AMPHIBIOUS ARCHITECTURE: AN ALTERNATIVE FLOOD MITIGATION STRATEGY FOR THE AMAZON REGION

Arquitectura anfibia: Una estrategia alternativa de mitigación de inundaciones para la región amazónica

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RESUMEN

La intensificación del ciclo hidrológico de la Amazonía debido al cambio climático ha vuelto inadecuados los métodos tradicionales de elevación estática, como los «palafitos», lo que ha ocasionado graves pérdidas socioeconómicas y desplazamiento de poblaciones. Esta investigación explora la arquitectura anfibia —estructuras que descansan sobre el suelo pero que se elevan con el ascenso de las aguas de inundación— como una estrategia de mitigación sostenible. A partir de implementaciones exitosas en el delta del Mekong en Vietnam, el estudio propone una readaptación de bajo costo para las viviendas tradicionales amazónicas. Estas edificaciones, ya elevadas sobre pilotes, pueden ser modificadas mediante plataformas de flotabilidad fabricadas con plástico reciclado y postes de guía vertical elaborados con maderas duras locales, como el huacapú. Más allá de su viabilidad técnica, las readaptaciones anfibias ofrecen importantes ventajas culturales y económicas al prevenir el reasentamiento forzado y preservar la relación espiritual ancestral entre las comunidades y el río. A diferencia de los diques, que resultan intrusivos, esta estrategia pasiva actúa en armonía con el ecosistema. No obstante, las corrientes de alta velocidad de la Amazonía, que alcanzan los 7 km/h, plantean importantes desafíos de ingeniería en cuanto a las fuerzas laterales y la durabilidad estructural. El estudio subraya que, si bien el potencial de resiliencia es elevado, se requieren refinamientos técnicos. En consecuencia, es necesario desarrollar el tema con mayor profundidad, con una visión técnica y realista que se adapte a las condiciones hidrográficas de cada localidad.

ABSTRACT

The intensification of the Amazon's hydrological cycle due to climate change has rendered traditional static elevation methods like "palafitos" inadequate, leading to severe socioeconomic losses and human displacement. This research explores amphibious architecture—structures that rest on land but rise with floodwaters—as a sustainable mitigation strategy. Drawing on successful implementations in Vietnam's Mekong Delta, the study proposes a low-cost retrofit for traditional Amazonian dwellings. These houses, already raised on stilts, can be modified using buoyancy platforms made of recycled plastic and vertical guidance posts crafted from local hardwoods like Huacapu. Beyond technical feasibility, amphibious retrofits offer profound cultural and economic advantages by preventing forced resettlement and maintaining the ancestral spiritual relationship between communities and the river. Unlike intrusive levees, this passive strategy works in harmony with the ecosystem. However, the Amazon's high-velocity currents, reaching 7 km/h, present significant engineering challenges regarding lateral forces and structural durability. The study emphasizes that while the potential for resilience is high, technical refinements are required. Consequently, it is necessary to develop the topic in more detail with a technical and realistic vision that adapts to the hydrographic conditions of each location.

Figure 1
Khoury "Life on the Amazon waters"

1. Introduction - Global warming and flooding

For centuries, communities have settled near the floodplain of the Amazon River and its tributaries (fig. 2) adapting to its annual rise and fall, whether it is for access to drinking water, food production, transport or to search for moderate temperatures (English, Klink & Turner, 2016). Using ancient construction techniques, these communities-built structures which could endure the usual flood periods of the river.

However, since the 1990s there has been a considerable intensification of the hydrological cycle of the Amazon due to climate change and its effects on rainfall and water rise (Towner, 2021), leading to an increase in the frequency and severity of flood events.

Figure 2
Marticorena "Amazon region diagram"

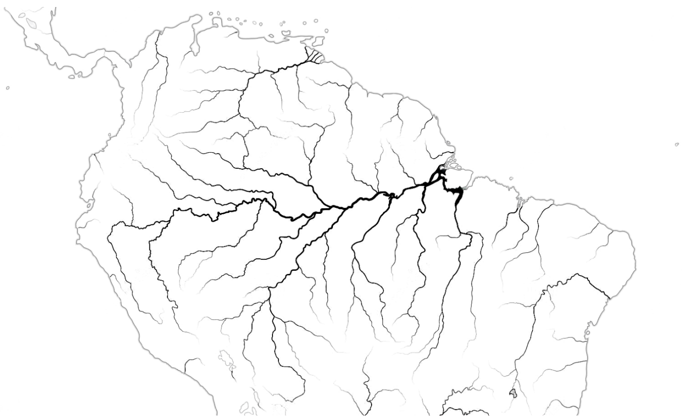


Figure 3
Odyssei "World map of Amazon selva region in South America"

Recent analysis on the topic indicates that factors such as climate change, deforestation and widespread fires are negatively influencing the natural water cycle in the Amazon region (fig.3) (Lovejoy & Nobre, 2018). Some examples of this inflection point in the Amazon's climate are the droughts of 2005, 2010 and 2015-2016, which along with the torrential floods of 2009, 2012 and 2014, constitute undeniable proof that the region's ecological system is failing (Marengo & Souza, 2018). In addition, a new extreme flood in the Amazon Basin was reported in June 2021, registering water levels above the emergency threshold of 29m, "surpassing even the previous historical flood of 2012." (Espinoza, Marengo, Schongart & Jimenez, 2022). This unprecedented succession of extreme floods in a short time period is clear evidence of the abrupt increase in the water levels, which are caused by climate change and other human induced factors that have only become worse in the last decades.

The sudden alteration of the river's water level puts local communities in danger, incapacitating the structures that once withstood the annual flooding conditions. The extreme floods have "large socioeconomic consequences impacting ecosystems, health, and transport links, and are particularly damaging agricultural and fishery practices." (Towner, 2021). Similarly, over a 4-year period from 2008 to 2011, flood events caused damage estimated at 1.4 billion US dollars in the Rio Branco basin, a tributary of the Amazon River in Brazil (Mundial Grupo Banco, 2014). These are only a few instances in which the infrastructure of numerous small towns is affected and even destroyed by flood events, many times causing people to lose their homes, and producing a large cost of rebuilding on the damaged areas.

A flood event can be measured and classified in a technical manner, for example by analysing the river discharge, however, it is important to consider its tremendous social impact. Apart from the economic loss, the destruction of different building types and, the increasing gravity of flood events is leading to the loss of human lives (Case, n.d). The increasing mortality rate is what makes, for example, the floods of 2007 and 2008 along the Mamoré and Guaporé rivers especially catastrophic. Both floods reported a number of over 250,000 people affected, and resulted in 49 deaths (CEPAL, 2008). In Brazil there have been 1040 deaths due to storm and flood disasters from 2010 to 2019, which compared to the 134 deaths registered in the 2000 to 2009 reports (Cuoto, Sanchez, Nobre & Avala, 2022), highlight that the issue is only getting worse. Leaving the enormous economic loss to the side, the increasing number of fatalities left by extreme flood events call for a sense of urgency when dealing with the problem, as it is no longer a matter of reconstruction, but one of survival.

On a global scale, this increase in sea and river levels has led to the spreading of traditional flood mitigation strategies. These strategies involve modifying existing buildings or creating new ones in order to have inhabitable spaces raised above the water level in the event of a flood. The most common mitigation measures include the construction of terp dwellings, which sit above an artificially earthwork mound, pile dwellings which are built above columns or stilts, and static elevation dwellings, which are regular small-scale residences retrofitted with stilts to be raised from the ground level (Anderson, 2014). In the tropical zones of South America, the traditional pile dwellings are known as "Palafitos", which for years have been used by people from the tropical river valleys of South America to endure the rise of river levels in the flood season and protect the inhabitants from the wildlife in the ground floor (Garcia, 1991).

Even though these methods have proven effective in the past in areas of high flood risk around the world, they cannot cope with the aforementioned unpredictable and rapid increase in the severity of flood events which threaten the possessions and lives of hundreds of thousands of people.

Other great scale approaches that are usually implemented in large cities to prevent flooding include levee and dyke building. These approaches function by altering the environment and the flow of the water, but, in spite of their high price and complexity, they can bring catastrophic consequences. In the long-term, the eventual failure of these strategies can cause tremendous destruction to the affected cities. A clear example is the flooding disaster in New Orleans in 2005, where, due to compound failures of the levee system, around 80 % of the city was inundated (Liu, Fellowes & Mabanta, 2006). Having seen the failure of the common building types to endure flooding and the large-scale infrastructures to combat it, it is clear that there is a need for an innovative strategy that can maximise the safety of people at risk and minimise the construction costs to be suitable for the most vulnerable areas, strategy which will be examined in this essay.

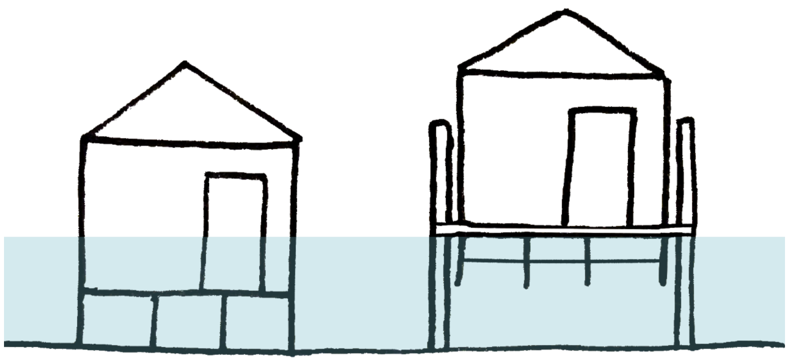
2. The amphibious alternative

Taking into consideration the inevitable failure of conventional mitigation strategies, the solution might come in the form of amphibious architecture. This architectural type grew in popularity because of the rapid rise of global sea levels, especially in relatively flat countries of low altitude. It consists in the construction of a dwelling which sits on land on the periods of low water but rises within the periods of high water, floating above the riverbed. Amphibious dwellings incorporate a buoyancy system beneath the house to provide flotation, and have a vertical guidance system, which restricts horizontal movement and allows the dwelling to return to the same position upon descent (fig.4) (English, Chan, Doberstein & Tran, 2020). It is in this way that an apparently ordinary structure can rise freely above the riverbed to an indefinite height, avoiding the consequences of flooding. According to Portocarrero, J (personal communication, October 15, 2025) a floating infrastructure was successfully used before at the dock of Talisman Petrolera del Perú, LLC, Peru Branch, for oil exploration activities on the Morona River where itś main objective is to support the logistical operations of loading and unloading. The pontoon was constructed with floating elements and piles in the form of tilting walkways, allowing it to change height with fluctuations in the river level. The main support structures were the piles. Their design took into account the forces acting on the piles, the water depth, the flow velocity, as well as the variation of both due to changes in depth. All these design considerations were used to determine the diameter and length of the piles and their material.

It is important to note that constructing this type of structure requires permits from the relevant authorities in the location and country where it is installed, including compliance with workplace safety criteria.

Figure 4

Marticorena "Static elevation vs Amphibious dwelling" (Amphibious dwelling)



A retrofit variation of this strategy has been utilized globally in flood-vulnerable populations with similar climatic, economic and social conditions to the marginalized communities of the Amazon region. Examples of amphibious strategies including the design of buoyant foundation retrofits for cities and communities such as Dhaka in Bangladesh, Malacatoya in Nicaragua, Port Maria and Bliss Pastures in Jamaica and the Mekong River Delta in Vietnam have proven to be effective as disaster mitigation measures (English et al., 2016). Due to testing in areas less developed in the economic and built environment, which will be explored to depth in this chapter, it is clear that, with the proper adaptation of materials, amphibious housing can be the adequate alternative to alleviate the risks of flooding for communities along the Amazon region.

2.1. Case Study: Amphibiation in the Mekong River Delta, Vietnam

In Vietnam, similarly to territories in the Amazon region, water is part of everyday life because of the existing complex system of rivers and canals which weave through the region (English, Chen, Zarins & Humenyuk., 2018). Due to the abundant presence of water, climate change is creating major challenges at a national level for the populations of flood-prone areas. One of the most affected areas is the Mekong Delta, a low-lying plain home to over 17 million people, located less than three meters above sea level and with a high susceptibility to disastrous floods

(English et al., 2018). Considering the similarities between the Amazon region and the Mekong River Delta, including both the presence of water and the extreme flood risk, it can be argued that the amphibiation strategy implemented for the flood prone communities in Mekong is directly relevant to the development of an amphibious flood mitigation project in the Amazon.

Due to the high importance of the area in terms of population, commerce and agricultural activities, the amphibiation initiative for the Mekong River delta received funding from several non-profit organizations, such as the Global Resilience Partnership and the Z Zurich Foundation, in addition to aid from government agencies (English, Chen et al., 2018). The Mekong Delta is home to 22 % of the national population of Vietnam, and, although the flood season can be beneficial for agricultural and aquaculture production, year after year storms and flood events put millions of people's lives and homes at risk (English, et al., 2020). The majority of the staple food and fish which is distributed to the rest of the country is provided by the Mekong Delta region to the point of this area being considered Vietnam's 'rice basket' (English, et al., 2018), which only highlights the value of the area in agricultural and aquacultural food production.

Parallel to the Mekong Delta, the Amazon region has also an immense value due to its natural resources being referred to as the "cradle of origin of important crops consumed both locally and worldwide" (Iriarte, Elliot, Maezumi, Alves, Gonda, Robinson, De Souza, Watling, Handley., 2020). The unmatched significance of the Amazon region in terms of its natural resources and economic activities make an amphibious retrofit strategy more than adequate a cause to have national and international funding for, in order to improve the quality and reach of the project.

In search of a mitigation measure for the area, the Buoyant Foundation Project, a non-charitable organization founded by professors, alumni and students of the University of Waterloo, designed a friendly amphibious retrofit strategy to implement on the residences in constant flood risk (fig.5). The concept behind the retrofit is to provide a sustainable and simple supplementary system to the existing dwellings raised on wooden stilts. The system was entirely built by local carpenters and inhabitants from the area, emphasizing the simplicity of the design. The friendly and simplified nature of the retrofits would allow for the creation of a standardized amphibiation method, which can be reproduced and expanded throughout the country (English, et al, 2018). With the proper design adaptation, this method being put to practice in the vulnerable areas of the Amazon region could represent the solution to the constant crises that extreme flood events leave behind.

Figure 5
Marticorena "Vietnam amphibious retrofit"

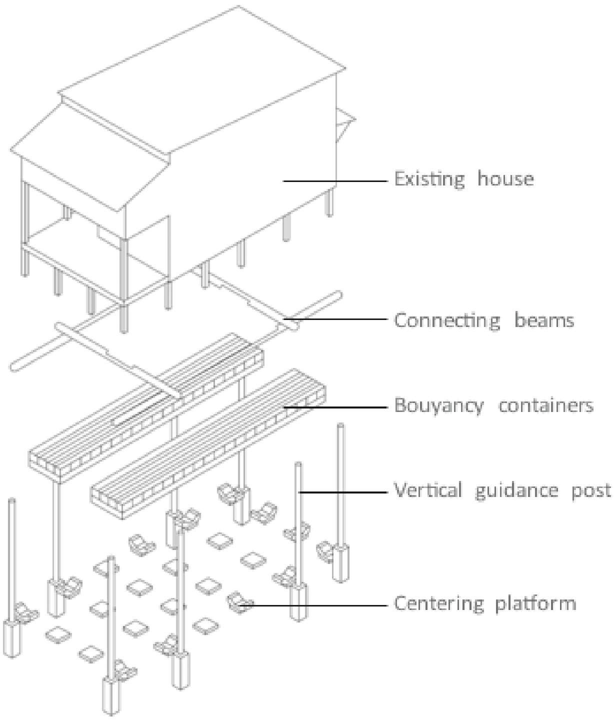


Figure 6
Marticorena "Vietnam amphibious retrofit"

The construction scheme implemented for the retrofits (fig.6) includes a reduced number of elements, making it ideal for the marginalized populations of the area. The scheme consists mainly of recycled buoyancy containers to maintain the structure afloat, steel guidance posts anchored into the ground to guide the structure on the vertical axis while eliminating its movement on the horizontal axis, and centering devices to safely direct the existing house stilts into their normal position when the water level drops (Anderson, 2014). The limited number of parts and materials allow for an easy elaboration of the retrofits, with the involvement of local carpenters and engineers (English, et al., 2020). Due to the scarcity of economic resources in the Amazon region, the concept illustrated in the Mekong Delta proposal of elaborating the retrofits with essential components only and by using sustainable materials greatly minimizes the building cost, therefore making it highly applicable to the flood mitigation developments to be implemented.

2.2. Principles and key details

Four retrofit constructions were developed in the project, for four different static elevation houses, each one varying in shape and dimensions. However, when dissecting each retrofit strategy there are certain common elements that stand out as the key elements, defining amphibious dwellings (fig. 8). These core elements are the essential requirements to construct a simplified retrofit design strategy.

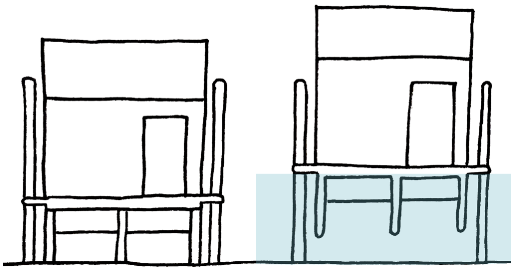


Figure 7
Marticorena "Amphibious elevation diagram"

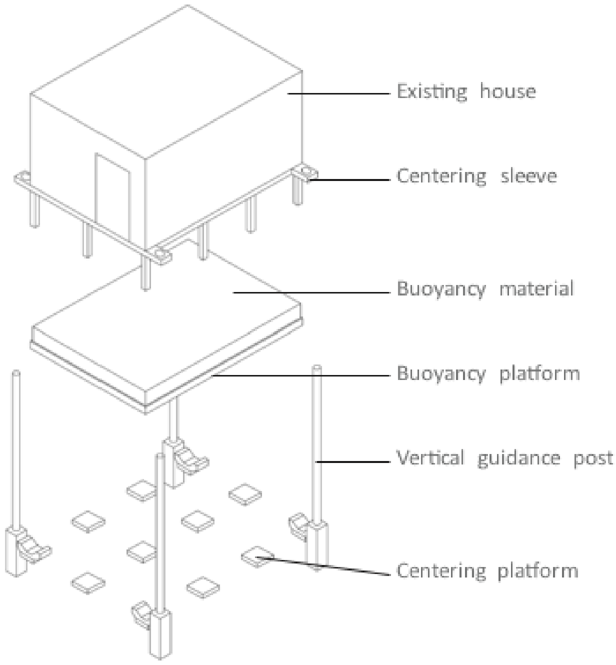


Figure 8
Marticorena "Dissected amphibious retrofit"

existing house to the guidance posts, allowing for a controlled and restricted vertical movement of the dwelling. The centering platforms, which control the descent of the house into the ground and provide a solid base for the existing house foundations to alight when the water level drops. The buoyancy system, which is what maintains the house afloat in the event of a flood that exceeds the height limits of the existing static elevation strategy. And finally, the buoyancy platform which serves to contain and evenly distribute the chosen buoyancy elements below the house. These five elements are the minimum requirements to allow for a secure vertical displacement of a small dwelling (fig.7).

The existing design of the dwellings in the Mekong River Delta is ideal for the implementation of a simple amphibious retrofit strategy. According to English, Tien, Trucc, Tran & Tran, (2018) houses in the Mekong Delta area are traditionally raised on stilts above ground level to mitigate property damage during flood events. Even though the mentioned static elevation strategy of these houses is no longer adequate to protect the residents due to climate change and its effects on the water levels (English, Tien et al 2018), the elevation of the houses serves to accommodate the buoyancy system in the resulting space between the ground and the structure of the house. This design characteristic can also be seen in the conventional unifamiliar dwellings of the Amazon rainforest, and it facilitates the incorporation of an amphibious retrofit strategy.

3. Amphibious possibilities in the Amazon

To set the scene for the possibility of a widespread amphibiation strategy for extreme flooding in the Amazon region, it is important to analyze the building types and construction methods in the area. By knowing the main characteristics that define the typical single family residential dwelling in the Amazon, it is possible to start conceptualizing an amphibious retrofit to fit accordingly, prioritizing the use of local and recycled materials.

3.1. The traditional Amazonian dwelling

What is considered the traditional Amazonian dwelling (fig. 9 & 10) is a perfect example of architecture that responds to the site. The design of all the elements of the house is a direct result of the natural conditions of the area. Examples of this are the leaf covered roofs used to insulate the interior of the house from heat and the sloping shape of the roof to direct the falling rain (Villanueva, 2020). Arguably, the most characteristic aspect of the Amazonian residence is its ground floor, which is lifted on stilts to avoid the dangers of the rainforest, which come in the shape of rising water or the diverse wildlife (Proyecto Araucaria XXI Nauta, Agencia Española de Cooperacion Internacional., n.d.). The constant natural difficulties present in the Amazon region have led to the creation of an architectural type to solve these issues, a type which for the purpose of this investigation will be analyzed in terms of its suitability for the implementation of an amphibious retrofit.

Figure 9
No author (2023) Almanaque, Casa Selva, Ediciones Abebul

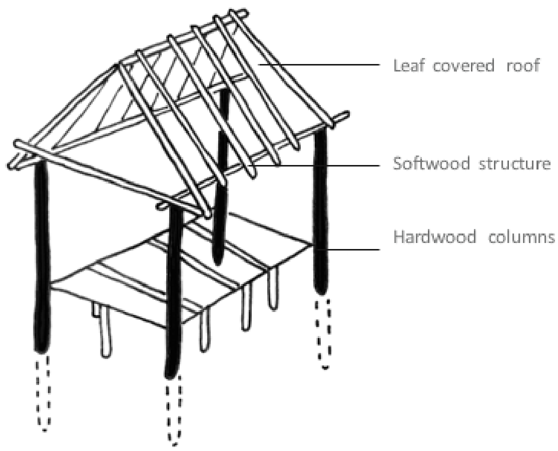


Figure 10
Marticorena "Traditional Amazon dwelling"

The primary structure of the typical Amazonian dwelling, similarly to the one of the houses of the Mekong River Delta, allows for an easy implementation of a buoyancy strategy. The first and most important element of the Amazonian dwelling are the columns, called "horcones" by local builders. These columns are buried into the ground, and constitute the only load bearing element of the house, supporting the floor and roof (Olortegui, 2015). As said by Olortegui (2015) said columns raise the wooden floor of the typical house in the Amazon region by one meter above the ground. According to English (2018), in order to accommodate a buoyancy system beneath a dwelling, said structure needs to be raised approximately one meter above ground level. The existing configuration and floor height of the house facilitates the attachment of a buoyancy system, saving the costs of any additional modifications that would need to be applied to a conventional dwelling sitting at ground level.

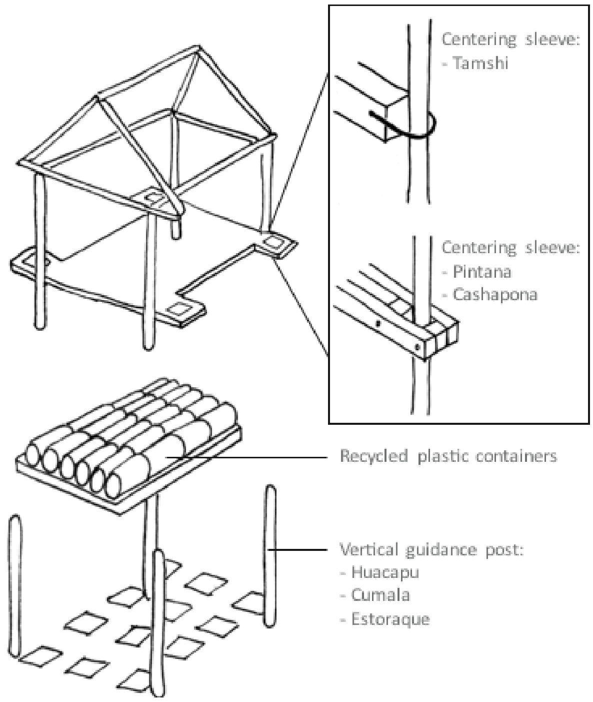
The materials of the traditional dwelling are compatible with the design of the amphibious retrofit, due to their qualities regarding weight, resistance and durability. As the stilts carry most of the load, they are conventionally made out of local varieties of heavy hardwood, such as "Huacapu" (*Minquartiaflora guianensis*), "Cumala" (*Virola albidiflora*) or "Estoraque" (*Myroxylon balsamum*) (Olortegui, 2015).

These woods are able to support the vertical load of the structure but also resist the lateral loads of the flowing water beneath the dwelling. Meanwhile, the floor and roof structure are made out of softer and lighter woods such as "Pintana" (*Podocarpus celatus*) or "Cashapona" (*Socratea exorrhiza*), which considerably reduces the weight of the dwelling (Olortegui, 2015). Many of the ties which join the structural elements together are made out of "Tamshi" (*Heteropsis linearis*), a highly resistant vegetable fibre native of the Amazon rainforest (Baluarte & Del Castillo, 2001). The skin or envelope of the dwelling consists of permeable "Huasai" (*Euterpe oleracea*) or "Pona" (*Socratea sp*.) wood cladding for the walls, and "Yarina" (*Phytelephas macrocarpa*) or "Irapay" (*Lepidocaryum tenue*) leaf coverings for the surface of the roof (Olortegui, 2015). The spacing in the cladding of the walls and the insulating properties of the leafs against the heat have the objective of reducing the temperature of the interior of the dwelling, however they both reduce unnecessary weight from the structure. The use of highly resistant hardwood for the foundations and load bearing elements of the house, paired with the lightweight secondary structure and envelope of the house allow for a possible amphibious retrofit which is resistant to the river current and is also light enough to be suitable for buoyancy.

3.2. Adapting the Amphibious retrofit

Figure 11

Marticorena "Adapted retrofit strategy"



The materials of the stripped down amphibious retrofit strategy can be replaced by local and recycled alternatives from the Amazon rainforest. The simplicity of the design of the amphibious retrofits allows versatility in construction materials, meaning the different elements of the standardized retrofit strategy are suitable to be composed of the materials found in the Amazonian typical dwelling.

A possible amphibious retrofit strategy in the Amazon region (fig.11) would implement the structural elements of the traditional Amazon dwelling and recycled materials into its construction. The vertical guidance posts would consist of highly resistant hardwoods, while the secondary structure of the buoyancy platform and the centering devices would be made out of lighter softwoods. Organic fibers would be used for variations of the centering devices and to hold the buoyancy elements into place. A large number of recycled plastic containers would serve as buoyancy elements beneath the house. The compatibility of the elements of the traditional Amazon dwelling with the elaboration of amphibious retrofits increases the accessibility and affordability of this mitigation strategy, and presents the possibility of implementing amphibious architecture as a conventional flood defense strategy.

4. The benefits of a different solution

4.1. Socioeconomic advantages

The natural resources of the Amazon rainforest are responsible for maintaining a large part of the region's economy. According to the Wilson Centre & Brazil Institute (2021), the agricultural and livestock sectors are two of the largest local employers in Brazil, with an estimate of 1.7 million workers, which represents 16 percent of the region's employed population. Another example of the importance of the Amazon's resources is that, according to the World-Wide Fund for Nature (n.d.), "fishing is the main source of income and food for riverside communities in the Amazon River basin". Considering the dependance of the region's population on the natural resources of the Amazon rainforest, when implementing a flood mitigation strategy, it is important to take into account the effects it has on the environment.

The continued use of conventional flood mitigation strategies could not only increase the long term consequences of extreme flooding, but also interfere with production activities which are essential for the affected communities in the Amazon. According to Chapman (2018) the use of dykes interferes "with the natural ecosystem, making food production difficult for low-income agricultural and aquacultural farmers". As a result of this ineffective flood mitigation strategy, people "can no longer find fish to eat and sell" (Chapman, 2018). Focusing on the Amazon region alone, according to Cardoso in Wenzel, Hofmeister, Papini & Gehm (2022) "dams change the natural course of water, impacting the biodiversity, the population of fish and the life of the Amazonian towns". As evidenced, flood mitigation strategies which affect the river course are prone to create serious damage to the local wildlife, affecting not just the environment but the economic activities that revolve around it. On the contrary, the use of an amphibious retrofit strategy can diminish the effects flooding has on the economic and social stability of communities in the floodplain of the Amazon River, as it will be explained in the following section.

Frequently, severe flood events force the large-scale displacement of entire communities, causing economic loss in construction costs and psychological trauma in the population. Relocation and resettlement programs have proven to result in limited success in terms of providing economic stability and psychological wellbeing to the affected communities (English et al., 2018). Regarding the economic effects of these programs, it is demonstrated that "relocated residents report a decrease in income and an inability to repay their debts after relocation" (Chun, 2015). On the other hand, with respect to the psychological distress of relocation it has been reported that this issue ranges from "anxiety, headaches and difficulty sleeping, to more serious symptoms such as post-traumatic stress disorder (PTSD) and depression" (Alderman, Turner & Tong, 2013). Considering that static elevation houses, such as the traditional Amazonian dwelling, by themselves are not able to adapt to the rapidly increasing flood levels (English et al., 2018), it is clear that the need for the relocation of communities will intensify as time passes. Unless an alternative flood mitigation such as the implementation of amphibious retrofits is undertaken, relocation and resettlement will continue to aggravate the economic and social crisis left by severe flood disasters.

As mentioned, the amphibiation of homes in the Amazon region is a viable strategy to break out of the repetitive cycle of relocation and reconstruction that currently plague the lives of the inhabitants of the area. Amphibious retrofits can "mitigate the threat of forced displacement for those communities that are vulnerable, under-resourced, and living in rural and under-served parts of the world" (English et al., 2016), reducing the magnitude of the consequences of extreme flooding. By eliminating the need for the displacement of entire communities, an amphibious retrofit strategy can essentially remove the reconstruction costs of the modified dwellings and simplify the installation of buoyant foundations, while still prioritizing the well-being of the vulnerable communities.

Amphibious retrofits have a reduced elaboration and construction cost in comparison to the reconstruction of a permanent static elevation. Amphibious housing is an economically viable flood mitigation strategy for communities that require a cost sensitive solution (English et al., 2018), as is the case for the marginalized populations of the Amazon. The calculation of the loss avoidance ratio (LAR) can quantify said economic advantage of amphibious strategies by comparing the damages of flooding to the installation cost of the mitigation strategy (English, 2018). According to Bourdeau (2015), an LAR greater than 1.0 indicates the installation cost of the amphibious retrofit is less than the cost of the damages in a single flood event.

Testing of different amphibious retrofits of a large variety of costs in Leville, Lousiana and in Lake St. Martin, Manitoba presented LARs ranging from 1.0 to 5.1, showcasing the outstanding cost efficiency of these mitigation strategies. Additionally, the cost of an amphibious retrofit on average would decrease by 40 % with self-labour (English, 2018), and conveniently, numerous dwellings in the Amazon region are built with the voluntary collaboration of the family members and the local community (Rodriguez, 2011). The affordability of amphibious retrofits in relation to the excessive damage costs of static elevation houses during floods, paired with the reduced labour costs of implementing amphibious strategies, evidence the economical superiority of this alternative strategy in the event of extreme flooding.

4.2. The cultural argument

Amphibious retrofits have a significant level of cultural sensitivity by adapting to the traditions of different communities which choose to settle near the presence of water. It is not unusual for human communities to have the desire to live adjacent to water due to matters of cultural heritage or settlement patterns (Anderson, 2014). This includes populations in the Amazon rainforest which perceive living in a high flood risk area a tradition rather than a danger. To them, apart from providing means of transport, agriculture and aquaculture (Butler, 2019), the Amazon River represents a source of life and pleasure (Vildosola, Alarcon & Andrews, 2022). Historically, according to Amazon Frontlines (2020), indigenous cultures have held a strong spiritual connection with the river, seeing water as a living being which helps to protect the balance of the Amazon. The cultural attachment of the Amazonian communities with the presence of water intensifies the issue with implementing a relocation strategy for the communities in flood risk areas, as such strategy would bring an abrupt end to the long-lasting traditions which join the people with the river. On the contrary, the use of amphibious retrofits could serve to maintain the sociocultural relation of the communities sitting on the floodplains of the Amazon rainforest with water, taking into consideration valuable traditions for the people of the area.

5. Conclusions

Challenges and limitations

The difference between the speed of the Amazon River flow with other rivers in which amphibious strategies have been tested can be an impediment for the successful application of secure retrofits. According to Rodriguez (2022), due to the aforementioned effects of climate change on the Amazon river's conditions, from 2015 to 2020 the water level and flow speed increased significantly during a short period of time. The Amazon River is registered as the fastest flowing river in the world, with its current reaching average speeds of 7 kilometres per hour (World Wide Fund for Nature, n.d.). Considering that amphibious retrofits "are not a universal solution as they are not currently designed to accommodate the lateral forces of high-velocity flow or the impact of sizeable waves" (English et al., 2016) it is clear that this increase in velocity of the river flow may limit the possibility of implementing an amphibious flood mitigation strategy in the Amazon region. Additionally, the construction techniques used in the Amazon are commonly informal and to some extent unsafe compared to the ones implemented in less marginalized locations, meaning that they present a higher risk of structural deterioration or failure when facing adverse natural conditions. The high velocities of the Amazon River combined with the defective local construction techniques and materials may call for a more structurally developed flood mitigation strategy in the Amazon region. So as the high speed of the Amazon River (7 km/h) is mentioned as a limiting factor; the technical discussion on how the vertical guide posts would withstand these specific lateral and scour forces must be additionally and technically study in-depth to ensure overall structural viability.

The model followed for the design of amphibious retrofits in the Amazon also presents a number of technical, social and environmental limitations. Even though the retrofit structure includes guidance posts to secure the vertical movement of the house, the buoyancy system underneath the house is not capable of stabilizing the floor of the house completely, as seen on figure 5. The flow of water beneath the dwelling can cause an irregular vertical movement, causing the floor surface to tilt slightly and producing unpleasant living conditions for the inhabitants. Another related consideration is the possible discomfort of the affected families due to the precarious aesthetic of the amphibious retrofits. However, the retrofits discussed in this investigation were based on optimal affordability and survival, and with appropriate funding these can be made into visually pleasing elements of the dwelling.

In terms of materials, in order to reproduce this strategy throughout the vulnerable communities of the Amazon rainforest, an excessive number of resources would need to be gathered, organized and distributed. Particularly, the mentioned use of recycled materials for the dwellings' buoyancy system would require the collection of vast amounts of plastic containers, which would most likely be achieved with the aid and funding of local governments in order to gain access to a centralized waste source. This issue and the extensive recollection of wood for the structure of the amphibious retrofit present a problem of organization, which can be solved with the correct investment and direct participation of pertinent organizations.

6. Final reflections

The mentioned retrofits of the Mekong River Delta are a valuable precedent for the design of an amphibious strategy to be applied in communities in the Amazon floodplain. Firstly, the natural conditions regarding the importance of resources, and the flood vulnerability of the area are the main factors which tie both sites together. Both regions count with unparalleled value in food production and wide-reaching commercial activities, and due to the severity of their flood events they require updated mitigation strategies that can protect their value. The combination of a simplified design scheme with the existing natural and built conditions of both areas make the current amphibious retrofits in the Mekong Delta a pertinent example for an effective flood mitigation strategy in the flood vulnerable populations of the Amazon region.

After analysing common construction practices in the Amazon region, it is clear that the qualities of the traditional amazonian dwellings further reinforce amphibious retrofits as a suitable flood mitigation strategy for exposed populations in the Amazon. The use of stilts, the raised ground floor and the light structure all facilitate the attachment of an amphibious retrofit. The existing characteristics of the traditional Amazonian dwelling are an advantage for the elaboration of amphibious strategy as their compatibility with the dissected retrofit strategy eliminates the need for any supplementary modifications. Additionally, the overall simplicity of the standardised amphibious retrofit could allow for the replacement of materials such as steel with local and accessible varieties of hardwood such as Huacapu, Cumala or Estoraque. Also, construction techniques used for the construction of the Amazonian dwellings can be translated to the elaboration of amphibious retrofits i.e. the use of wooden foundations to erect vertical guiding posts and handmade organic ties to serve as centering devices. It is evident the analyzed characteristics of the standardised amphibious retrofit works in harmony with the attributes of the traditional Amazonian dwelling.

The use of an amphibious retrofit strategy in the flood prone communities of the Amazon region, apart from providing an effective mitigation measure, would bring outstanding socio-economic benefits. In contrast to the inefficiency of conventional flood mitigation strategies which alter the environment and the resources it provides; amphibious retrofits present a cost sensitive solution which does not hinder the economic activities that revolve around the river and are crucial for the populations of the Amazon rainforest. The LAR calculations evidence the economical superiority of amphibious retrofits, composed of minimal structural elements and affordable materials, in comparison to the commonly used static elevation dwellings which are obsolete when faced with the increasing severity of flooding. Amphibious retrofits are also able to alleviate the need for displacement of entire communities after extreme flood events, relieving the victims from reconstruction expenses and from the psychological trauma often caused by forced resettlement. The reduced chances of relocation also preserve the strong spiritual bond between people and the river which especially exists in the more traditional settlements of the Amazon region. From a socioeconomic and cultural perspective, the large-scale implementation of amphibious retrofit in the Amazon would achieve a balance between affordability and well-being, by providing an accessible mitigation strategy which protects the customs and identity of the local communities.

Overall, it can be said that even though the realisation of a wide-reaching amphibious flood defence strategy in the Amazon region would face structural, social and environmental issues, the numerous virtues of this alternative mitigation method are undeniable. In comparison to conventional strategies which alter the natural conditions of the area and often fail to protect the income and health of the local communities, amphibious architecture aims presents a passive strategy which prioritises on the well being of the people and the environment. Therefore, it can be concluded that with the appropriate management and planning, a reliable amphibious retrofit can be implemented to suit the challenges and conditions of the Amazon River floodplain, in order to make use of the substantial economic, social and cultural benefits it brings to the region.

As so as the speed of the Amazon River (7 km/h) is mentioned as a limiting factor; the technical discussion on how the vertical guide posts would withstand these specific lateral and scour forces could be more studied in-depth in order to ensure overall structural viability.

It would be advantageous to include a complement additional technical proposal on how to reinforce the wooden guide posts or the centering sleeves to better absorb the impact of debris or the high-speed current mentioned in the limitations.

Unlike the Mekong River with its calm waters, the Amazon faces engineering challenges due to its high velocity and fluctuating flow, and the need for structures designed to withstand lateral forces. It is necessary to explore the technical feasibility of installing plastic containers, ensuring they are secured in a way that prevents contamination of the river if they become dislodged.

7. Additional Comments:

1. The construction of floating structures is proposed, either on the banks of the Amazon River or on tributaries within its watershed. Hydraulic and sedimentological conditions can vary considerably in each of these scenarios.
2. In both scenarios, the structures will be located on curved alignments of the waterways. Straight alignments are practically non-existent in natural watercourses.
3. In all selected areas, the structures must be located on the concave bank of the river bend, where the erosive capacity of the flow is lower.
4. The flow velocity toward the banks is significantly lower than the average velocity of the river and that of the central section.
5. The average velocity of the Amazon River, 7 km/h (or 1.95 m/s), is only a reference point and will vary along its length and width, and will differ among its tributaries.
6. In areas near the confluence of a tributary, water depth and flow velocity will be closely related to the profile of the Amazon River at any given time.
7. The river flow will generate longitudinal thrust, especially on the flotation system. This thrust must be counteracted by the foundation piles and/or anchor piles on the riverbank.
8. The moorings for the floats and the anchors must be high-safety-factor and redundant systems to guarantee their safety and allow for repairs.

8. Recommended additional studies:

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10. Illustrations

Figure 1 Khoury, D., (2023) Life on the Amazon waters. Available at https://www.holcimfoundation.org/ (Accessed: January 2024)

Figure 2 Marticorena "Amazon region diagram"

Figure 3 Odyssei., (2024) World Map of AMAZON SELVA REGION in SOUTH AMERICA. Available at: https://www.dreamstime.com/ (Accessed: January 2024)

Figure 4 Marticorena "Static elevation vs Amphibious dwelling"

Figure 5 Buoyant Foundation Project. (No date) Lac's house after amphibious retrofitting. Available at: https://www.buoyantfoundation.org/ (Accessed: November 2023)

Figure 6 Marticorena "Vietnam amphibious retrofit"

Figure 7 Marticorena "Amphibious elevation diagram"

Figure 8 Marticorena "Dissected amphibious retrofit"

Figure 9 no author. (2023) Almanaque, Casa Selva, Ediciones Abebul. Available at https://stores.2023saleonline.ru/ (Accessed: January 2024)

Figure 10 Marticorena "Traditional Amazon dwelling"

Figure 11 Marticorena "Adapted retrofit strategy"