A study on new amphibious housing solution for vulnerable communities in Kuttanad

T S Adithya\textsuperscript{1,3} and K K Manoj\textsuperscript{2}

\textsuperscript{1}Department of Disaster Management, KUFOS, Kochi, Kerala, India
\textsuperscript{2}Keral state institute of design (KSID), Kollam, Kerala, India
\textsuperscript{3}E-mail: adithyats28@gmail.com, kinimanoj@gmail.com

Abstract. Face of Kerala is changing with climate making it more vulnerable to flood and flood related hazards. Flood hazard mitigation strategies requires a greater degree of adaptability, which calls for the development of new housing types that build resilience among vulnerable population. Kuttanad is a low-lying deltaic region in Kerala with highest number of flood displaced population per year. The economically weaker section of this region is striving for a flood resilient house. Huge house damage loss followed by Kerala flood 2018 paved the way to think about a construction that lives with water without making any obstruction to its flow. Amphibious housing is a sustainable flood mitigation strategy that works in synchrony with the flood vulnerable region’s natural cycle of flooding. These type of constructions are already a part of Netherlands and Rural Louisiana since 1970’s. This paper reviews the case studies of existing amphibious buildings globally and present flood resilient constructions of Kerala. It also analyses the possibility and proposed a new amphibious housing solution based on timber for the vulnerable regions in Kuttanad. The material selection was based on certain parameters which ensure the sustainability of prototype. These type of construction can act as a permanent housing solution for the flood displaced population of Kuttanad.

Keywords. amphibious architecture, flood, flood resilience.

1. Introduction

In Kerala, with the population growth and rapid urbanisation, a large community especially the low income people occupied the flood prone areas and this along with climate change is the principal factor behind the huge flood hazard losses. A meteorological unpredictability is looming around Kerala in form of flood as in August 2018. Kuttanad is one of the most vulnerable flood plain settlements in Kerala and the flood of 2018 had displaced approximately 1,70,000 residence of Kuttanad to the relief camps [2]. The recent climatic trends in Kerala, mainly the south west monsoon makes the situation of Kuttanad worst. As this climate change is not predictable and preventable the only solution for the sufferings of people in flood prone areas is flood adaption. Amphibious constructions are the most widely accepted flood mitigation strategy by the flood vulnerable communities globally. As the technologies are advanced, it’s the time to install the amphibious architecture in Kuttanad where it has a wide acceptability and possibility. Though the flood resistant Permanent Static Elevated (PSE) houses are a part of Kuttanad after 2018 flood, elevated construction increases wind vulnerability and loss of neighbourhood characteristics [7]. Elevation makes the accessibility of vulnerable group like disabled, aged and pregnant ladies difficult. If the Amphibious
architecture implementation found to be suitable, it would be a great relief for the flood victims of Kuttanad and it can overcome the limitations of PSE.

2. Aim
To analyse the possibility of flood resilient construction and to suggest the best prototype of amphibious architecture as a flood mitigation strategy to the rising flood water levels of Kuttanad.

3. Objectives
- To mitigate the flood risk associated with the human settlements residing in Kuttanad region.
- To evaluate the amphibious architecture of other nations and construction practices that prevails in Kerala.
- To suggest and design a suitable prototype of amphibious architecture.

4. Research questions
- What can be done to mitigate the flood damages related to households in Kuttanad?
- Which is the most accepted method of flood resilient construction globally?
- Which amphibious prototype is suitable in Kuttanad?

5. Research methodology
The major concern of this research was to evaluate the flooding situation in Kuttanad, a place which located 2.5-3 meters below the MSL [2] and to suggest a sustainable, low cost amphibious house using locally available materials to mitigate the flood related house damages. The research design of this study [Figure 1] consist of four research methods, which includes 1) gathering of all documents related to amphibious housing and Kuttanad 2) conducting interviews with authorities dealing with flood mitigation projects in the study area [Table 1], 3) conducting a population surveys with the local residence in the study area [Figure 6] and finally 4) suggesting a suitable prototype of amphibious house. Case studies of various amphibious architecture are used as a source of information on building technology. From the information’s gathered a new amphibious prototype was suggested in Kuttanad.

![Figure 1. Methodology flow chart (Source: Author)](source:image)
6. Theoretical study - Amphibious Architecture

Amphibious house [Figure 2] is a building that rest on the ground but whenever a flood occurs, the entire building rise up in its dock, where it floats, buoyed by the flood water [4]. The 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 exactly the same place upon descent [4]. It works based on Archimedes principle: The mass and the volume of the house is less than that of water, and what determined its buoyancy [5].

The floating base is almost invisible from the outside. Its design can vary to suit the location and owners preferences. These type of foundations are a proven, low-cost, low-impact flood protection strategy that gives vulnerable regions to enhance the flood resilience and improve its ability to recover from disaster [6]. It is a sustainable flood mitigation strategy that allows an ordinary structure to float on the surface of rising flood water than succumb to inundation.

![Figure 2. Amphibious house and its main components. (Source: Author)](image1)

Amphibious construction is an adaptive flood risk reduction strategy that can works in synchrony with a regions natural cycle of flooding, rather than attempting to obstruct the flow of flood water. It is also a low impact Hurricane mitigation strategy that provide flood protection without increasing exposure to strong winds [7].

7. Site study

7.1 Geography

The present study was conducted in Kuttanad, located 0.5-2.5 meters below the sea level in south central Kerala, India [2]. The region is subjected to severe flooding during the monsoon and saline water intrusion during summer season. It extends between North latitudes 9° 8’ and 9° 52” and East longitudes 76° 19” and 76° 44, spread across three districts in Kerala, namely Alappuzha, Kottayam and Pathanamthitta with major portion in Alappuzha district [2]. It is the land surrounded by water bodies like rivers, lakes, backwaters and the coastal ecosystem. In Kuttanad, garden land is the area where human population is inhabited which is up to one meter above MSL. The networks of canals and rivers are extensively used for transportation, reclamation and livelihood means.

7.2 Population

Kuttanad is one of the six taluks of Alappuzha district of Kerala with a total population of 1, 93,007 as per Census India 2011. The total area of Kuttanad taluk is 289.39 sq.km with population density of 667 per sq.km [17]. The life and livelihoods of Kuttanad revolves around water and water based activities. The top vulnerabilities of this region includes high flood water level [Figure 5] almost throughout the year, drinking water scarcity, high water pollution and poverty which makes the life of 23,697 inhabitants of this place miserable.

![Figure 3. Comparison of a normal house and an amphibious house during dry and flood seasons](image2)
Japanese Encephalitis, rat fever and dengue are the contagious vector borne diseases reported in this area. Due to high water pollution the residence of this area have to leave their shelter immediately at the time of flood and it takes more time and money to clean their shelter for residing after flood. The information’s gathered from the population survey is shown in Figure 6.

7.3 Flood condition
Kuttanad was one of the most affected region of Kerala in 2018 flood. Nearly 2.7 lakh people were evacuated from Kuttanad during flood times [1] and they have to shift from more than one relief camp as it also get water logged. During the flood times, transportation route get flooded and the residence of this region get isolated. Most of the houses were displaced in flood by few inches due to the displacement of foundation. The water that enters the house cause structural damage to the materials inside the house. People are getting hospitalised due to this contaminated water and also flood makes their sanitation difficult.
7.4 Flood mitigation projects in study area
The economically weaker section of this area can access financial support for the new amphibious house from Care Home Project and Livelihood Inclusion and Financial Empowerment (LIFE) Mission. Information collected from district project co-ordinators is listed below [Table 1].

Table 1. Information collected through interview

| Project            | Details                                                                 |
|--------------------|-------------------------------------------------------------------------|
| Care Home Project  | ▪ Cooperative department schemes for flood victims.                     |
|                    | ▪ Area: 600 Sq. Ft.                                                     |
|                    | ▪ ₹ 5 Lakh project (₹ 1 lakh- KSDMA+ 4 lakh-C.D).                       |
| LIFE Mission       | ▪ Safe and affordable housing for landless and homeless.                |
|                    | ▪ Area: 400 Sq. Ft.                                                     |
|                    | ▪ ₹ 4 lakh project                                                      |

8. Literature case study

8.1 The LIFT House, Bangladesh
The LIFT House pilot project was constructed on the grounds of the Housing and Building Research Institute in Dhaka, Bangladesh in 2011 [Figure 7]. The house provides all essential services to its residents, including water collection, filtration and reuse, solar electricity, and composting toilets [8].

Figure 7. LIFT House, Bangladesh (photo courtesy: Prithula Prosun)
Figure 8. Rectangular reinforced concrete box (photo courtesy of Prithula Prosun)
Figure 9. Recycled empty plastic water bottles supported on a bamboo frame (photo courtesy of Prithula Prosun)
In this prototype, the two housing units have different systems for achieving buoyancy. The first unit’s foundation consists of a rectangular reinforced concrete box [Figure 8]. The buoyancy system for the second unit is supported on a bamboo frame [Figure 9], which is then filled with bundles of recapped, recycled empty plastic water bottles [8]. Eight thousand air-filled bottles displace enough water to lift the house and its occupants during flood conditions [8].

8.2 Permanent Static Elevations of Kuttanad
Flood resistant permanent static elevations are a part of Kuttanad after the flood of August 2018 [Figure 11]. They are constructed above usual flood water levels of Kuttanad. It helps to keep the properties safe from the flood water. Since it was built at certain heights access by the disabled ones, who were considered as the most vulnerable group in the community, finds to be difficult. And also height makes the construction vulnerable to wind. But this type of construction are seen widely in certain regions of Kuttanad with different heights.

8.3 Timber building in Thazhathangadi, Kottayam
It is an old fashioned settlement house near Meenachil River in Thazhathangadi, Kottayam. This timber building constructed in the traditional way successfully overcame the effects of flood waters that hit Kerala. Although not placed on a very high plinth, these wooden houses follow the traditional prefabricated system of construction [10]. The ara, which are wooden-panelled walls, are used not only for storing but also as a vent in case of calamities, as spatially it is located within another walled enclosure[10].

Figure 10. Permanent Static Elevated house model (Source: Dr. Manoj Kumar)  
Figure 11. PSE House funded by LIFE Mission in Kuttanad (Source: Author)

Figure 12. Timber building, Thazhathangadi, Kottayam (Source: Traditional architecture of Kerala and sustainability)
9. Analysis of building material

Construction practices in Kerala can be categorised as traditional and modern method of architecture. The change from traditional technology to modernisation had contributed to flood related damages. By taking this into consideration the most commonly used building materials of traditional and modern buildings in Kerala were identified [11] and categorised as 1) Foundation and basement, 2) Superstructure, and 3) roofing as shown in the Table 2.

Table 2. Comparison of building materials in Kerala and other nations. (Source: Author)

| Building elements | In Kerala | Presently using materials |
|-------------------|-----------|---------------------------|
| Foundation and basement | Laterite, Rubble | Laterite, Rubble, Concrete |
| Superstructure | Wood, Laterite, Mud, Rubble | Bricks, Concrete blocks |
| Roofing | Wood, Palm Leaves, Thach, Tiles | Concrete, tiles, Aluminium sheets, Cement sheets, Galvanised Iron sheets, FRP Sheets |

9.1 Amphibious architectures globally

Amphibious buildings and its details such as year of establishment, height it can attain during a flood, the buoyancy and vertical guidance system used in the construction and the building materials are collected [4 -8] as in Table 3.

Table 3. Comparison of amphibious architecture globally (Source: Author)

| Amphibious project name+Location | Year of establishment | Max height during flooded condition+ area | Buoyancy + Vertical guidance systems | Building materials |
|---------------------------------|-----------------------|------------------------------------------|--------------------------------------|--------------------|
| Fishing camps, Louisiana        | 1970’s                | 15-25 feet 540-960 sq ft                 | Expanded Polystyrene (EPS) blocks fastened under the frame with sleeves that slide upon fixed vertical guidance posts | Steel/timber, Eps foam for buoyancy |
| Maasbommel Mass River, Netherlands | 2006                  | 18 feet 1600 sq ft                       | Concrete box provides buoyancy and forms the basement on which the wooden superstructure is built and held there by 2 large steel posts | Timber, concrete, steel |
| LSU Prototype, Louisiana        | 2007                  | 5 feet 312 sq ft                         | Expanded Polystyrene (EPS) blocks fastened to a steel substructure with sleeves sliding on four fixed vertical guidance posts | Steel/timber, EPS foam for buoyancy |
| Building | Date | Height | Area | Materials and Construction Details | Special Features |
|----------|------|--------|------|-----------------------------------|------------------|
| Noah's ark project, New Orleans, | 2007 | 12 ft | 2,700 sq ft | A hollow 3-foot high barge welded together from plate steel and iron trusses that carry the weight of this steel-framed home. Wooden vertical guidance posts at the four corners of the house. | Steel for the frame, timber for vertical guidance posts. Prefabricated construction |
| FLOAT House, New Orleans | 2009 | 12 ft | 1000 sq ft | The base of the house is re-conceived as a chassis- acts as a raft, allowing the house to rise vertically on two steel guidance posts. Chassis made from polystyrene foam coated in glass fiber reinforced concrete. | Steel, concrete, EPS foam coated in glass-fiber reinforced concrete, house is wood frame construction |
| LIFT House, Dhaka, Bangladesh | 2010 | 5 ft | 400 sq ft for each | Buoyancy is achieved from two different systems- one is of hollow ferrocement foundation and the other is bamboo frame foundation filled with recapped empty water bottles. The steel vertical guidance system attaches the bamboo dwelling to the brick and concrete service spine. | Bamboo, masonry, ferrocement, plastic water bottles for buoyancy, slotted steel tubes cast into masonry base for vertical guidance |
| BFP projected for New Orleans, Louisiana | 2011/2012 | 25 ft | 700-1100 sf ft | Coated EPS foam for buoyancy fastened to the steel substructure- telescoping vertical guidance posts that pull out of the ground as the house rises are being developed. | Steel, coated EPS foam for buoyancy |

The materials used for constructing the building elements of amphibious architecture globally [Table 3] is compared with table 2. From the comparison, nine building materials which were commonly used in the construction work that can withstand the climatic condition of Kerala is selected from both Table 1 & 2 for further evaluation.

**10. Evaluating building materials**

Building materials are chosen based on certain parameters such as durability, strength, aesthetic appeal, building cost, local availability, feasibility to local climate, sustainability, maintenance, renewable nature and the availability of skilled labours. Each of these parameter is provided with a mark out of ten [Table 4]. The material proved best quality is awarded with more marks as in the Figure 13. The grading is done with the reference to the literature section- Evaluation of Technology options: Kerala of the research paper Sustainable - Affordable Housing for the poor in Kerala [11].
Table 4. Grading of building materials (Source: Sustainable - Affordable Housing for the poor in Kerala)

| Building materials              | Durability | Strength | Aesthetics | Cost | Local availability | Flexibility to local climate | Sustainability | Maintainability | Reusability | Skilled labor availability | Total score 100 |
|---------------------------------|------------|----------|------------|------|--------------------|-------------------------------|----------------|-----------------|-------------|--------------------------|-----------------|
| Laterite                        | 8          | 8        | 9          | 10   | 8                  | 8                            | 9              | 8               | 9           | 10                       | 86              |
| Rubble                          | 10         | 10       | 9          | 8    | 9                  | 10                           | 10             | 10              | 9           | 10                       | 95              |
| Reinforced Concrete             | 10         | 9        | 8          | 8    | 9                  | 10                           | 10             | 9               | 8           | 8                        | 89              |
| Expanded Polystyrene (EPS) blocks | 9       | 9        | 8          | 9    | 9                  | 9                            | 8              | 8               | 8           | 8                        | 86              |
| Plastic bottles                 | 8          | 8        | 8          | 10   | 9                  | 9                            | 8              | 8               | 8           | 8                        | 84              |
| Timber                          | 9          | 10       | 10         | 9    | 10                 | 10                           | 10             | 10              | 10          | 10                       | 97              |
| Bricks                          | 10         | 9        | 8          | 10   | 9                  | 10                           | 9              | 5               | 9           | 10                       | 94              |
| Steel                           | 10         | 10       | 8          | 8    | 8                  | 8                            | 9              | 9               | 8           | 9                        | 87              |
| Tiles                           | 8          | 8        | 10         | 9    | 8                  | 8                            | 8              | 8               | 8           | 10                       | 86              |

Figure 13. Evaluating materials for suggesting suitable prototype (Source: Author)

Figure 13 and the case study of timber building Thazhathangadi, Kottayam reveals the fact that a wooden prototype of amphibious architecture can resolve the problem faced by the residence of Kuttanad related to flood damages. It can benefits the residence and environment as shown in the Figure 14 thereby enhancing the flood resilience of the community.
10.1 Recommended prototype- Timber/ Bamboo

Timber had been used extensively as the traditional construction material in Kerala from ancient time onwards and timber joinery is the traditional craft skill used by the Keralities. Weight of a timber building is less than that of a masonry building and is suited to the soil whose bearing capacity is low. Framed systems can be adopted for superstructure so that the ground movements by swelling and shrinking of the soil do not affect the structure. A prefabricated unit of bamboo or wood can be constructed within the factories and possible to transport and install at the site of construction. Since timber is a renewable resource its prospective demand can be assessed and quality yielding timber can be cultivated and harvested in a time based manner. It is easy to train the carpenters to construct similar structure based on suggestive design. As Kerala is a land blessed with woods, availability of this material is more and since it is renewable in nature it can be used for next generation also.

Table 5. Characteristics of the wooden prototype (Source: Author)

| No. of family members | 4 |
|-----------------------|---|
| Area                  | 500 sq. ft. |
| Foundation            | Wooden hollow box |
| Superstructure        | Timber, bamboo |
| Roof                  | EPS panels |
| Maximum height it can reach | 2.7m |
10.1.1 Foundation
The buoyant foundation can be constructed with elongated wooden planks with reference to the house boats of Kuttanad. It can be coated with black greasy resin of cashewnut shell which makes the wooden part waterproof and it prevent the premature rotting due to prolonged exposure to water [13]. The density of wood is less than water, which makes the applied buoyancy force by water more than the weight force of the wood. The foundation is expected without using a single nail.

10.1.2 Superstructure
Both timber, bamboo and EPS panels can be used to construct the super structure such as the wall and structural framework. Bamboo as a building material has high compressive strength and low weight. Due to a distinctive rhizome dependent system, bamboos are one of the fastest growing plants in the world so it can be cultivated and harvested in a time based manner [3]. Capability of bamboo to resist fire is very high due to the presence of silicate acid and water.

10.1.3 Roof
EPS panels within a wooden structural frame work is preferred for roofing. It repels water, prevents humidity and bacterial growth. As its closed porous structure consist of 98% air, it is light, and does not place additional load on building [12]. EPS application is quick and easy due to its flexible and light weight structure. Therefore, it saves time and keep labour costs low. The cost of EPS products for construction sector is lower by approximately 1/3 compared to other alternative products. It provides excellent thermal insulation and the material is heat, cold and fire resistant in nature [9, 12].

![Figure 16. Floor plan of the house (Source: Author)](image)

This project plan depends solely on rainwater harvesting [Figure 16]. Placing of rainwater cistern within the house can save the residence from water scarcity and certain pathogens. In Kuttanad, sunlight is available in abundance and it can be used as an alternative source of renewable energy. Electricity can be derived from the two solar panels attached to the roof [Figure 15]. It reduce the dependency on traditional power sources.

11. Inference
Amphibious houses are a proven low cost flood mitigation strategy that can be installed successfully in the flood prone areas of Kuttanad. As wooden prototype is sustainable and renewable, low environmental impact is expected from these type of constructions. Like the timber house boats in
Kuttanad, these wooden prototype will survive in the flood water for a long time by creating aesthetic appeal. The kayal reclamation in Kuttanad and change in global climatic pattern makes the region more vulnerable to upcoming floods. Scope of these type of architecture is more in Kuttanad as no relief camps other than amphibious constructions can operate in the rising water level.

12. Conclusion
The study suggest timber/bamboo based amphibious prototype as a permanent solution to the rising flood water levels of Kuttanad. Timber with proper treatment can increases its durability. The financial aid of LIFE Mission and Care Home Projects can be used by the economically weaker section of the region for building amphibious house. 70% population of the study area are willing to adopt the new technology. The house boats with timber foundation exemplify the possibility of timber based buoyant foundation system in Kuttanad. The study reveals that by comparing other building materials timber is a low cost sustainable, water resistant material.

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