Living-with-Water: a Comprehensive Design Proposal to Build Flood Resilience in the Roncador River Region, Brazil

MARIA LUIZA OTTONI
University of Waterloo

ELIZABETH C. ENGLISH
University of Waterloo

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Informal settlements on riverbanks in impoverished Brazilian peripheries have been increasingly suffering from more intense annual urban floods, as in the Roncador River region in Duque de Caxias City. This article proposes a comprehensive solution for flood risk reduction (FRR) through an integrated approach in design. By recognizing water as an ally, this study connects a system of green areas along the river corridor and within the urban fabric with amphibious evolutionary housing as an adaptive solution that protects houses from flood damage. As a low-impact intervention, it prioritizes nature-based strategies and local community practices, fostering local economies to fight gentrification and contributing to building a more equitable future.

The methodology identifies the region's problems and opportunities, followed by a literature review on FRR solutions and incremental housing design strategies. Lastly, two sites were selected to propose the design intervention. As a result, the design applies adaptability strategies on different scales, accepting floods, allowing transformations, and adapting to the local context. The proposed green areas' system on the watershed scale increases soil permeability and water storage and reduces stormwater runoff. On the housing scale, residents are provided with a low-cost, flexible, and amphibious starter house that is half the potential final house area on safe nearby lands.

The design solution promotes economic benefits, as implementing a network of parks improves the land value and generates local sources of employment. The project's innovation is combining incremental design strategies with amphibious architecture to offer good quality and affordable housing that adapts to floods, empowering marginalized communities to thrive in healthier riverscapes. In addition, this solution could be applied to improve the livelihood of other flood-prone communities in similar informal contexts.

INTRODUCTION

Global climate change has been increasing extreme rainfall events and flood risk in developed areas, posing risks to the 20% of the world's population that inhabits riverine floodplains[1]. Climate-induced floods disproportionally affect low-income communities living in exposed areas that lack basic infrastructure[2]. Because these marginalized groups experience enduring patterns of inequality and spatial segregation, they have no choice but to inhabit inadequate spaces such as river edges and floodplains[3,4]. People in this context suffer from a chronic environmental injustice issue. Increased floods are detrimental to local communities, as they damage houses and infrastructure, generate trauma, and often force these populations to relocate to distant locations, disrupting their livelihoods[5].

Riverbanks' informal settlements in impoverished Brazilian peripheries have been increasingly suffering from more intense annual urban floods, as in the Roncador River region in Duque de Caxias City. The growing housing crisis, lack of public investment in urban planning and housing policy, and increasing land speculation exacerbate social inequalities, significantly expanding the number of informal settlements over the last decades. Consequently, the community has been suffering from several disease and financial burdens related to the impacts of floods and chronic sanitation deficits.

The location of favela typology in urban riverbanks or floodplains hinders the implementation of sanitary infrastructure due to high costs and complexity, thus not being prioritized by governments[6]. Hence, the rivers in these informal contexts are associated with disruption and trauma when the flood occurs. Likewise, the deficient public housing program in Brazil and the lack of policies to tackle the chronic social inequality have been causing the rise in housing deficit rates over the last decades, exemplified in Duque de Caxias City. The housing crisis in the city has been exacerbating evictions and the emergence of informal settlements in the most undesirable lands, including riverbanks[7].

Located in the third district of Duque de Caxias City, within the Metropolitan Region of Rio de Janeiro, the Roncador River lies in a low-lying geological region characterized by having

frequent floods[8]. The municipal government has implemented numerous traditional flood control interventions in the city over the past two centuries to prevent river sedimentation and floods. Yet, criticized for not being integrated with comprehensive regional planning, they proved inefficient, mostly focusing on quickly discharging pluvial waters away from urban centers. These interventions intensified the annual floods in the region over the last decades[9]. By changing the rivers' natural courses and increasing impervious surfaces and deforestation, conventional engineering interventions in rivers may contribute to worsening floods[10].

Currently, the Roncador River region has over 450 informal houses on the riverbanks, and the community lacks recreational spaces. When destructive floods occur, the financial burden on impoverished residents can be substantial, sometimes forcing them to relocate, as their low-quality informal housing most of the time cannot withstand the flood impacts. As water and housing problems are deeply intertwined in the Roncador River region, this article argues that it is imperative to tackle them by seeking comprehensive solutions that integrate them.

Many scholars have been tackling flooding issues by prioritizing nature-based strategies in the macro-scale to increase permeable surfaces and improve the natural water cycle in urban areas[11, 12, 13, 14, 15, 16, 17]. Yet, most approaches fall short on addressing flooding within the complex and conflicting context of informal settlements in riverbanks, where substantial housing deficits are in play and need to be addressed with the flood problems. Additionally, these nature-based solutions require space to be implemented, which is not necessarily available in urban contexts. In a degraded urban watershed precariously inhabited by informal settlements, which design strategies would enhance the community's adaptive capacity to floods and allow them to safely stay, grow, and thrive in the long term?

This article proposes a comprehensive FRR preliminary design solution through an integrated design approach within an informal settlement context. By recognizing water as an ally, this study aims at designing an affordable, flood-resilient, and evolutionary community, contributing to building their adaptive capacity to stay instead of retreating. By envisioning water not as a problem but alternatively as an opportunity to enhance the local community's life, this article is grounded on the living with water framework to empower marginal flood-prone communities to build their resilience.

LITERATURE REVIEW

Flood risk is defined as "the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event" [18]. Increasing soil permeability for natural or artificial water storage as well as applying flood-protection structures help reduce flood risk. Exposure is related to communities and buildings located in at-risk areas and can be mitigated by implementing regulations to avoid building developments in floodplains. Vulnerability relates to how prepared a community is to face flood events and implementing both structural and non-structural measures can help mitigate their vulnerability. It is crucial to limit exposure and vulnerability and reduce sources of flood hazard to increase adaptation[19]. Flood adaptation refers to a group of actions that make existing socioeconomic and ecological systems stronger in the face of flooding impacts[20]. Adaptation measures should also tackle developmental needs to increase the adaptive capacity of vulnerable communities[21].

Resilience is when a building or community has the capacity to respond to stress caused by changes in climate-related conditions[22]. Resilience and adaptation are directly related, in which the former can be built and enhanced by identifying and improving the community's adaptive capacity[23]. A flood-resilient design prepares for floods by protecting, restoring, and improving the ecosystem services and built environments, acting in several scales to improve their adaptative capacity, and encouraging creative design collaboration and innovation in policy and technology[24]. Adaptive capacity is the community's potential to adapt to climate-related issues such as flooding, considering their available resources, knowledge, social networks, and skills[25].

There are well-known sustainable approaches for managing stormwater in the urban context that not only reduce flood risk, but increase biodiversity, reconnect people to nature, and provide better leisure and recreational areas, which align with the approach of living with water. Two widely discussed nature-based approaches in the literature to manage urban stormwater are the Blue-Green Infrastructure (BGI) and Sponge City. BGI provides an integrated and multifunctional network of natural areas, including water bodies and green spaces, designed to protect and enhance ecosystem services and biodiversity, improve water quality, manage water quantity, and provide recreational opportunities[26]. BGI applications work as FRR solutions when part of a large-scale rainwater management system, besides offering financial, environmental, and social benefits to urban communities[27].

The Sponge City is a relatively recent concept that refers to having the urban environment performing as a sponge that absorbs and releases water, as a systematic urban planning and design strategy to reduce floods and enhance the environmental quality[28]. Widely applied by the Chinese government since 2013, this approach promotes a paradigm shift from traditional urban stormwater management to more flood-resilient and green infrastructure practices, aiming to harvest, control, store, and reuse rainwater more sustainably and effectively[29].

There are FRR approaches that go beyond their primary function, also integrating water into the design of the built environment. Aquatecture, defined as an approach to design

Figure 1. Design proposal in three scales: (A) Watershed, Neighborhood, and Housing scales of intervention; (B) Proposed interventions across three scales, highlighting strategies on the watershed scale. Source: The authors.

centered on water, supports development growth while managing flood risk to create more resilient buildings and cities[30]. By prioritizing nature-based design solutions, this framework merges architecture with water, incorporating it into the urban environment across multiple scales in an integrated approach. Its principles are based on making space for water, living with water, and developing eco-design buildings. Aquatecture also suggests new building types and retrofits that adapt to increasing floods. Amphibious Architecture is an innovative solution to protect houses from flood damage, designed to float temporarily during floods and rest again on the ground in dry conditions due to its buoyant base[31,32]. This FRR strategy

has proven reliable and feasible for homes, reducing livelihood disruption and physical, social, and financial losses related to flooding[33]. Studies have been developing strategies to retrofit homes based on the concept of "amphibiation" by using a buoyant foundation as a low-cost, low-impact, and place-specific solution for flood adaptation, a strategy proven to work well in low-income contexts of developing countries[34, 35, 36].

However, solutions based on sustainable stormwater management approaches such as Aquatecture or BGI require significant area to accommodate water and greenery. In consolidated urban settlements, especially in low-income informal communities characterized by land conflicts, finding space for water becomes a challenge, potentially creating conflicts related to eviction. Applying this approach within the Roncador River context would mean removing the informal settlements on its edges and relocating their residents, likely increasing the housing deficit. Because the public housing policy in Brazil is deficient and has proven inefficient in addressing the current housing crisis[37], green interventions towards FRR should be carefully planned and strategized to avoid causing forced displacement of low-income residents and community disruption.

Past top-down green interventions in rivers for urban renewal only accelerated gentrification processes because the local communities were neglected[38]. It is imperative to think about the housing problem in the Roncador River region in relation to its river and the lack of other services and seek comprehensive responses that integrate both housing and water issues. Hence, appropriate solutions for the local floods should consider keeping the at-risk residents in their communities, and enhancing their adaptive capacity to address their needs and aspirations in the long term. This work questions the chronic housing issue in the region by grounding on the conceptual framework of evolutionary and adaptable architecture, which increases housing affordability and sustainability[39, 40, 41].

In marginalized, low-income contexts, flexibility and adaptability become relevant points to building a community's resilience. Evolutionary housing uses flexible design strategies to increase residents' agency and control over changes to their spaces to address their needs and aspirations according to their stage of life and budget limitations[42]. Buildings that are flexible, customizable, and recognized as a process instead of an end-product also contribute to sustainability as they can adapt to different functions and, thus, become more durable[43].

METHODOLOGY

The methodology consisted of (i) identifying and analyzing the region's problems and opportunities, (ii) conducting a literature review on FRR solutions and incremental housing design strategies and (iii) proposing a preliminary design solution that merges FRR concepts with evolutionary housing framework as a tailored solution for the region's floods in informal contexts. The literature review included published and unpublished works in academic and grey literature and also conducted research on the flooding issues in the region. The contextual analysis phase consisted of the elaboration of maps and diagrams. Finally, the design phase incorporated the lessons from this reflection process to propose design interventions in selected sites in the Roncador River region.

The design proposal for the Roncador River is divided into four phases: (1) Identify vacant and underutilized lands in the region that could fulfill their social and housing functions; (2) Build new low-cost, incremental houses on nearby vacant lands, adaptable to floods and integrated with a holistic nature-based system in the watershed scale; (3) Relocate the impoverished residents from the riverbanks to the new nearby houses to enhance their adaptive capacity to floods and increase their agency over the housing production; (4) Implement a nature-based system throughout the watershed to mitigate floods.

RESULTS AND DISCUSSIONS

The proposed design solution connects a system of green areas along the river corridor and within the urban fabric with amphibious evolutionary housing as an adaptive solution that protects houses from flood damage. As a low-impact intervention, it prioritizes nature-based strategies and local community practices, fostering local economies to fight gentrification and contributing to building a more equitable future. The proposal applies FRR and adaptability strategies in an integrated approach on three scales: watershed, neighborhood, and building (Figure 1).

The design gestures on the watershed scale are based on creating a nature-based riverside park and a system of green spaces in vacant lands within the urban fabric. These macro, long-term solutions, which include the restoration of riparian vegetation, will mitigate floods by increasing soil permeability and reducing runoff. They also enhance environmental qualities by allowing the continuity of ecosystem services. The at-risk informal settlements on the riverbanks will need to be removed to implement these green strategies and their residents will be relocated to new affordable housing within the neighborhood, addressed in building scale intervention.

On the neighborhood scale intervention, existing vacant and abandoned lands near Roncador River are identified to be repurposed with green areas for recreation and food production functions for the local community. Some of these lots will also be repurposed for building new affordable housing to reduce the housing deficit and redirect residents who formerly lived in at-risk houses on the riverbanks. Examples of nature-based recreation spaces include lowering the existing soccer field and providing permeable squares and skateparks to retain stormwater and reduce runoff, thus mitigating floods.

The application of green streets and mid-block green spaces are some nature-based urban design strategies that will also

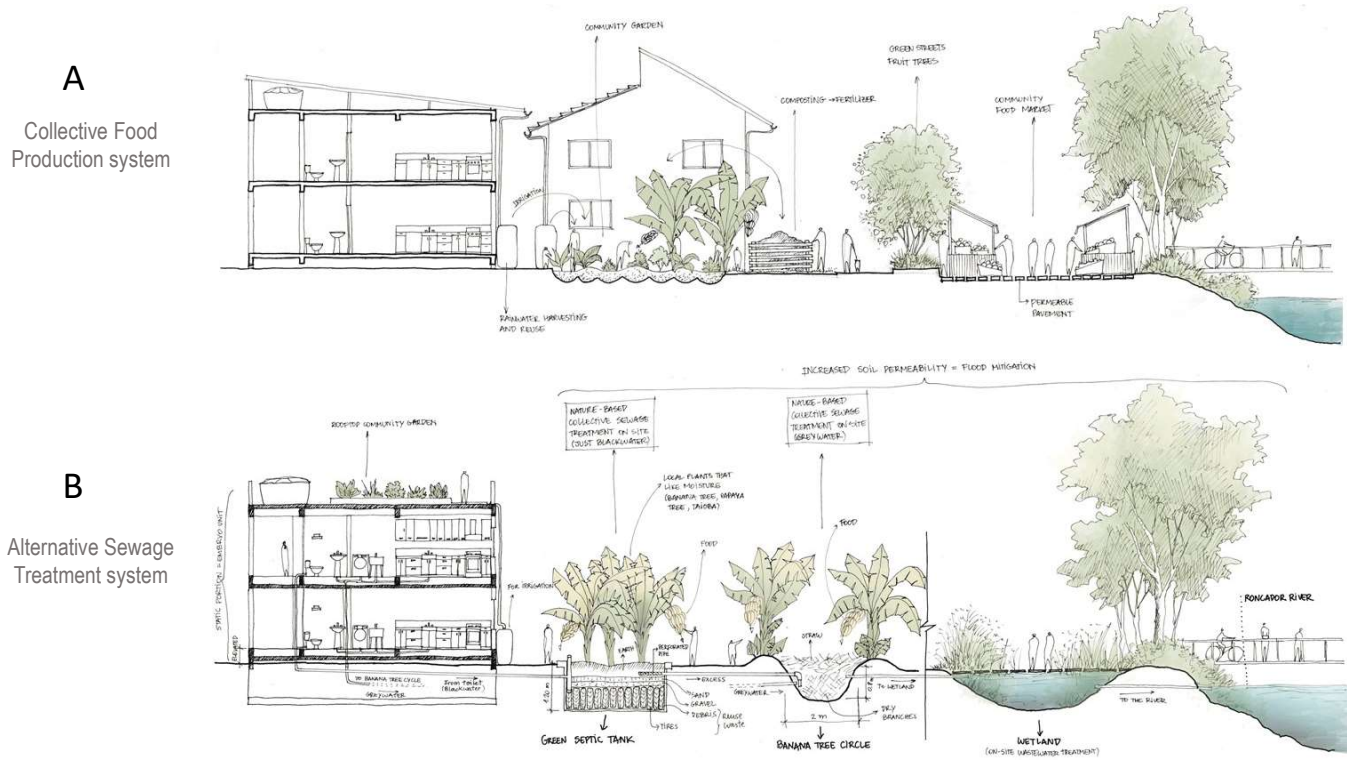

Figure 2. Nature-based strategies applied on the neighborhood scale: (A) Collective food production system; (B) Alternative sewage treatment system. Source: The authors.

be proposed on the neighborhood scale. These also work as collective productive spaces, such as community gardens for urban agriculture, floriculture, and fruit farming which enhance the existing community bonds, reinforce local traditions such as food markets, and foster local economies. The vacant lands in the neighborhood can also be used to implement a low-cost and easy-maintenance wastewater treatment system that applies nature-based and local techniques strategies. These strategies, such as green septic tanks and banana tree circles interconnected with wetlands, are sustainable solutions that not only treat domestic wastewater but can engage the community as a collective maintenance activity and generate food and sources of income for them[44] (Figure 2).

On the building scale, residents are provided with an amphibious starter house that is half of the potential final house area on safe nearby lands, made of local materials and construction techniques. Starting with an embryo house makes housing production more affordable. The residents have the opportunity to increase their agency in the housing production over the years, as their houses are designed to expand through self-construction (a traditional practice). Expansions can occur horizontally and vertically up to four storeys in numerous variations and might include adding a rental unit or a workspace or retail to increase the residents' income in time, according to their needs, aspirations, and budget. Due to its flexible design strategies, from the starter unit until the final expansion, the house can double its space to accommodate several uses in different stages (Figure 3). As amphibious buildings, the starter houses receive a buoyant foundation that allows them to float when floods occur and rest on the ground when they are over (Figure 4). The design also includes rooftop rainwater harvesting to be reused for non-potable uses, contributing to mitigating floods by reducing stormwater runoff.

Two housing types are proposed in the Roncador river's expansion zone: single-family house and multi-family low-rise building types. The lots are in a region with numerous and extensive vacant lots, which allows the proposition of a series of incremental and flood-resilient affordable housing of different sizes for low-income residents. The support elements, which are fixed and should not be changed, are provided initially in the starter house. They include the structural frame (in wood or reinforced concrete), the amphibious foundation, the roof (made of locally reused ceramic tiles or corrugated metal sheets), the plumbing stacks, bathroom and kitchen fixtures, and plumbing and cabling. The infill elements include non-load-bearing brick masonry walls (locally available materials), reused windows and doors, and handrails, and can be modified and customized by the residents. The buoyancy elements in the amphibious foundation are made of reused water bottles which foster waste reuse to reduce pollution[45].

CONCLUSION

In summary, this article proposes living with water and FRR design solutions across scales to a low-income and flood-prone community in Duque de Caxias city, Brazil, to mitigate their flood risk and enhance their adaptive capacity. As flexible, low-cost and low-impact responses, they aim at improving the community's quality of life and agency, empowering their resilience. In addition, this work discusses the local housing issues that could be intensified by implementing a riverside park in the Roncador River area and offers a solution that fights green gentrification. The major strategy to find space for water is by repurposing local abandoned lands to provide affordable housing to resettle people living informally on riverbanks and implementing a system of nature-based spaces to restore ecosystem services. This way, the residents can stay (and thrive) in their communities instead of having to relocate when floods happen (Figure 5).

The design solution promotes economic benefits, as implementing a system of green areas improves the land value and generates local sources of employment[46]. Incremental housing design also increases residents' income with rental and retail opportunities[47]. The project's innovation and contribution to the literature relates to combining incremental design strategies with the "amphibiation"[48] technique to offer good quality and affordable housing capable of adapting to floods, which empowers marginalized communities to thrive in healthier riverscapes. This work sees housing production as a process and not as an end-product, which makes it more affordable in a low-income context and empowers residents to become the agents of change and address their needs and aspirations over their life stages. Increased control over the housing production process contributes to high quality of life and sustainability.

However, combining design strategies for adaptability and flexibility with the FRR amphibious architecture approach presents a challenge related to limitation to expansions. Starting with a single-storey house that can expand horizontally and vertically up to four storeys might compromise the building's stability during floods and the buoyancy if the expansions exceed their spatial and weight limits. Expansions should be guided by parameters that allow people to expand with control and defined limits. Having the control parameters for expansions within the building code would be ideal, but this is a very distant scenario, as amphibious architecture does not appear in any building code anywhere in the world to date.

Achieving an integrated approach on multiple scales beyond the design stage largely depends on integration with the policy level, as well as political will and the community's acceptance, which becomes a challenge due to its complexity. For this project to be implemented and successfully last, it is paramount

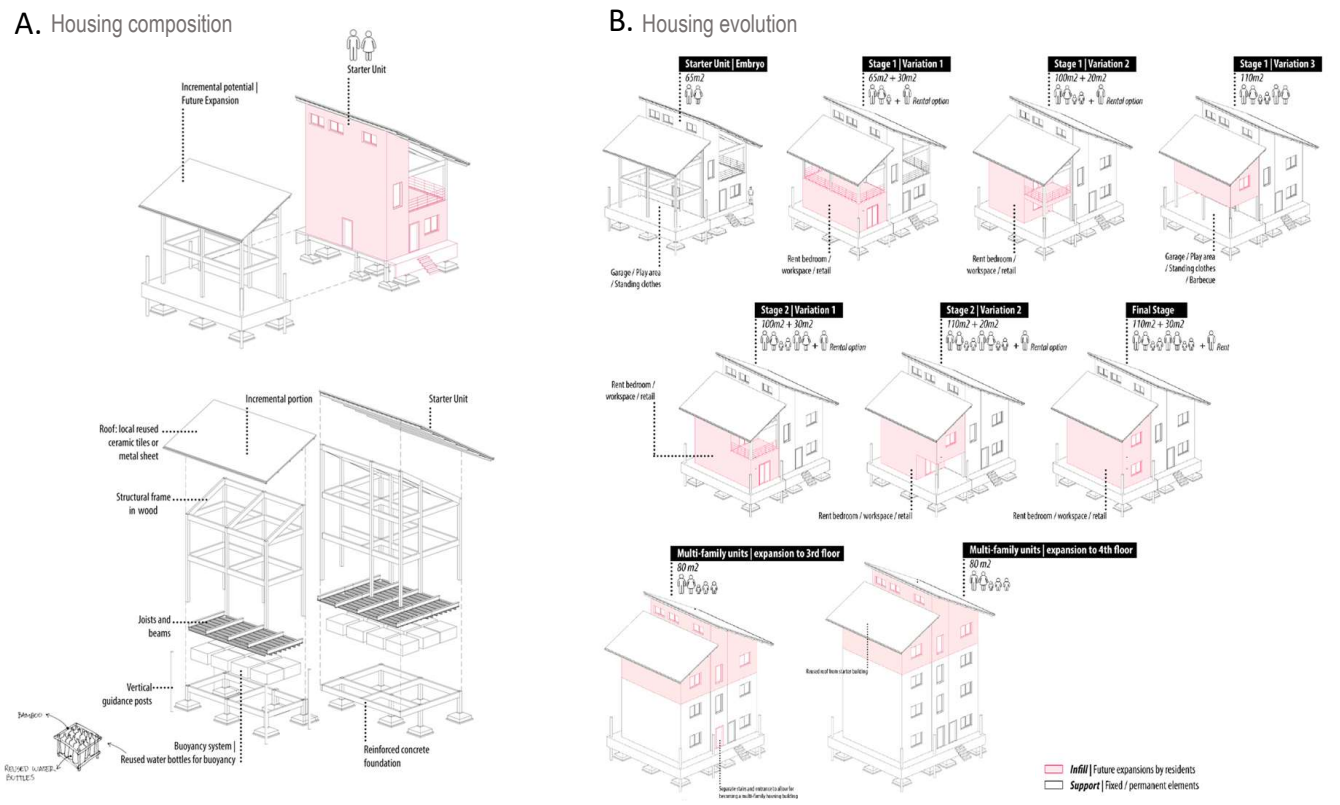

Figure 3. Design strategies applied on the building scales: (A) Housing composition and amphibious foundation parts; (B) Stages of evolution of the proposed housing. Source: The authors.

that policies be created to integrate with urban planning, sanitation, and housing policies.

The potential negative consequences of implementing the proposed solutions such as green gentrification and conflicts with resettlement might be avoided if the community is included and collaborates in all levels of decision-making, from concept to implementation and maintenance. If also supported by public policies to guarantee that social equity is central to the project, then these solutions can potentially help build more inclusive urban projects.

A barrier to implementing the proposed housing strategies is the lack of political will to accept a more flexible design. It would require shifting the current inefficient mindset of rigid and repetitive design to one that is more adapted to local specificities and provides increased control to the user. Expansions under an incremental design framework should also be incorporated into building codes to allow people to expand their houses in a controlled way. Additionally, social housing provisions alone will not solve the housing problem since it needs to be integrated into other policies, especially related to water.

Due to the limited scope of work, this article focused on envisioning a solution and testing strategies conceptually. Therefore, it did not address relevant aspects such as feasibility and cost of the project. These aspects are encouraged to be further analyzed in future studies, especially due to the impoverished context in which this community is located.

Another direction for future research includes developing the specifications and detailing of one amphibious evolutionary housing in this region, including sizing the buoyant foundation elements to understand its limitations in terms of budget and size. Future research could also study the limits to the housing expansion up to four storeys in relation to buoyancy requirements to inform control parameters for expansions.

Moreover, precisely measuring and quantifying the current vacant lands and how many people would be impacted by this research in the region would be a next step if the proposed solutions are to be implemented. Another potential direction for future studies would be to make an inventory of projects in similar contexts that address the same issues, to extract lessons from them and potentially integrate relevant solutions.

Since the problems in the Roncador River surroundings are typical of metropolitan peripheries in developing countries, this solution could be applied to improve the livelihood of other flood-prone communities in similar informal contexts and enhance their resilience.

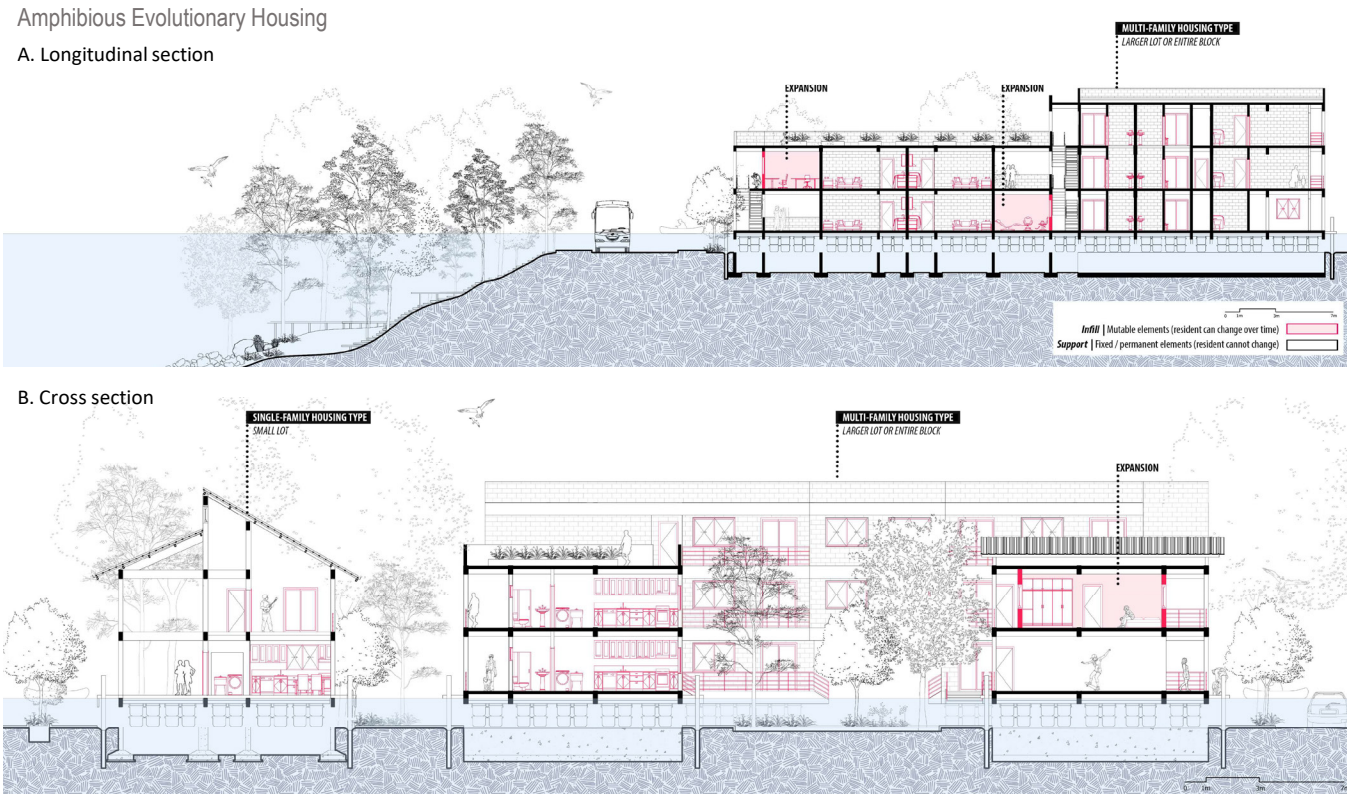

Figure 4. Longitudinal (A) and cross sections (B) showing the proposed amphibious evolutionary housing in flood condition. Source: The authors.

Figure 5. Perspective views showing the proposed design intervention in the Roncador River region. Source: The authors.

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