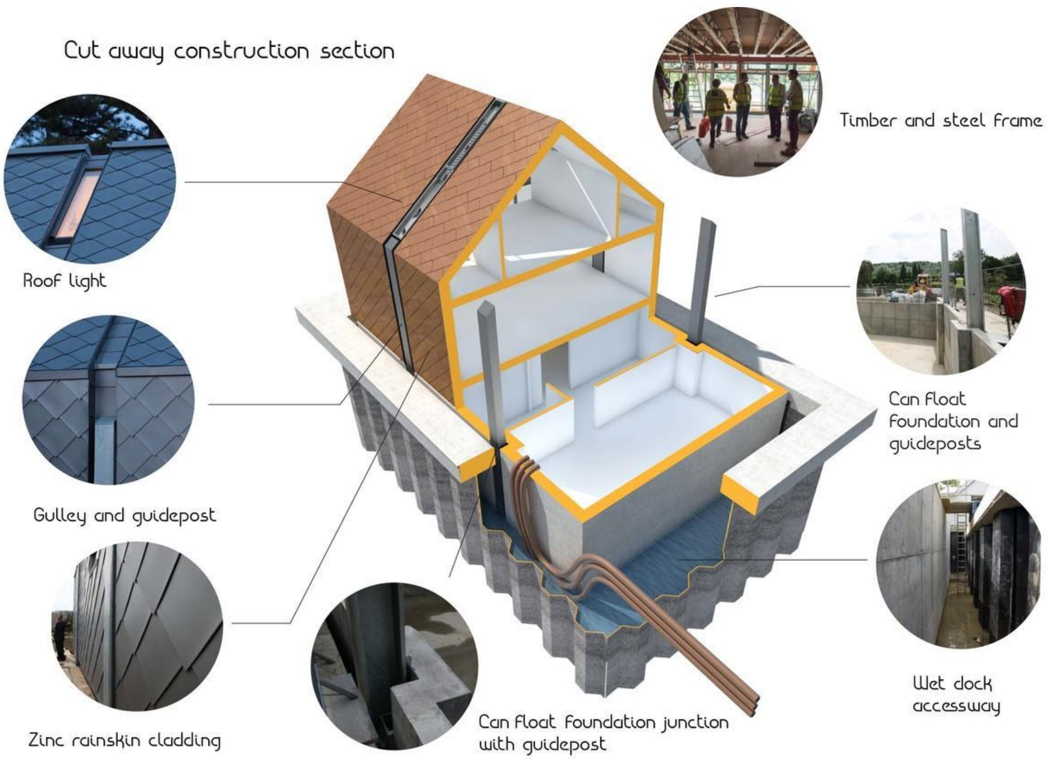


Figure 3.28 Construction details

3.1.3.5 **Services**

Services connect the house with land. Insulated and flexible pipes run along the side of the house, within the wet dock, to pump wastewater into a treatment tank set in the ground.

3.1.3.6 **Flood condition**

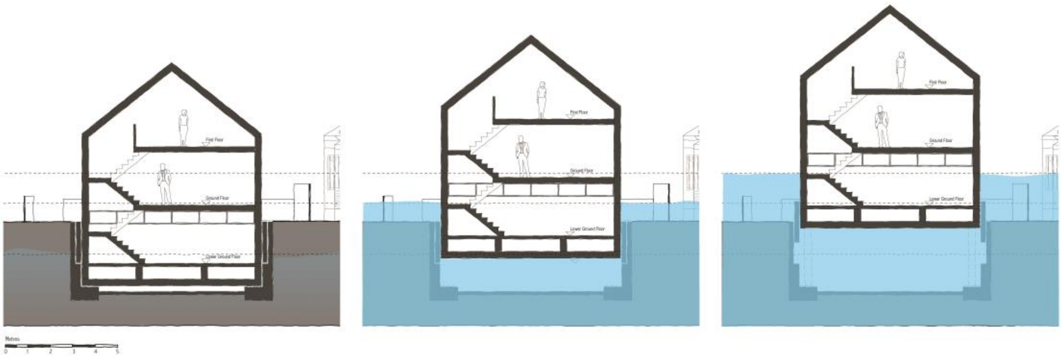


Figure 3.27 House in Thames during different conditions (a- normal, b- rising water, c- flood condition)

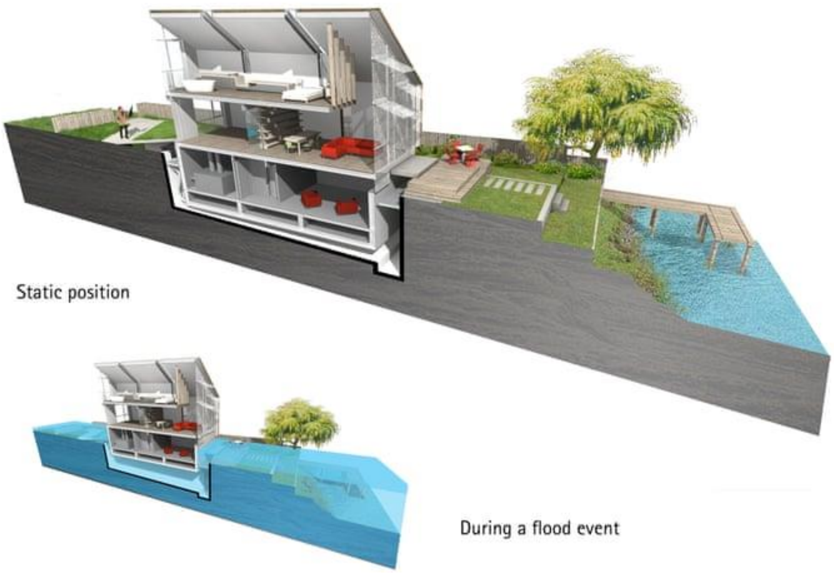


Figure 3.28 Sectional view

3.1.3.7 **Conclusion**

This amphibious house demonstrates that architecture, engineering and flood strategies can be holistically combined to create beautiful buildings that allow occupants to enjoy living near water safely.

3.1.4 LIFT house, Dhaka, Bangladesh

3.1.4.1 Project brief

Water Type: *Salt water*

House Type: *Amphibious*

Buoyancy Material*: Hollow Ferro cement and Bamboo frame work filled with plastic water bottle*

Size: *570 sq.ft*

Figure 3.29 LIFT house

3.1.4.2 Introduction

The LIFT House (Low Income Flood proof Technology) project was designed and constructed in Dhaka, Bangladesh as a solution for sustainable housing for low income communities in flood prone areas. It is an approach to housing that provides all the basic service to its residents without connection to the city service system, through the use of indigenous material and local skills. The lift house provides a low cost flood resilient housing that is amphibious, functioning both in land and water. The two amphibious units of the lift house floats upward with the rising flood water and return to ground level as the flood water recedes.

Amphibious architecture is cost effective and safe alternative to permanent static elevation and it is achieved by the design of buoyant foundation. Instead of relying on the struggling service system of the city, the lift house is self-sustaining in providing basic services without relying on city infrastructure by using passive resources such as solar power, natural ventilation, rainwater harvesting and composting toilet.

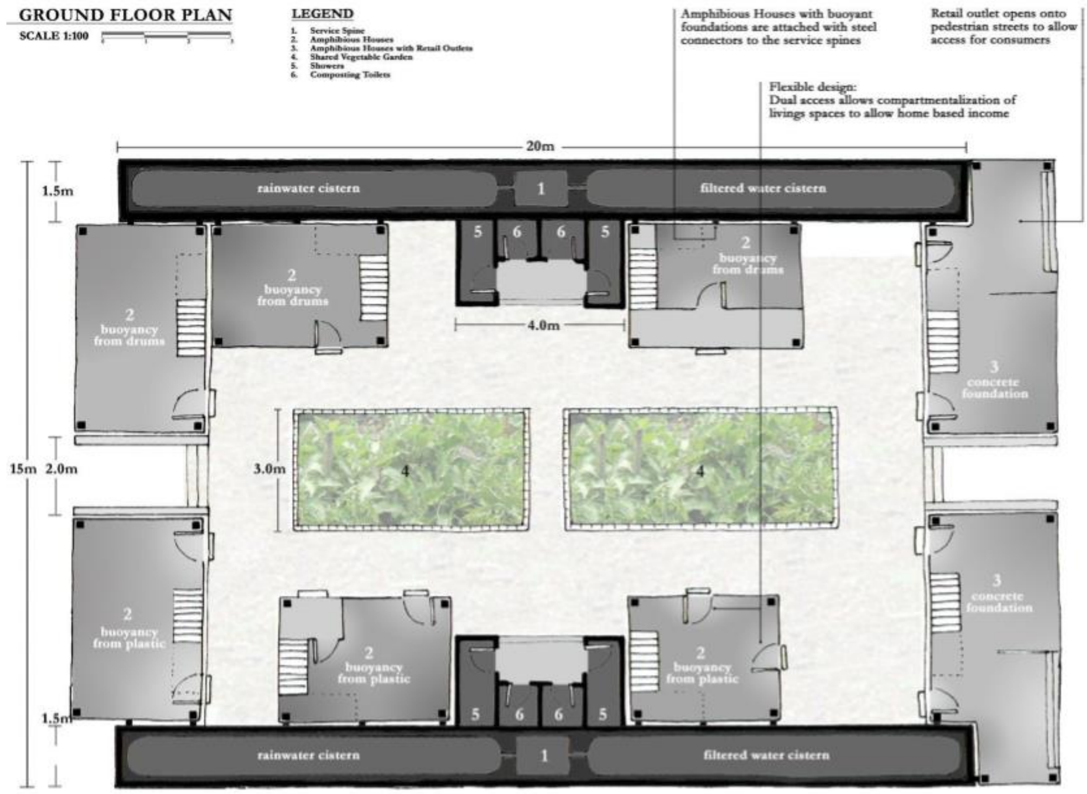


Figure 3.30 Floor plan of LIFT house

3.1.4.3 **Foundation**

Figure 3.32 Ferro cement foundation

Two types of amphibious foundation were used in this house.
(1) a hollow Ferro cement structure
(2) bamboo frame filled with empty used water bottles

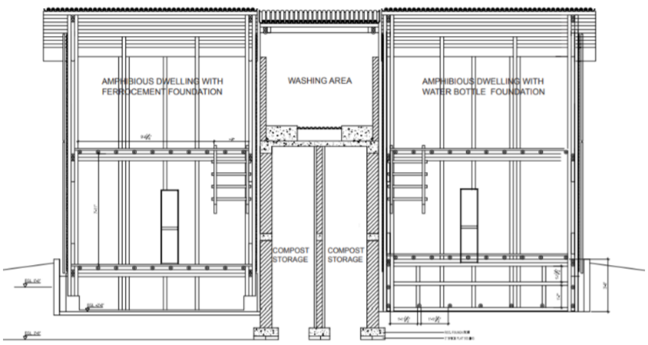


Figure 3.31 section showing two types of foundation

Figure 3.33 water bottle foundation

The depth of the foundation was calculated by finding the dead and live load of the structure.

Ferrocement Foundation:	
D. L. of dwelling: 55 lbs/sq.ft. D. L. of foundation: 52 lbs/sq.ft. Total Dead Loads: 107 lbs/sq.ft	L.L. on 1st floor: 20 lbs/sq.ft. L.L. on 2nd floor: 20 lbs/sq.ft L.L. on roof: 10 lbs/sq.ft Total Live Loads: 50 lbs/sq.ft
Total Load / Weight of Water = Minimum Depth of Foundation 157 / 62.4 = 2.5ft As a safety consideration , a foundation depth of 36" was applied	

Table 1 Calculations for the depth of ferrocement foundation

Water Bottle Foundation:	
D. L. of dwelling: 55 lbs/sq.ft. D. L. of foundation: 20 lbs/sq.ft. Total Dead Loads: 75 lbs/sq.ft	L.L. on 1st floor: 20 lbs/sq.ft. L.L. on 2nd floor: 20 lbs/sq.ft L.L. on roof: 10 lbs/sq.ft Total Live Loads: 50 lbs/sq.ft
Total Load / Weight of Water = Minimum Depth of Foundation 125 / 62.4 = 2 ft Since the water bottle foundation contains a lot of voids between bottles that do not contribute to buoyancy, a foundation depth of 39" was applied	

Table 2 Calculations for the depth of water bottle foundation

The Ferro cement foundation was 14’ x 10’ with ribs of reinforced concrete.
For water bottle foundation, 8000 used water bottles were collected from local hotel

3.1.4.4 **Construction**

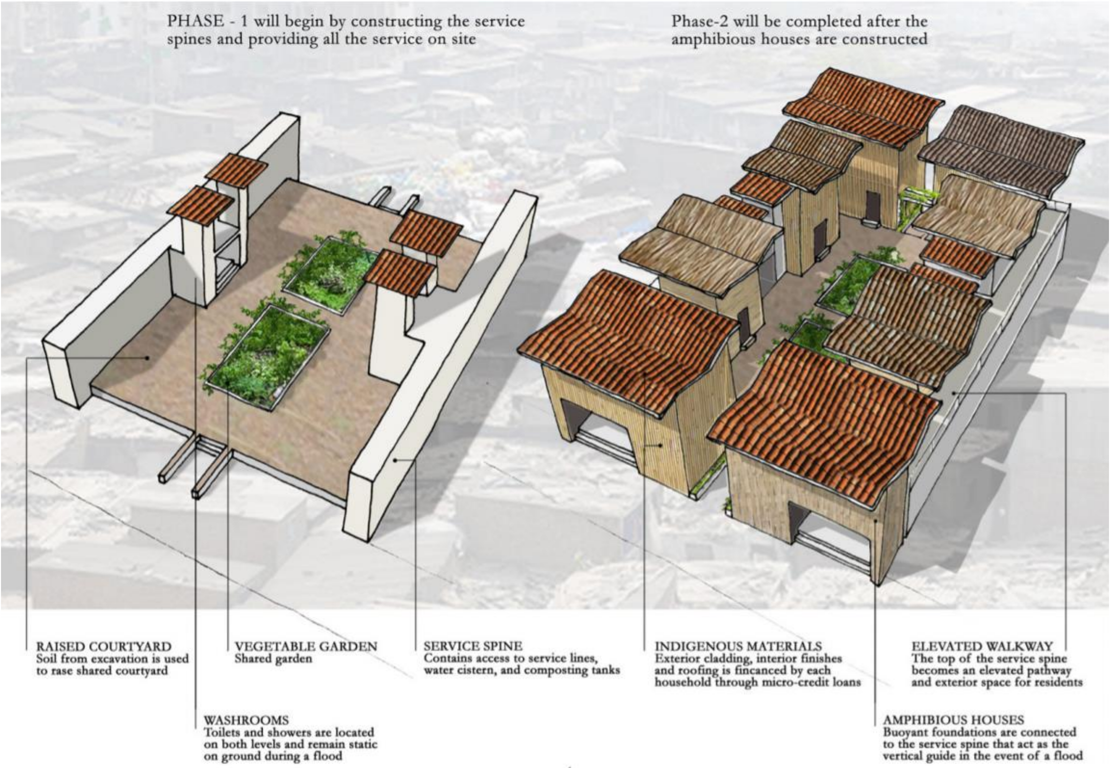


Figure 3.35 Two phases

Figure 3.34 Different stages of construction

3.1.4.5 **Services**

3.1.4.5.1 Service spine

The service spine is constructed out of brick and reinforced concrete. Kitchen, bathroom, composting toilet storage tank and two types of water cisterns are located in this structure. The interior of the cistern is lined with a layer of Ferro cement in order to stop moisture penetration. The foundation for the service spine is concrete slab on grade with a 15 inch thick perimeter brick wall. The wall of service spine is 10 inch thick with two lintel bands of concrete. Two sets of three lintel band across the interior of service spine in order to prevent the buckling of brick wall. The top slab is usable exterior space accessed through the second floor of the dwelling. Thus is will make it safe during flooding. It has a concrete floor with a bamboo railing that is attached with a steel rod, concrete and steel clamps

3.1.4.5.2 Electricity

Electricity is derived from two 60W solar panels. Two Canadian solar panel is connected with a local solar batter, wiring and fixtures to provide electricity for 1 fan and 5 energy saving light fixtures for each unit. A network of electrical wiring is threaded throughout the bamboo wall and roof panels. A large slack in the wire that connects the solar panel above the toilet roof to the solar battery inside the dwelling allow the units vertical movement during flood. Solar power is very desirable and has a high initial cost for the quantities of power consumed by these income group. The lifestyle of the urban poor requires minimal electricity to carry on their daily activities, making the solar energy on the ideal source of power for a city blessed with an abundance of sunlight.

3.1.4.5.3 Sanitation

In Bangladesh the access to the urban sewerage system is very limited. The LIFT House redirects the responsibility of sewage disposal from a large centralized system to an onsite composting system, turning the urine and solid waste into resources that residents can use. The composting latrines divert urine and deposits into the soil of the garden through an underground pipe where it can be used as a fertilizer. By diverting the urine from solid waste, the latrine system in the lift house is less prone to leaching and will naturally compost at a higher rate. It is placed in the second level accessible from the top surface of the service spine. The latrine pans are custom to divert urine and solid waste with a slope of 25 degrees with water traps to eliminate undesirable smell and flies. This system does not contaminate the pond or groundwater since bacteria cannot travel more than 12 feet horizontally and 3 feet vertically. The two families of the LIFT House have access to hygienic sanitation that is ecofriendly, technically appropriate and has no additional utility costs.

3.1.4.5.4 Rainwater cistern

The water in the city becoming scarce even for the planned, upper class communities within Dhaka. The LIFT house project depends only on harvesting and recycling rainwater through non mechanized system. The two water cisterns combined have a capacity of 48,000 liter which will be adequate for 10 residents throughout the dry season. Rainwater is collected from the roof and top slab of the service spine in the first cistern and passes through a filter that traps dirt and insects. If a small particle of dirt enter the cistern the natural sedimentation process will settle these particle at the bottom of the cistern. Residents have access to this collected rainwater via a hand pump located on the top of the service spine. Used water is then collected through a bio sand filter pipe that removes bacteria, chemical and other unwanted things. This filtered grey water is then accessed through another hand pump for secondary use like for toilets, washing.

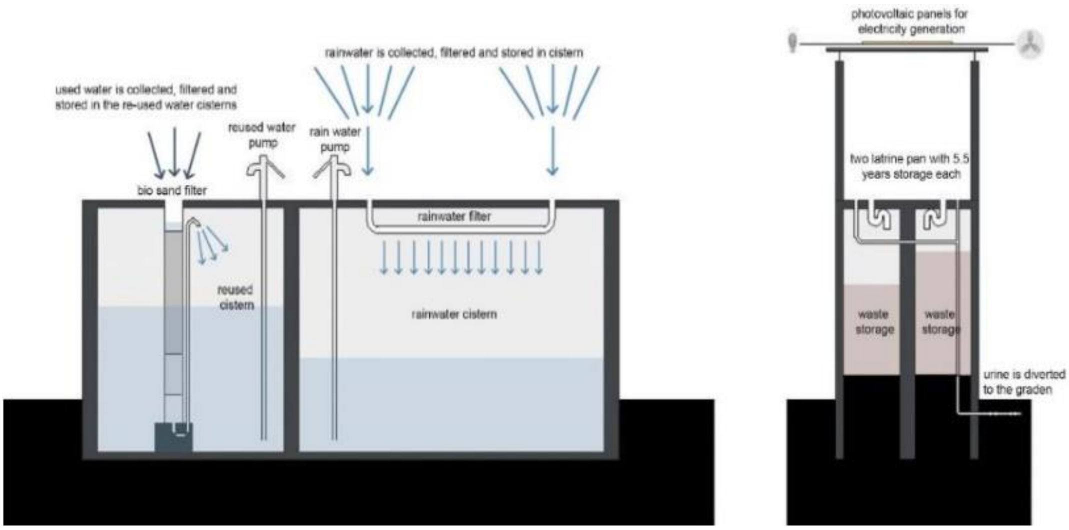


Figure 3.36 Details of rainwater cistern

3.1.4.6 **Materials**

Bamboo was chosen as the building material for the amphibious dwellings due to its versatility, light weight, environmental benefits and low cost. The bamboo was 3 inch in diameter and cut into varied length depending on the usage. Two holes were drilled at every hollow section of the bamboo. These poles were then submerged in a diluted chemical mixture, a combination of water, boric acid and borax which protects the bamboo from insects attack. The holes in bamboo will allow the mixture to pass through the interior cavities breaking the starch content that attracts the insects. Two types of connection were used (1) a metal rod inserted tightly through a pre drilled holes across two members (2) hand tied nylon rope that counteracted the tendencies of the member to pull apart. The prefabricated columns of four long bamboo poles with small stiffeners were the first member created.
Roofing is one of the most important design elements for Bangladesh. The LIFT House roofing was designed to be light weight, affordable and maintainable. The common material choice of corrugated tin was rejected due to inappropriate climate and thatched roof due to scarcity of material in urban area. Bamboo was used in 3 layers for roofing. The topmost layer is exposed. Mulli bamboo skins were used of roof which is most durable part of the plant. Galvanized metal wire was used to tie the bamboo to support frame by hand. The roof system is custom designed based on indigenous methods to suit the amphibious dwellings. Doors of the house are made on site to overcome to difficulty of varying sixe of openings in bamboo wall. Bamboo was also used in the stairs railing that spanned from the ground floor level and become the railing on the second floor.

3.1.4.7 **Conclusion**

The LIFT house has proved to be low cost amphibious homes for Bangladesh people. Using of low cost material and locally available material can improve the vernacular character of the place and also efficiency of the structure. Its implementation was successful and people living in it are satisfied with the facilities but its effectiveness during a flood condition was not available but it did floated or were successful on the test.

3.1.5 Overall summary of literature case studies

Sl.no	SHOTGUN HOUSE	HOUSING IN MAASBOMMEL	HOUSE IN THAMES	LIFT HOUSE
1	WATER TYPE			
	Salt	Fresh	Fresh	Salt
2	COST PER UNIT			
	150,000 $ (20% more)	310,000 $ (17 % less)	840,000 $ (20% more)	3700 $
3	FOUNDATION			
	Sub-frame with EPS blocks	Concrete hull with rebar	Concrete hull	Ferro cement and water bottles
4	PLOT AREA (Sqft)			
	700	2865	2250	570
5	MAXIMUM HEIGHT THAT CAN BE STRETCHED (ft)			
	13	18	9	15
6	ADVANTAGES			
	-Uses existing house -Maintains neighboring character -Retrofit is cheaper than static elevation	-Attached homes minimize sway from waves, vast interior space -Levee berm allows house to rest on land, minimizing corrosion	-Prefabricate -Better and vast interior space	-locally available materials are used -low cost structure
7	DISADVANTAGES			
	-Visible EPS foundation system	-Proximity to neighbors	-Height of house causes sway by waves	-Proximity to neighbors

Table 3 Comparison of literature case studies

3.2 LIVE CASESTUDY

3.2.1 Housing conditions in Kuttanad

A Variety of housing types are now presently seen in Kuttanad regions. Some houses completely destroyed and damaged by the recent flood of 2018, some which are partly destroyed, some new stilt houses or static elevated houses, new stilt houses under construction and some other houses which are now raised by piles using hydraulic jacks ie, elevating the existing houses. Thus floating building typologies are now recently seen in the regions of Kuttanad.

3.2.1.1 Static elevation

Figure 3.37 One storey elevated house in Mancombu

Figure 3.38 One storey elevated house, Kainakary

3.2.1.2 Pile dwellings

Figure 3.39 Pile dwelling, Pallathuruthy

3.2.1.3 **Pile dwellings under construction**

Figure 3.40 Ongoing construction of pile dwelling, Kumbam

Figure 3.41 Pile dwelling under construction, Ponga

3.2.1.4 **Houses destroyed by flood**

Figure 3.42 Flood affected house, Ramankary

3.2.1.5 **Houses lifted using hydraulic jacks**

Figure 3.43 House made to rise using hydraulic jacks

3.2.1.6 **Heavily flood prone houses at the edge of AC canal**

Figure 3.44 Example of vulnerable houses

Figure 3.45 Example of vulnerable houses

Figure 3.47 Example of vulnerable houses

Figure 3.46 Example of vulnerable houses

3.2.2 **Emerald Pristine Island Resort**

Figure 3.48 Floating cottages of Pristine Island Resort

Figure 3.49 Electric lines drawn to the cottage

Figure 3.50 Water supply pipe from the supply main

STRUCTURAL DESIGN	Form is rectangular with sloping roof. Living room, bedroom, toilet and sit out with light weight materials for the superstructure. Built on a floating ferrocement platform. Wooden poles are inbuilt in the platform which are connected to the platforms using rope.
FOUNDATION	Concrete hulls.
MATERIALS USED	Platforms of laminated ferrocement. Walls built with Teak wood panels or gypsum boards with thermocol in between and thatched roofs.
SERVICES	Services such as sewage tanks, electrical, etc are incorporated within the float. A single float consists of two cottages each having a separate sewage collection tank 5 ft deep. The 19 cottages have a single STP. Electric lines are brought through underground cables and taken through holes incorporated in the floor during the time of manufacture.

3.2.3 **Poovar Island Resort**

Figure 3.51 Poovar Island Resort

STRUCTURAL DESIGN	Form is rectangular with sloping roof. Living room, bedroom, toilet and sit out for the superstructure with light weight materials. Built on a floating mass platform. The floating mass is made hollow structured made up of ferro cement
FOUNDATION	Concrete hulls or pontoons of size 7x4.6 m.
MATERIALS USED	Sandwiched laminated panels for walls made of ferrocement. Teak wood panels and thatched grass roofs. Bison panels are fixed on the timber framework of the roof by using coconut timber reapers. Brown tiles for flooring.
SERVICES	Services and utility lines are drawn from the shore through pipes simply laid in water to the floating cottages. Sewage from the toilets is taken out through pipes which are connected to the main sewer of the hotel through underground.

CHAPTER 4 SURVEY

4.1 SURVEY FORM

- With the frequent flooding in Kuttanad and its adverse effects, which would you prefer?

  ☐Relocation

  ☐Adaptation

- During flood times, what you actually do?

  ☐Stay at the home itself

  ☐Take refuge in other safer homes

  ☐Move into relief camps

- Do you think lack of implementation of proper technologies are the reason for the worsening of damages caused by flooding?

  ☐Yes

  ☐No

- Are you aware of floating architecture?

  ☐Yes

  ☐No

- How much do you know about floating homes?

  ☐Zero knowledge

  ☐Some vague idea

  ☐Average/general idea

  ☐High knowledge

- Which forms of floating architecture/dwellings are you familiar with?

  ☐Terp dwellings

  ☐Static elevation

  ☐Pile dwellings/Stilt buildings

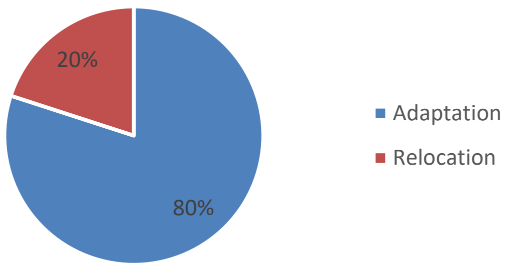
  ☐Houseboats

  ☐Amphibious dwellings

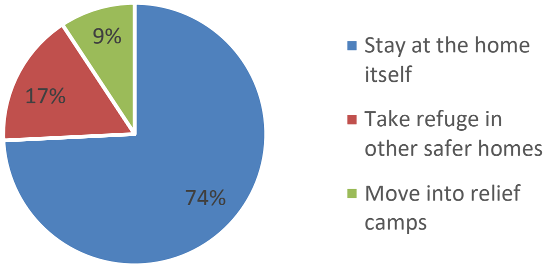
- How much do you know about amphibious houses?
  - ☐Zero knowledge
  - ☐Some vague idea
  - ☐Average/general idea
  - ☐High knowledge
- Will you be willing to have amphibious homes?
  - ☐Yes
  - ☐No
- As means of resisting flooding, which one would you prefer?
  - ☐Elevated/Stilt structures
  - ☐Amphibious structures
- What are the factors/reasons that prevent you from shifting to an amphibious community?
  - ☐Cost
  - ☐Fear of trial/failure
  - ☐Other reasons
- In amphibious dwellings, which one would you prefer?
  - ☐Whole new amphibious construction
  - ☐Retrofit/ use buoyant foundation in existing buildings

4.2 DATA COLLECTED FROM SURVEY

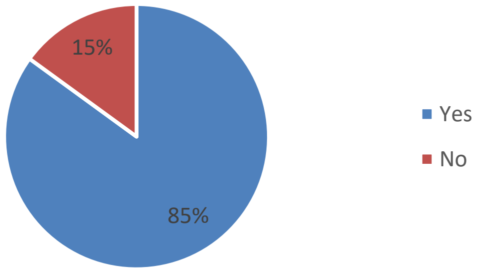
- With the frequent flooding in Kuttanad and its adverse effects, which would you prefer?



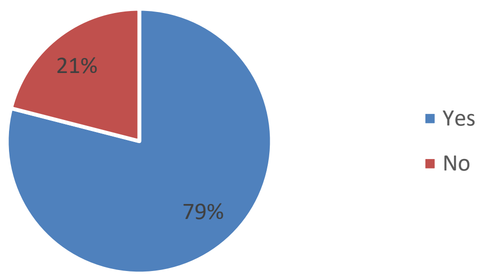
- During flood times, which would you prefer?



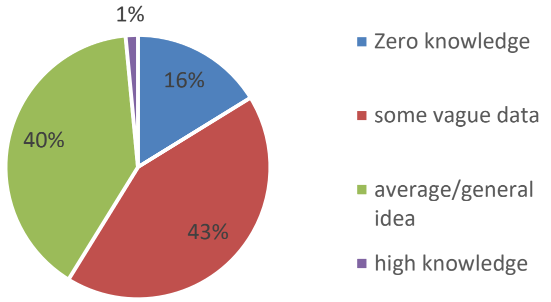
- Do you think lack of implementation of proper technologies are the reason for the worsening of damages caused by flooding?



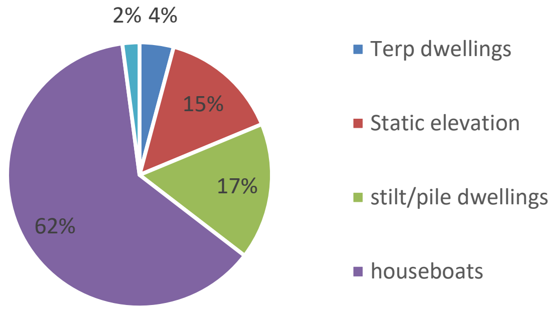
- Are you aware of floating architecture?



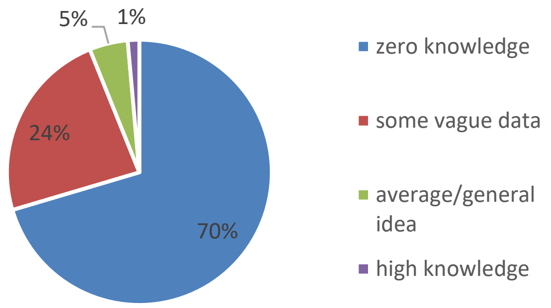
- How much do you know about floating homes?



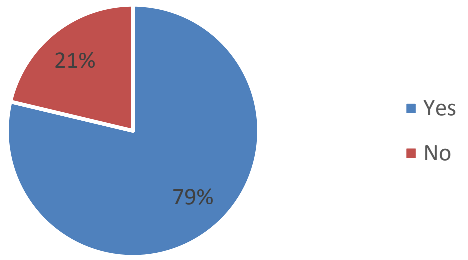
- Which forms of floating architecture/dwellings are you familiar with?



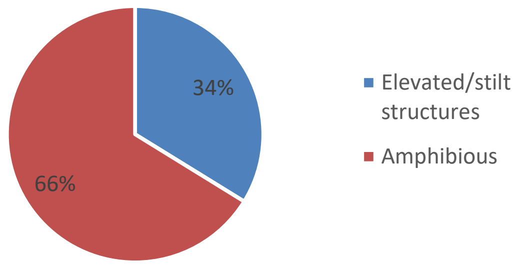
- How much do you know about amphibious houses?



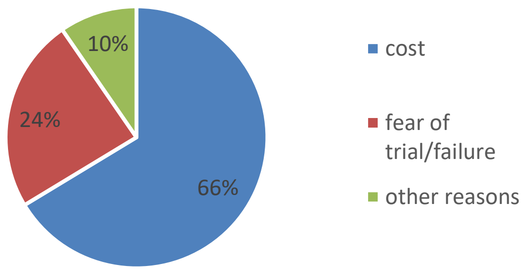
- Will you be willing to have amphibious homes?



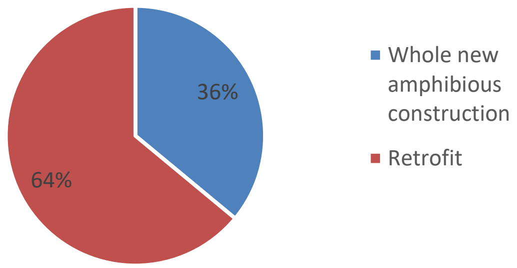
- As means of resisting flooding, which one would you prefer?



- What are the factors/reasons that prevent you from shifting to an amphibious community?



- In amphibious dwellings, which one would you prefer?



CHAPTER 5 **DESIGN PROTOTYPE**

5.1 Prototype 1

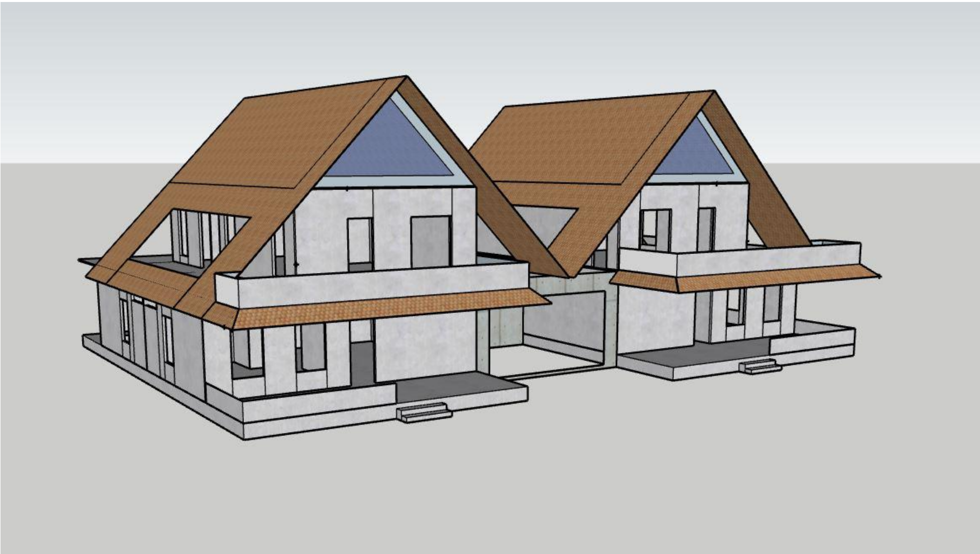


Figure 5.1 View of prototype 1

5.1.1 Brief

Units:	2
No. of family members per unit:	5
No. of floors:	2
Area of one unit:	1600 sqft
Foundation:	Concrete hull
Foundation depth:	90 cm
Materials:	Ferrocement
Weight:	
Maximum height it can reach:	2.7m

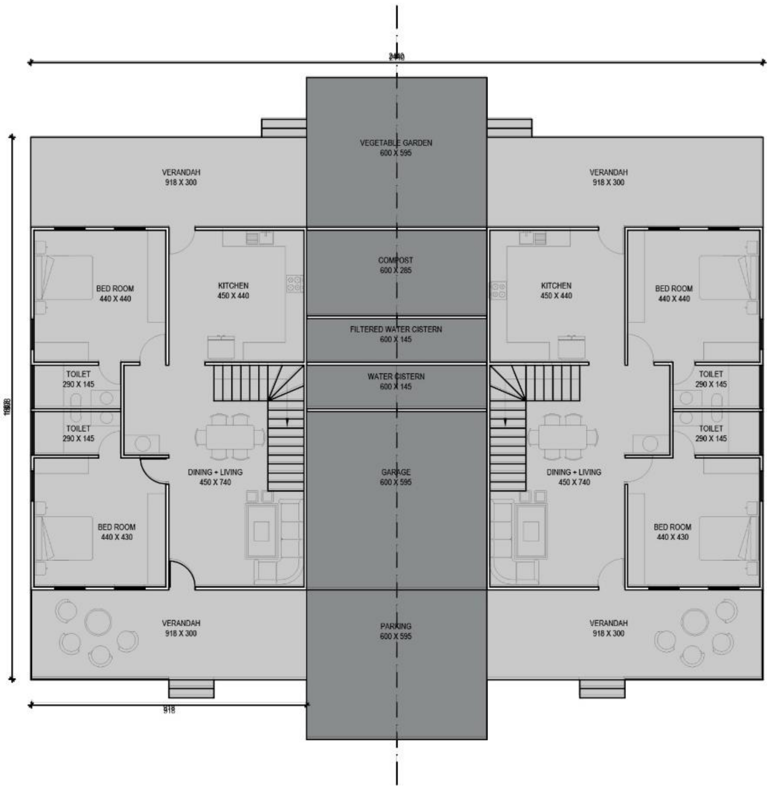


Figure 5.2 Prototype 1- ground floor plan

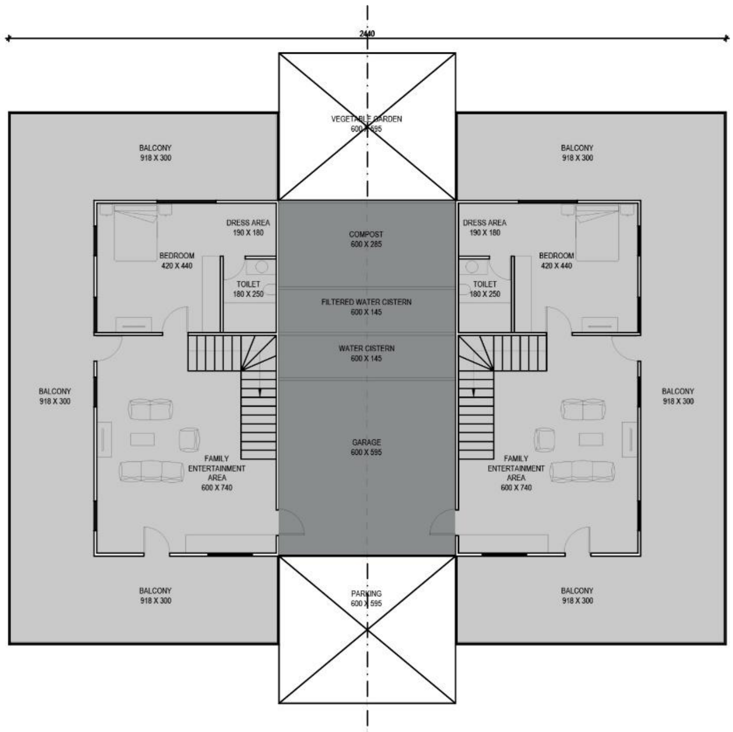


Figure 5. Prototype 1- first floor plan

5.2 Prototype 2

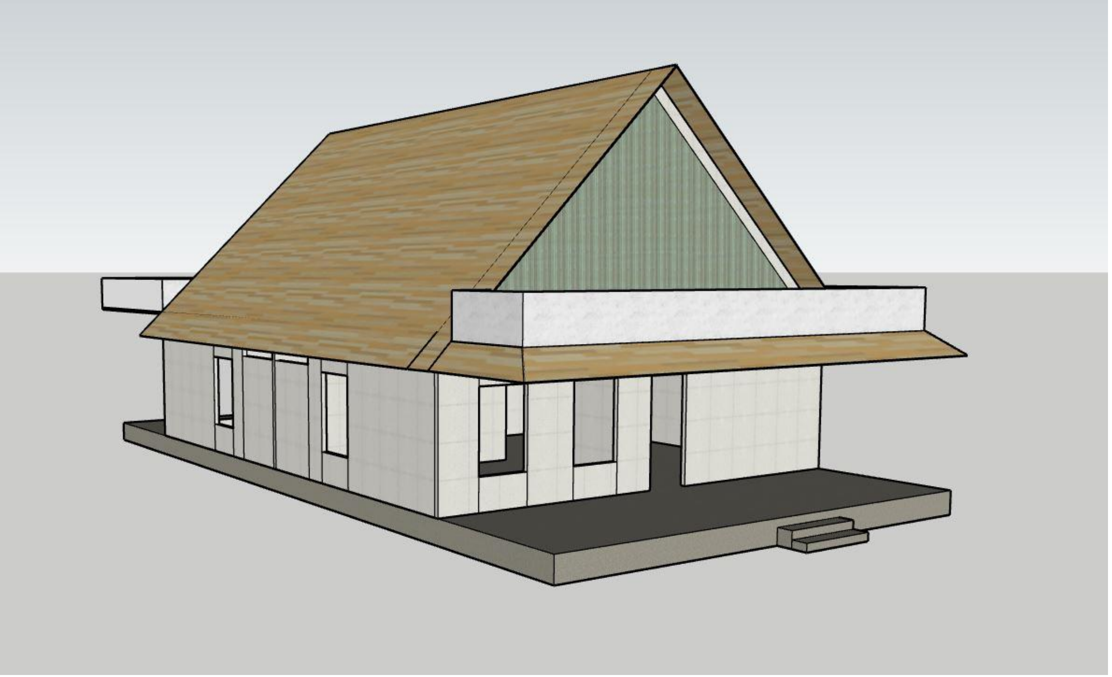


Figure 5.2 View of prototype 2

5.2.1 Brief

Units:	1
No. of family members per unit:	4
No. of floors:	1
Area of one unit:	1600 sqft
Foundation:	Plastic bottles
Foundation depth:	120 cm
Materials:	Bamboo, EPS Panels
Weight:	
Maximum height it can reach:	3.5 m

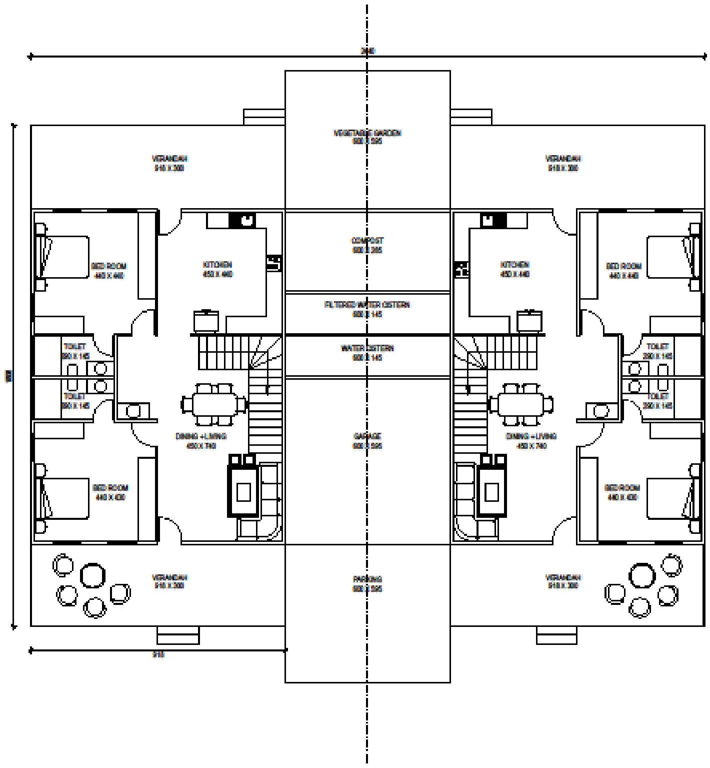


Figure 5.3 Prototype 2- ground floor plan

CHAPTER 6 **INFERENCE**

- This research realizes the scope of floating architecture in regions of below sea level Kuttanad which is heavily prone to flooding
- Floating architecture can be a permanent flood mitigation strategy which can be used in Kuttanad and could resist the frequent flooding happening in this area.
- Amphibious dwellings can be more suitable and important in the Kuttanad, since it works in synchrony with the Kuttanad’s natural cycles of flooding which is necessary for the farming rather than obstructing it.
- The scope of adopting amphibious structures which is a part of floating architecture as flood mitigation strategy in Kuttanad is high because now there already exists different types of floating architecture like static elevated structures, stilt or pile dwellings, houseboats.
- Amphibious structures have been successfully implemented in different parts of the world as a flood mitigation strategy and thus it can be implemented in Kuttanad also.
- When successfully implemented, Kuttanad could stand as a development model for the world.
- Floating modules needed for construction are costly and since 70% people residing in Kuttanad are below poverty line the cost for construction will be a great issue.it will be successful only if the government take essential initiatives regarding this and a mass production of this floating houses should be promoted, only thus the cost could be minimized.
- Kuttanad is known as the rice bowl of Kerala and also the only place where farming is done below sea level, so floating farms as part of floating architecture has a great scope and thus the contribution of Kuttanad in food production can be increased.
- Materials used in the construction should be lightweight. The observed common material used is ferro-cement concrete hulls as the floatation base with lightweight sandwiched panels for walls.

- Corrosion resistant materials should be used since the flood water is mainly saltwater.

CHAPTER 7 **CONCLUSION**

Amphibious buildings are proven low impact flood protection strategy that gives a community enhanced flood resilience and improves its ability to recover from disaster. When flooding occurs the water dwelling vertically rises with the water levels to remain safely above water then settles back into places as the water recedes. Successful amphibious foundation system are functioning in the Netherland, New Orleans, Sausalito and Bangladesh, they can provide flood protection that is more reliable and more convenient than the permanent static elevations. The LIFT house in Bangladesh has proved low cost and sustainable building using locally available material and the house provides service system by not depending on government.

This dissertation has proved the stability and workability of existing amphibious residences and its importance in Kuttanad. With the reference of the different case studies and detailed description of the building material, the construction technique of the amphibious structures, sustainable and low cost amphibious structure can be built in Kuttanad. This residents can also be like normal residents on land because all the same amenities as a building on land can be provided including heating, cooling and ventilation. The waterfront development can be developed by developing these amphibious dwellings. Quality of these structures is also maintained same as the building on the land.

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