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Amphibious Architecture: A Benchmark for Mitigating Flood Risk

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Abstract**—**This article aims to define strategies for applying innovative technology so that housing in regions subject to floods can be more resilient to disasters. Based on case studies of seven amphibious and floating projects, it proposes design guidelines to implement this practice. Its originality consists of transposing a technology developed for fluctuating buildings for housing types in regions affected by flood disasters. The proposal could be replicated in other contexts, endowing vulnerable households with ability to resist rising water levels after a flood. The results of this study are design guidelines to adapt for houses in areas subject to flooding, contributing to the mitigation of this disaster.

Keywords**—**Amphibious housing, disaster resilience, floating architecture, flood mitigation, post-disaster reconstruction.

I. Introduction

DISASTERS are increasing around the world. Worldwide data on disasters compiled by CRED demonstrates a gradual growth that has intensified in the 21st century [28]. Fig. 1 illustrates the visible increase in the occurrence of natural disasters with the largest proportion being that of floods, indicated in dark blue.

Regarding the number of affected, floods, which are present in almost all countries, represent the majority of the world, counting 2 billion people (45%), considering the period between 1998-2017. Second, ironically it is drought that most affects the population, with 1.5 billion people (33%) [1].

Some places where floods were reported in 2011, a particularly tragic year, were on the Mississippi River in the USA; in the Serrana region of Brazil, where simultaneously landslides intensify the disaster and in areas of Thailand. China and India are also countries that appear on the map most prone to flooding, in addition to the places that flood occurred in 2010: Queensland, Australia, South Africa, Sri Lanka, Philippines and along the Indus River basin in Pakistan [3].

Floods affect urban settlements of all types, from small towns and medium-sized cities and service centers, for example, along the Indus River, to major cities, megacities and metropolitan areas like Sendai, Brisbane, New York, Karachi and Bangkok, all of which have been hit by recent floods. The population with a perception of risk alone develops some strategies to deal with the situation, but these can be improved. This means that there is already a knowledge that the area where they live is susceptible to flooding and they know it before the flooding happens. At this point, a technical contribution is welcome, as the community understands that these are real needs.

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The risk must then be managed in order to mitigate the effects on these people and their context to a minimum. Through planning, organization and control of human and material resources, it is possible to provide housing in unexplored areas following the fluctuations in water level, as is the case with the construction of amphibious and floating houses which will be presented as case studies.

II. Methodology

This study applied the following methodology:

1) State of the art about amphibious architecture.
2) Research on the historical aspects of floating architecture including vernacular solutions.
3) The current practice analysis: three key technical aspects on seven relevant case studies. The first is anchoring, the second floating and the third living in safe conditions.
4) Proposal for technological transfer in places affected by floods for low cost solutions: half public and half private.

III. Opportunities for Innovation in Amphibious Architecture

Amphibious and floating buildings represent an opportunity for architectural innovation, perceived as a response to climate change, the risk of rising seas and rivers after heavy and intense rains. If dwellings with common structures are adapted to float on the surface of the floodwater, instead of succumbing, it can build resilience in vulnerable communities.

Bignami et al. [4] present the main techniques to protect buildings in a strategic planning, which are:

- Relocation of the buildings,
- Elevation of the buildings,
- Floodwalls or levees,
- Dry flood proofing (external predisposition of a construction),
- Wet flood proofing (internal predisposition of a construction),
- Floating,
- Ground lowering/levelling of free land for waterway diversion and/or local storage.

Especially the last two: floating and ground lowering levelling will be studied in this article. Both allow a building to float on water when floods occur, with the difference that the leveling foundation maintains the building’s connection to the ground, supporting it firmly when it is dry. This bond with the land, which allows the building to be installed in dry periods as well as in floods, characterizes the amphibious aspect of architecture.

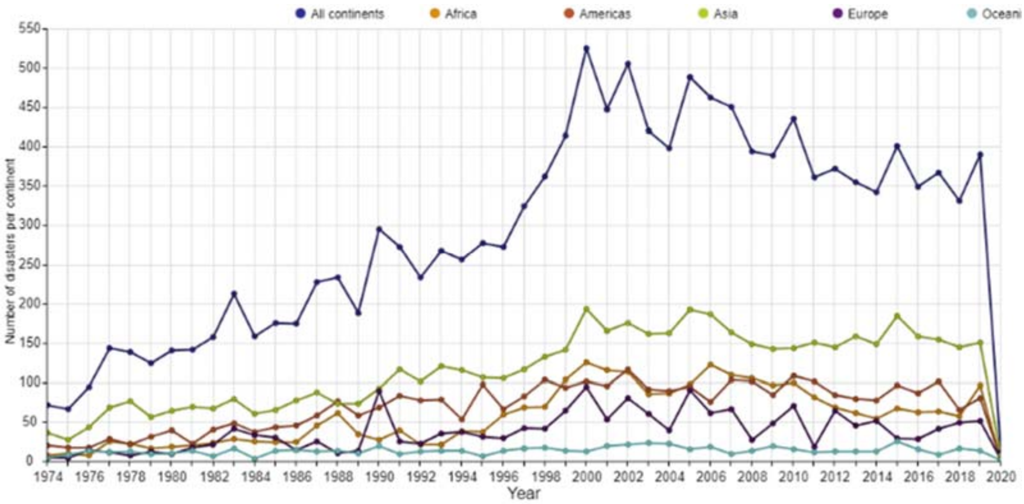

Fig. 1 Total number of natural disasters reported between 1974 and 2003 [2]

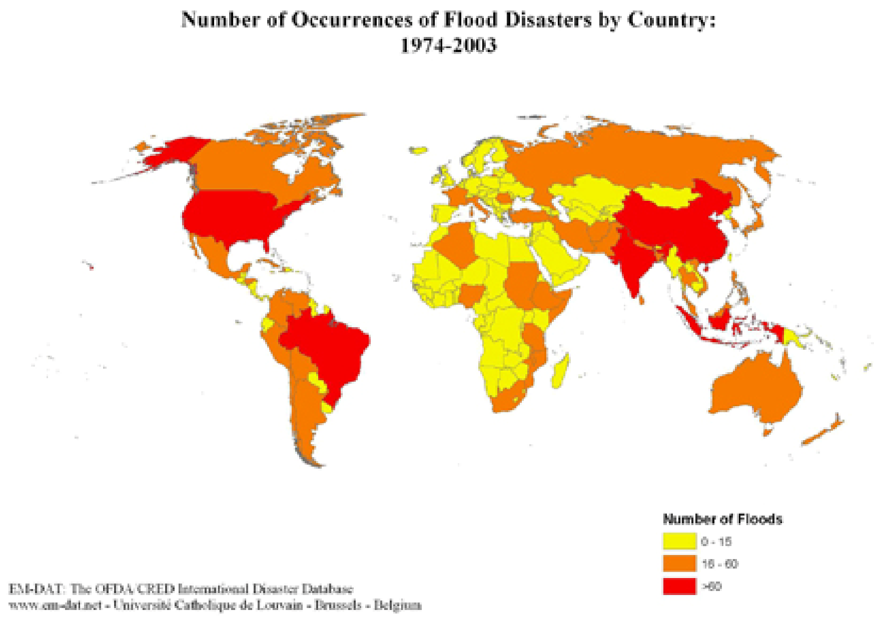

Fig. 2 Number of floods by country between 1974 and 2003 [2]

According to The Buoyant Foundation, any house that can be elevated can be made amphibious [27]. An executive committee composed of Benjamin Casper, Elizabeth English and Łukasz Piątek from the International Conferences on Amphibious Architecture, Design and Engineering declared:

> "Amphibious construction may also refer to one of several hybrid conditions. One such is where the weight of a structure is partially supported by both land and water simultaneously. Another situation is where a mechanical system as jacks or hydraulic pumps are used to elevate the structure temporarily. "Wetproofing" is another hybrid strategy, whereby residents occupy the first floor during dry seasons and move to an upper floor during periods of flooding" [5].

Through a type of renovation or adaptation of the original construction, this is a flood mitigation strategy that follows the natural flood cycles of a flood prone region. Necessary technical knowledge includes infrastructure issues, system components, mechanical systems, selection criteria and concerns with coding and certification.

> "The system consists of three basic elements: buoyancy blocks underneath the house that provide flotation, vertical guideposts that prevent the house from going anywhere except straight up and down, and a structural sub-frame that ties everything together. Utility lines have either self-sealing 'breakaway' connections or long, coiled 'umbilical' lines" [6].

Governments are realizing the potential for investment in urbanization of areas prone to flooding, such as plains between rivers and dikes that retain their waters, and releasing where construction was never allowed before. The proposals for the development of amphibious structures meet this opportunity and represent a promising architecture.

Some countries like Thailand have extensive experience with floods that happen every year during the monsoon season. For this reason, governments have announced measures such as "Thailand's Water Resource Management Strategy" which encourage construction cost effective amphibious houses for future urbanization [7].

The Netherlands Ministry of Housing, Spatial Planning and Environment, in a fifteen year program (2005-2020), purchased and set aside land as floodplain, mainly along the river banks. As almost a quarter of the country is recovered from the sea, while half is at or below sea level, there are several ideas for the use of water, and not just its defense with floating architecture.

IV. The Diversity of Floating Buildings Around the World

Humanity has been experimenting with floating typologies for more than 5,000 years. One of the oldest is in the swamps of southern Iraq, documented by the Sumerians. The Madan People (or Marsh Arabs) built houses out of reeds harvested from the complex of lakes, swamps and floodplains, near the Tigris and Euphrates in Mesopotamia [8]. It is also possible to consider that the buoyant architecture refers to a historical heritage from Noah's Ark.

Examples of floating home diversities can be found spread all over the world:

1) Vernacular adaptations built on wooden rafts and straw in Pacific Islands (New Zealand, Palau, Solomon Islands, Fiji) and on the banks of the Amazon River (Peru and Brazil);
2) Traditional houseboats in China, India, Thailand, Cambodia, Vietnam;
3) European canal boats in The Netherlands, Britain, France, Belgium, Sweden;
4) Floating home communities in North America (United States and Canada).

Fig. 3 Traditional houses on wooden rafts in Iquitos, Peru during the Amazon floods [9]

There are several floating residential communities that are concentrated in the Pacific Northwest of North America that each manages an average of 300 and 400 homes. Some of these marinas and communities in United States are in California, at Sausalito Floating Homes Association Inc. (Richardson Bay, CA) and further north on Bridgeton Neighborhood Association (Portland, Oregon). Due to the historic flooding in the Louisiana areas of the USA, even before the end of the 1970s, there were variations for floating foundations. In Canada, especially in the British Columbia (BC) region, there are several nuclei such as Canoe Pass Floating Village (Lander, BC); Fisherman's Wharf (Victoria, BC): Sea Village joined Granville Island (Vancouver, BC); Maple Bay Marina's float homes (Cowichan/Vancouver); and Toronto Float Homes (Scarborough Bluffs in Ontario). It means that this is a possible reality, which many people are already living in houses on the water and it is not a utopia.

A historical example is particularly interesting, since it was made by an important visionary architect, who realized how a resource such as a disused boat could meet a need for a social project. In 1929, the Salvation Army acquired the "Liege" barge, built in 1919 by the National Navigation Office for the transportation of coal. Le Corbusier was then called upon to prepare the restructuring project for this boat, sponsored by Countess Cantora de Polignac and Madeleine Zillhardt. This floating architecture was supposed to accommodate refugee women who were in the city of Paris after the First World War [10]. Unfortunately, with the increase in water levels in the River Seine, the barge was submerged in February 2018. As it was aged and unused, restoration work had already started since 2005. After the accident, a group of Japanese people resumed the restoration efforts, since some exhibitions on this work had been programmed. The "Asile Flottant JAPAN ARCHITECT Exhibition" was scheduled to be held inside the barge, in continuity with the exhibition that presented the restoration project in four locations, including Tokyo from August 5-22, 2017 [10].

Originally, the intention was for the barge to move and have different uses, according to the climate. In winter, it arrives in front of the Louvre Palace to shelter homeless people from the cold, removing them from the arches of the bridges. In the summer, it could take children to summer camps near Paris. The barge is composed of an 80-meter-long room, divided into three compartments. 160 beds were fitted out, a dining room, kitchens, toilets, sinks, showers, the sailor's apartment, the manager's apartment, and a hanging garden on top of the barge. Corbusier added modernist elements such as *piloti*, horizontal ribbon windows, and a flat roof terrace with greenery.

V. Seven Relevant Technological Case Studies

Traditional models of elevated houses called 'stilts' for areas prone to flooding have been built for a long time, but amphibious solutions are recent. The list of seven projects shows amphibious experiences for resilience to flood disasters, which, unlike the more traditional vernacular constructions, present a type of more technological construction solution.

Some projects have shown good results, such as those in the Netherlands, which has applied floating solutions at least since the 1990s. The selected case studies present elements that are important in adapting a floating architecture for amphibious communities. Table I lists the projects and its contributions to review proposals for areas at risk of flooding.

A. Floating Houses Maasbommel

- Location: Bovendijk, Maasbommel, The Netherlands
- Client: De Gouden kust bv: Dura Vermeer Infrastructuur in cooperation with Watersportcentrum Maasbommel
- Size: 120 m²
- Design Factor: Architecten/Dura Vermeer/Boiten Ingenieurs
- Year: 2005

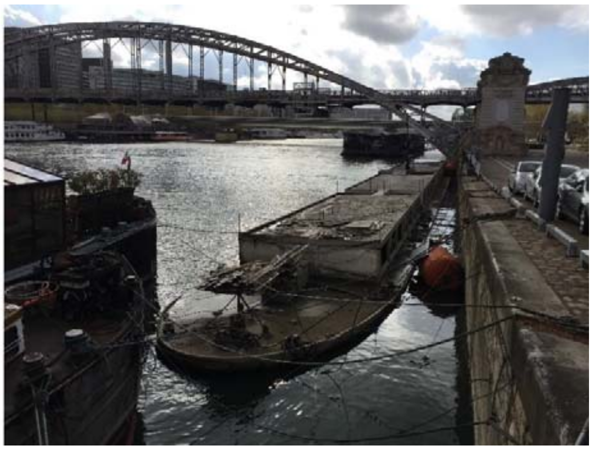

Fig. 4 Le Corbusier: Asile Flottant, 2018. Sunken [10]

TABLE I
PROJECTS AND CONTRIBUTIONS FOR AREAS AT RISK OF FLOODING

S.No	Author	Project	Location	Year	Contribution
1 A	Fator Architecten, Dura Vermeer	Floating houses Maasbommel	Bovendijk, Maasbommel, The Netherlands	2005-6	Village with 46 Houses: 14 floating and 32 semi-floating homes
2 B	Morphosis Team	Float House	New Orleans, Louisiana, United States of America	2007-9	Reconstruction after flood
3 C	Chuta Sinthuphan	Amphibious House	Chiang Mai, Thailand	2011-3	Four types of floating buildings to community's needs
4 D	Baca Architects	Amphibious House	Buckinghamshire, UK	2014	House that rises up in its dock and floats there buoyed by the floodwater
5 E	Atelier2	Tintero Boat Restaurant	Torretta di Legnago, Verona, Italy	2014	Technology to floating architecture
6 F	Koen Olthuis and Waterstudio	Floating City Apps for Wet slums	Rijswijk,The Netherlands shipped to Dhaka, Bangladesh	2014	Floating containers for urban services
7 G	Elizabeth C. English and Buoyant Foundation Project	GRP Vietnam Retrofits	Mekong River Delta, Vietnam	2018	Amphibious foundation retrofits

Description

The set of 46 houses consists of two types: 14 permanent floating houses that are on the water by means of a concrete floating body and 32 amphibious houses that float only when the water level rises. These houses rest with a floating concrete body on a concrete pile base and are driven vertically with high water with strong steel piles. Connections for gas, water, sewage and electricity are flexible and continue to operate on the high seas.

Sold for around 320,000 euros, while average residential house was around 222,000 euros in 2005, these recreational houses were considered expensive for Dutch standards. Dura Vermeer offered a 15 year guarantee for the floating ability, but there is still a fear of people investing in the risk involved due to the application of new technologies [11]. In this case, the waters rise a lot only once every 20 years on average. There was a flood in February 2011 and the project was tested. That study was based on projections indicating that the water level will rise by more than 70 cm once every five years. The homes can withstand swings of up to 5.5 meters. They were designed between 1998 and 2004 and constructed between 2004 and 2005. This project won the Water Living & Space Award professional prize, during the National Water Living & Space Congress on September 8, 2010 in Almere.

Program

The barges are approximately 2 meters high and can be used as basements or, if part of the house has two floors, as bedrooms.

Fig. 5 View of the Floating houses Maasbommel [12]

Floating Solution and Materials

This is a very robust project: concrete barges weigh 72 tonnes each, while the wooden frame buildings weigh around 22 tonnes. Low center of gravity ensures stability. The concrete barges are made of ordinary concrete with an aggregate to make them waterproof. The joints are reinforced with an additional water-resistant sealing strip.

B. Float House

- Location: New Orleans, Louisiana, United States of America.
- Client: Make It Right Foundation
- Size: 945 ft²/88 m²
- Design: Morphosis Team
- Year: 2009

Description

The floating solution seeks to meet the needs of water related disasters, such as Hurricane Katrina. It is an example of mass-producing low-cost homes suitable for flood responses.

The community acceptance was to include the typology of the shotgun house, common from local culture of the neighborhood of Lower Ninth Ward, in New Orleans. This house also meets sustainability requirements, once it can sustain its own water and power needs [13].

Program

This single-family residential unit follows the shotgun house style, a New Orleans residential type. Spaces such as the living room, kitchen, bedrooms and bathrooms are lined end to end on a 16’ x 58’ bar and accessed by a hallway.

Floating Solution and Materials

The prefabrication consists of a single modular chassis in expanded polystyrene foam clad in fiberglass reinforced concrete, with all necessary wall fixings, electrical, mechanical and hydraulic systems pre-installed. This module is transported in its entirety from the factory to the site.

The remainder for the structuring, i.e., the pillars and concrete blocks on which the chassis rests, are constructed on site using traditional labor and construction techniques.

The paneled walls, windows, interior finishes and the roof set are prefabricated and must be assembled on site along with the installation of accessories and appliances. This approach integrates modern mass-production and reduces waste.

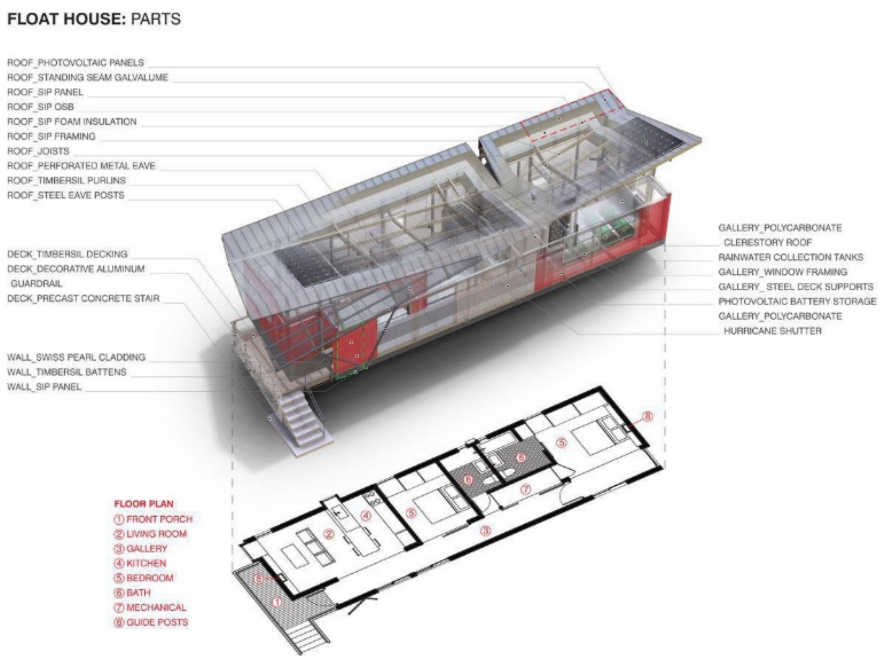

Fig. 6 Parts of Float House (Drawing by Morphosis Team) [13]

C. Amphibious House

- Location: Chiang Mai, Thailand
- Client: National Housing Authority
- Size: 100 m²
- Design: Chuta Sinthuphan and Site-Specific Co. Ltd. and Prefab Laboratory
- Year: 2011-13

Description

The architect was inspired by traditional houses in southern Thailand, built on stilts and rafts. He proposes a modular and prefabricated steel framing architecture to make it lighter and float.

The construction system can be divided into different parts and can happen simultaneously, with one part being done on-site and the other being done in a factory, it will increase the efficiency of the construction system.

This house was completed for 2.8 million baht (US $86,000) in the village of Ban Sang. It was tested in September 2013 and rose 85 cm (2.8 feet) when the large underground space under the house was filled with water. The prototype was used as an office for a while but then was unoccupied.

Program

Four different types of buildings have been designed to accommodate most of the community’s needs, including a residential, commercial, hybrid-commercial building and civic buildings. A plan was made to organize new buildings in mini-communities made up of 5 to 10 buildings, so that families can help each other during the flood before help arrives.

Floating Solution and Materials

Undercarriage made of buoyancy tanks is placed under the house. Sliding columns allow the house to rise and fall with the water level. Guideposts and pontoons filled with Styrofoam can elevate the building up to three meters.

The flotation system is underground, leaving it hidden while it is dry, it allows collecting rain water that accumulates in the ditch and the house starts to float before major floods occur.

The house is also self-sufficient as it includes solar panels, rainwater harvesting and turbines. The house would be anchored to the lake shore, complete with electricity and flexible piping [14].

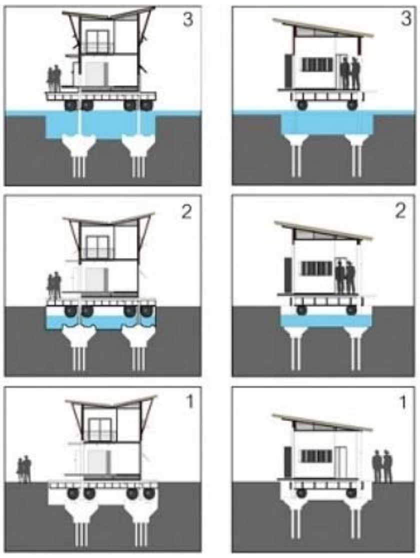

Fig. 7 Prefabricated steel floating system of Amphibious House (Drawings by Site-Specific Co. Ltd.) [15]

D.Amphibious House

- Location: Located just 10 m from the edge of the River Thames in Buckinghamshire, UK
- Client: Private
- Size: 225 sqm
- Design: Baca Architects with a houseboat company
- Year: 2014

Description

It is the first amphibious house in the UK, which is often affected by rainfall and floods. Baca's research through practice has led to the appointment of Richard Coutts to the HM Government's Flood Advisory Group. This British studio performed other works with this focus later, however this project has won multiple awards, such as the 2014 London Design Award for Innovation.

Program

This is a luxury dwelling with three bedrooms. The floating basement provides a utility room, study, dining room and cinema room with the entertaining spaces and bedrooms arranged over a further two upper floors.

Floating Solution and Materials

The building sits in a wet dock and rises as the water table collects and elevates the house during flood situations. The house is supported by a concrete hull creating a 'floating pontoon', situated between four permanent vertical guides. These vertical posts keep the house fixed so it does not float. The building can oscillate more than 2.5 m, an amount greater than the expected flooding level, considering climate change.

The zinc shingles, which cover the walls and the roof, allow an aesthetical aspect that resembles the scales of an amphibian animal, while protecting it from water.

E. Tintero Boat Restaurant

- Location: Torretta di Legnago, Verona province on the banks of the Bianco Fissero Tartaro Canal, 135 km waterway that connects Mantua to the Adriatic Sea, Italy.
- Client: Private, Giancarlo Battilani
- Size: 200 m^2 (25 x 8m)
- Design: Atelier2, Imperadori e Gallotti and Minimal (contractor).
- Year: 2014

Description

This example explores the tourist and commercial potential of a river channel called Idrovia Padana, formed by the Fissero-Tartaro-Canal Bianco Rivers that connect the city of Mantua to the Adriatic Sea with Porto Levante - Isola di Albarella. The location of this floating restaurant, in a region of Veneto still little explored, allowed to verify that places where the very slow waters can allow not only navigation, but also the floating architecture [16].

The office Atelier2 in collaboration with Giancarlo Battilani and Minimal (contractor) built the Tintero Boat experience, measuring 88 m². They had the challenge of constructing this building on the waterfront with 2 floors, near the Renzo Piano Aquarium, in Genoa, Italy.

Program

The restaurant is composed of a small veranda corresponding to the lounge bar and the dining room overlooking the river with large windows and the service spaces facing the continent.

There are three rooms, two small, one dedicated to Pier Mondrian and one to Macau with a big painting by Carlos Marreiros, and one big room with a big fish painted by Ugo Re.

Floating Solution and Materials

The structure is metallic and consists of two watertight floating boxes. The system is made up of hermetic boxes, on which a horizontal deck rests and steel frames in standard profiles.

The envelope is made by Isopan (polyurethane sandwich panels) for the outside shell and roof (metal insulation panels against thermal dispersion for buildings), inside is gypsum boards made by Knauf, so the ceiling is made of special microperforated plasterboard sheets with the addition of zeolite for internal acoustic effects. Bamboo elements provide shading around the perimeter, protecting the large windows.

Photovoltaic panels complement the restaurant's energy supply. It has sealed chambers that can be used to house the systems and for the accumulation of waste water, so that the connection to the sewer system can be discontinuous.

Fig. 8 Metal structure during construction of Tintero Boat Restaurant (Photo by Giancarlo Battilani and Minimal) [17]

Fig. 9 View of Calypso (Photo by Giancarlo Battilani and Minimal) [18]

F. Floating City Apps for Wet Slums

- Location: Rijswijk, The Netherlands shipped to Dhaka, Bangladesh
- Client: Floating City App Foundation
- Design: Koen Olthuis/ Waterstudio
- Year: 2014

Description

Today, there is probably no one more experienced in floating architecture than Koen Olthuis of Waterstudio. Also known as the "Floating Dutchman", he has built more than 200 floating homes and offices through Waterstudio, which was founded in 2003 [19].

Koen Olthuis graduated from Delft University of Technology and is PhD fellow of the UNESCO-IHE Flood Resilience chair group. In an interview with The New York Times, he presented his idea of the future of housing and advocates that in 20 years cities are going to be different than today [19]. He reflects that we are always looking for more space, to densify cities. Unlike waste landfills, which cost a lot and negatively interfere with the aquatic ecosystem, floating ones are much simpler to build.

When challenged to consider the plight of the needy population living in areas prone to flooding, he suggested Floating City Apps. These are installations in floating containers as urban components with flexible and reusable functions. To implement the project, after the diagnosis of the local problem of the favela had been identified, a network of local consultants (hydraulic engineers) opened the way for partnerships with NGOs, embassies of universities and local politicians. The pilot application in Bangladesh was scheduled for 2017, next to Banani lake, adjacent to the Korail slum with 40,000 inhabitants, in the capital, Dhaka. It seeks sponsors to provide internet and join the foundation he created (Dutch Docklands) that receives funding from Dutch partners.

Program

This concept of application city is based on the volatile need to use some services (equivalent to software) that are exchanged when satisfied. It reproduces all the complexity of a city in a floating version: social housing (shelters), floating schools, etc. For sanitation, it floats sewage filters (water); for energy, solar collectors and floating agricultural land (food).

The first prototype was developed as a Communication App, with 20 tablets and two TV screens, serving as a social and educational platform that connects favela residents to the Internet. The application has the ability to provide a multifaceted platform that ranges from businesses and enterprises, communication center, education of children to digital craft market, education and training for women, and health education. The interior of the application has a built-in wall unit that covers the digital equipment, which allows maximum space.

Floating solution and materials

The standard sea-freight container must be transported from The Netherlands to the slum. The bench was made in Corian due to the sponsorship established.

Locally, the floating foundation will be built from collected used PET bottles supported by a steel frame.

Fig. 10 View of Floating City Apps [20]

G.Global Resilience Partnership (GRP) Vietnam Retrofits

- Location: Mekong Delta, Vietnam
- Client: Private
- Design: The Buoyant Foundation Project
- Year: 2018

Description

Elizabeth C. English and her team in the Buoyant Foundation Project research amphibious foundation retrofits to build resilience in vulnerable communities. There was a research stage by the Canadian project team that worked in Vietnam. They chose four houses that were in places vulnerable to flooding and made the renovations. A Vietnamese team was responsible for monitoring when floods occur. Post-flood interviews collected data on what the residents detected.

The aim is to propose a simple solution using low cost materials so that it can be easily reproduced by local people.

Program

This was just the retrofit that adapted four houses in two rice-growing communities: two houses in An Giang Province and two in Long An Province, both in the Mekong Delta, Vietnam. In the summer of 2018, monitoring was carried out to collect wind and movement data and calibrate floating stability to determine foundations.

Buildings are fitted with guide rails, a buoyant base and an anchor to not move laterally when it rises.

Floating Solution and Materials

They consulted with local villagers and carpenters to select inexpensive and recycled materials for the retrofits. So, they used gallons of water to float the buoyant base and details of moorings on the structure. The guide rails were made in a metallic tubular profile.

Fig. 11 GRP Vietnam Retrofits during a flood [21]

VI. Performance Achieved by the High Points of the Projects

The best aspects of the examples demonstrated the following requirements for adapting buildings to flooding:

Benefits of a floating building:

- The buildings are constructed on a floating foundation that can be stabilized by fixed stilts. This makes them flood proof and more accessible;
- They can combine engineering the submerged foundation below with floating house vernacular, with regional materials and methods above.
- Cost effective amphibious houses are an alternative to conventional elevated houses.
- Boats and containers can be renovated and adapted to the vernacular characteristics of dwellings in areas at risk. The reuse of buildings not only generates savings in construction costs, but reduces the impacts of waste from the environmental point of view.
- It may seem obvious, but the big advantage of these buildings is that residents can stay at home during the flood [22].

Critical and possible problems offered by a floating building:

- They must obtain building and planning permissions according to the location;
- If it is mobile like a boat, it is subject to storms and accidental collisions;
- It is subject to strong external loads due to wind, rain, ice and other environmental conditions;
- Applicability will depend on the type of material and the weight of the construction;
- They have to consider some type of access to the underside for the maintenance of hydraulic systems;
- The height of the mooring post limits the house, which cannot be built as a multi-stored building.

Such comparison allowed to glimpse opportunities for innovation in amphibian architecture.

VII. Strategies for Applying Innovative Technology

The proposed strategy for communities that are in areas prone to flooding is to live with water, do not fight it. However, it is crucial that projects are adequate to withstand flood situations.

The suggested design guidelines are:

- The solution needs to provide flexible and immediate responses in areas that are frequently flooded (as an average, return periods lower than 5 years with inundation depths 0.6 m and beyond) enough to accommodate higher inundation levels;
- Amphibious solutions (which allow the building to float when the water level rise) are preferably applied if the water depth is > 0.6 m and < 4 m). Other technologies may vary between: dry proofing (if < 0.3 m); wet proofing (if between 0.3 m - 0.6 m); or elevated (if between 0.6 m – 2.5 m) [23];
- The structure's buoyancy system can be made with various materials: hollow concrete or steel tanks, Styrofoam, polystyrene, plastic or fiberglass pillows, bamboo or wood logs and even barrels combined to form a base under the house. This design solution makes the building float, which can be a barge, raft, platform or hull.
- In addition to the base, it must have a vertical guidance system to ensure that the foundation moves and returns to the same location, preventing any horizontal movement.

- It differs from a boat house because it does not have motor. However, they are mobile, so they need to be towed over long distances or maneuvered manually for short ones.
- To ensure durability and resistance to water deterioration, it is necessary to meet requirements that can be checked by a marine surveyor or professional engineer: flotation devices are subject to mechanical damage due to floating debris, electrolytic action, water-borne solvents, organic infestation or physical abuse [24].

Case studies have shown that many initiatives are still very expensive and require an investment that considers this as a measure with medium and long-term returns. Despite the cost of amphibious adaptation surpassing conventional construction, compared to other flood mitigation strategies, it is a worthwhile investment considering its good performance in loss prevention studies [25].

According to the studies carried out, the conclusion is a proposal for technological transfer in places affected by floods for low cost solutions: half public and half private. This proposal consists of three key technical aspects:

1- Foundations: Made with conventional materials like steel or concrete, this is what ensures the stability of the house on the ground. It can be provided by the State.
2- Anchoring and floating: It can be a mixed solution, where, for example, the State guarantees the anchoring made by the large poles, which must be of sufficient height when the waters reach the maximum level of flooding. Private institutions or collective financing can provide the execution of the structure that guarantees the fluctuation, which can be made with different materials, including reuse and low cost.
3- Safe house: This is the private part, which is customized according to the local culture. The components that guarantee the floating and anchoring are attached to the base of the house.

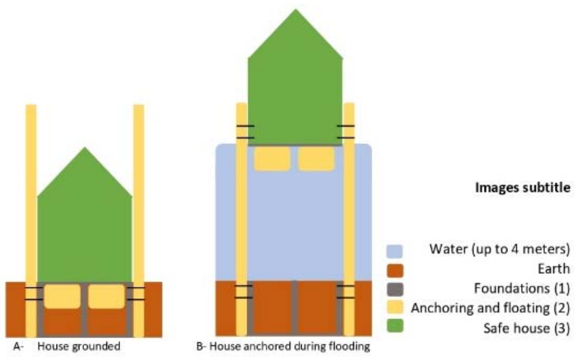

Fig. 12 Drawing studies by the author

VIII. Conclusion

The constructive methods of amphibious building are a viable technology that can change the scenario of risky housing in the near future. There is the challenge of adapting existing buildings in a transition phase, which may represent a change to occur in the coming decades.

"Properly designed and monitored projects for repairing and retrofitting houses can drastically improve the reconstruction process in terms of cost, environmental impact, speed, supply of resources, community participation and satisfaction, recovery of psychological wellbeing, and heritage conservation" [26].

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