Local Materials, Global Impact: Bamboo for Climate and Seismic Resilient Neighbourhoods in Latin America

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Local Materials, Global Impact: Bamboo for Climate and Seismic Resilient Neighbourhoods in Latin America

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Abstract. The increasing frequency and intensity of climate-related and seismic events globally call for innovative, resilient approaches to social housing development. This study explores the potential of bamboo, as an abundant, locally available, rapidly renewable, and structurally resilient biobased material, to serve as the foundation for climate-adapting neighbourhood's creation in social housing resettlements in the coastal region of Manabí, Ecuador. By adopting a cross-sectoral collaboration approach, and integrating insights from architecture, materials science, structural engineering, and human geography, a multi-domain approach is proposed. This was defined through the engagement with a broad range of stakeholders, including local architects, international firms, local risk managers and NGOs. The proposed approach demonstrates that bamboo is a practical and adaptable solution for housing projects creation or adaptation, not only enhancing structural resilience, but also reinforcing social cohesion and local empowerment in vulnerable Latin American neighbourhoods. The utilisation of bamboo also addresses simultaneously environmental, economic, and social challenges, fostering the growth of communities, which are most affected by such hazards, while respecting ecological sustainability goals. The findings reported here are the result of an international interdisciplinary research programme aiming to define strategies for development of housing and neighbourhood for wellbeing, so that they are structurally resilient, low-carbon, and allow sustainable growth of communities affected by multiple hazards in Latin America.

1. Introduction

In the last decades, our planet has been facing an increasing number of climate-related and seismic events and often the most affected areas are in the Global South (1). South America due a combination of geographical, socio-economic and infrastructural factors, appears to be particularly vulnerable to both climate change and natural hazards. The vulnerability of many Latin American city's infrastructures to natural hazards results not only in a high number of losses, but also in a high population of survivors struggling to recover from the trauma and return

to their daily life, both during the emergency, as well as sometimes years after the disaster occurred.

According to the Overview of disasters in Latin America and The Caribbean 2000 – 2022 (1) of the 20 countries most exposed to earthquakes worldwide, 11 are in Latin American or the Caribbean. Central America and the west coast of the South American continent are situated within the 'Ring of Fire', a path located along the Pacific Ocean characterised by active volcanoes and frequent earthquakes. The western coast of South America is one of the most seismogenic zones in the world, with more than a quarter of the world's 8.0-magnitude or greater earthquakes having occurred there (2). Since 2000, South America has been a focal point for seismic activity. Approximately 65% of earthquakes with a magnitude of 8.0 or higher have occurred in the region. Additionally, there have been 57 earthquakes of magnitude 7.0 or greater, distributed as follows: 26 in Central America, 26 in South America, and 5 in the Caribbean. In April 2016, the Manabí region in Ecuador, experienced a devastating 7.8-magnitude earthquake that impacted several coastal and inland areas, resulting in 663 deaths. According to data, this earthquake ranks among the 10 most powerful ever in terms of energy released to have affected South America and the Caribbean region (1). Reconstruction following this catastrophic event has been challenging and further complicated by the COVID-19 pandemic, which spread through temporary settlements before residents could be relocated to permanent housing.

This study presents the results of a co-design practice exploring bamboo as a resilient, sustainable material for social housing resettlements in the coastal region of Manabí, Ecuador. The study was part of the NOVAVIDA (Novel Approach for Vital Infrastructure Post-disaster) research program, that initially critical analysed the aftermath of the earthquake, and the material and social conditions of the post-earthquake resettlements in four provinces of the Manabì. This involved local communities as well as professional, politicians, academics, and NGO's for the rethinking of future more resilient and sustainable approaches for housing reconstruction after hazards.

The analysis of the resettlements built by the central government in the aftermath of the event, showed a large use of reinforced concrete thin wall panel systems, for quick construction, resulting in large resettlements lacking social amenities, characterised by reduced functionality, poor flexibility of the units and poor thermal comfort. The second phase of the NOVAVIDA project aimed at rethinking how to develop resettlements that could be resilient in the longer term, provide an appropriate indoor comfort and allow the growth of local communities. To define the design objectives and strategies, a series of focus groups took place. During the focus groups, bamboo stood out naturally among the available resources, as bamboo is economically sustainable, while capable of guaranteeing a local economic development. It is, indeed, an environmentally friendly material and most of all is already part of the Ecuadorian construction culture. The versatility and abundance of bamboo is encouraging the development of re-visited vernacular systems as well as a new one in industrialised processes in the form of panels and/ or in its natural shape as poles. Among, the vernacular techniques, the one known as *bahareque encementado*-wattle and daub construction, is resurging internationally for the development of low-cost resilient housing projects. The interest by the scientific community in bamboo and the *bahareque encantado* technique continues to grow, due to the benefit of bamboo plant itself and the potential of bamboo construction to reduce embodied carbon. With this purpose, the *Composite Bamboo-based Share Walls (CBSW) System* has been included in the Blueprint for a Solutions Deployment Platform lunched in November 2024 during the Cop29 in Baku (3), as good

practice for the decarbonisation for construction of affordable housing in emerging countries, by both international practice and non-governmental organizations.

In the following sections, a discussion of the theoretical framework developed, which includes the integration of the need for long-term resilience of housing and the understanding of bamboo as an environmental, economic, and socially sustainable material is reported (section 2). The NOVA VIDA research methodology is briefly described (section 3), while the resulting scenarios, which include bamboo as the basic principle for sustainable developments are discussed in sections 4 and 5.

2. Theoretical framework

2.1. The Need for Resilient and Innovative Social Housing

The destruction of the territories across the Manabí region, and particularly the fragility of the built environment demonstrated once again the urgent need for a different approach to urban development, to construction practices, and a more sustainable development safer for people.

According to UN Sustainable Development Goal 3 and 11, post-disaster resettlements should be conceived and developed considering the long-term social, spatial, and environmental impacts they can have on inhabitants. However, many are the cases where the long-term implications have not been at the heart of decisions, especially in emergency contexts such as in the aftermath of disasters, as identified by the NOVAVIDA research programme on the Ecuadorian case (4). As too often happens in an emergency, the amount of responsibility to manage during the reconstruction process represents a load too heavy to carry for a single organization. As many studies testify, due to the complexities of the decision-making processes, and the short time available to resolve the housing emergency, the design processes for post-disaster resettlement finalises in the realisation of a single typology house, sometimes too small, without any cultural relationship with the local architecture and repeated many times in order to maximise the land usage, and speed up the construction process (5).

As argued by Maly (6), in this sense, the general disposition offered by the Build Back Better framework (7) presents some limitations and needs to be implemented with actions in the direction of the social wellbeing of the communities. In the mentioned study the approach proposed, “People Centred Housing Recovery”, is based on the involvement of the residents in the decision-making process at various stages. An interesting point of view about the involvement of the beneficiaries and the “post-occupancy growth” is offered by Lizarralde (8), and in particular about the question of the “incremental housing”, that has become popular in the last decade for the projects by Elemental in Chile and Mexico (9). Lizarralde argued that the incremental construction, conducted and managed by beneficiaries, helps not only the households' needs but also keeps them participating in a significant way in the post-occupancy phases. Beyond the houses, the comprehensive spatial design plays a paramount role in a successful reconstruction project and is fundamental the choice of appropriate design for the urban environment and the landscape design (10). Reimagining the resettlement as an integrated part of the city, made of diverse parts, functions, and uses, rather than an isolated enclosure, marks a big step forward. Within this kind of environment, communities would be able to restart their own lives, grow, and become more resilient, adapting and recovering from challenging events. Social regeneration must be supported by the built environment, through the creation of sustainable buildings that reflect the local architectural identity and culture. These buildings, houses and collective structures, in an innovative perspective, should not only provide shelter but also grow with the community, resist adverse events, and empower their inhabitants.

2.2. Bamboo as a Sustainable Solution

Bamboo (Figure 1) has been recognised worldwide as an alternative to wood in the construction industry due its mechanical properties, but also because its fast growing, its carbon sequestration capacity as a plant, and a sustainable production cycle from raw material to element ready for the construction site with very low impact processing requirements (11). Beyond the use of bamboo as a structural element in the natural shape of poles, treated only to preserve them from dump, fungus and insects, a big interest has been paid internationally to structural elements obtained by the lamination of bamboo. Several studies have demonstrated the good mechanical characteristics of engineer elements obtained from bamboo scrimber or bamboo lamination sheets (12). Use and production of bamboo elements for construction are linked to the areas where this plant is already abundant, and South America is one of those areas, in particular Colombia and Ecuador. The *guadua angustofila kunt*, bamboo autochthone specie of those countries, has been recognised for its structural integrity after the 1999 earthquake in Colombia, that devastated a large region. In the case of the 2016 Manabí earthquake, most of the conventional concrete buildings collapsed and almost 60% of all buildings fell down, while bamboo buildings only reported minor structural damages. After the seismic event, interest in research on the mechanical response of bamboo and its suitability for construction has resulted in its standardization in the seismic-resistant Colombian code NSR-10 (13). Nowadays, the international standard ISO 22156:2021 (14) plays a key role in validating bamboo as a sustainable and seismic resilient material in modern practice, supporting its integration into both traditional and innovative construction systems worldwide. Together with the interest around the qualities of bamboo as a construction material, there has been a growing interest in the opportunities offered by its cultivation, transformation, and production of bamboo as a booster for the local economy in both rural and urban areas. Of the 24 provinces of Ecuador, Manabí is the first for bamboo production in natural forest and plantation, reaching 24% of the entire production of bamboo in Ecuador (15).

Figure 1. Key benefits of adoption of bamboo in local communities.

2.3. Bahareque encementado - Composite Bamboo-based Share Walls (CBSW) System

Through the centuries, the use of bamboo in the Manabí region has defined the development of new construction methods, and new typologies for both urban and rural areas, through the adaptation to the climate and environmental condition of the architecture knowledge brought by

the colonies (16). One of the most common methods of construction, *bahareque encementado* consist in the construction of share walls made from a Guadua bamboo skeleton, sometimes bamboo and wood that work as primary load-bearing elements (Figure 2). The primary frame is usually completed with bamboo slats obtained by sectioning small diameters bamboo canes, nailed horizontally to the main poles, then covered on the external or both faces with a layer of cementitious mortar applied on a metal (chicken) mesh. This creates a composite structure, where (i) the bamboo provides high tensile strength and flexibility, (ii) the mortar layer contributes to compressive strength, fire resistance, and durability, and (iii) together, they form a shear wall, which resists lateral forces such as those caused by earthquakes and high winds (17,18). In the past decades, significant advances have been made to enhance and promote this construction method, including its inclusion in codes, and its standardisation of structural elements to guarantee safety and a good and durable design (18). A growing number of studies on Composite Bamboo-based Share Walls (CBSW) Systems, have demonstrated its practical use, analysed the most recurring design mistakes, misconceptions and good practices, not only in the Manabí region in the aftermath of the April 2016 seism (19, 20) but also in other areas of Ecuador (21) and worldwide such as in Asia, for low-income resilient housing(22).

(a) **(b)**

Figure 2. Photographs showing (a) a wall made of *Bahareque encementado* implemented in a composite bamboo-based share wall, and (b) aerial view of a house produced with the CBSW system.

3. Methodology

The NOVAVIDA research programme, initially conducted a critical evaluation of the (re)settlements built after the 2016 Muisne earthquake in Ecuador, looking specifically to the cities of Portoviejo, Manta, Bahía de Caráquez and Pedernales, which accommodated 90% of the resettlements built by the central government. The analysis of the re-construction showed that all the neighbourhoods, that were rebuilt by the local government, consisted of a series of arrays of dwellings, primarily of semidetached houses over two floors made of loadbearing reinforced concrete walls and steel roof finished with corrugated steel sheet that tends to become extremely warm during the day. This developed construction typology demonstrated to be under-dimensioned for the local needs, un-comfortable, incapable of adapting to future potential extensions, and completely disrespectful of any vernacular architecture character (4). The results were un-homy and socio-technical vulnerable houses and neighborhoods.

In antithesis, our work aimed to understand the possibility to develop alternative construction systems, that could be respectful of the local knowledge, and future proof for future climate changes and population growth. To achieve that, the NOVAVIDA engaged local communities, including politics leaders, academics, professionals and NGOs, through a multi-scalar approach, which was articulated with focus groups, interviews, workshops and surveys to develop design proposals aimed to (i) the reduction of the vulnerability, according to the Sendai principles of Building Back Better, (ii) improving the environmental and social sustainability through the use of local resources and boost the local economy in order to increase the resilience of future post-disaster reconstructions and their inhabitants (23). The project foresees that the reduction of the vulnerabilities coupled with involvement of the communities in the definition of future scenarios would increase the resilience to future shocks.

The design proposal for Portoviejo offers scenarios that integrate housing with other essential structures, such as community centers, for an alternative and more resilient resettlement. This developed both at the urban and at the architectural scale, that can be compared, in terms of size and location, to the resettlements realized after the 2016 earthquake in the Manabí Province. Initially a morphological analysis of the city of Portoviejo along with the study of Ecuadorian vernacular architecture was conducted (24-25). Special attention was paid to those implemented at both, the urban and rural area of the Manabí province. These proposals were intended to be co-produced with local inhabitants through virtual reality experiments, allowing for direct engagement and feedback. By involving the community in the design process, the aim was to foster a sense of ownership and reappropriation of urban spaces, ensuring that the evolving cityscape aligns with the needs, aspirations, and cultural identity of its residents. This participatory approach highlights the importance of co-production in urban planning, emphasizing that cities should not be static but should continuously evolve in response to the communities they serve. A schematic diagram of the overall NOVAVIDA methodology is represented in Figure 3.

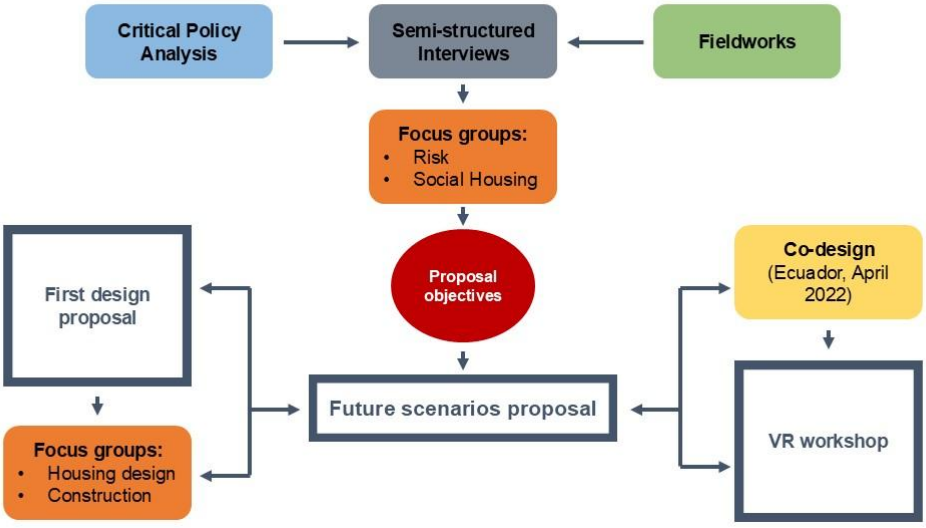

Figure 3. Schematic of the research methodology developed for the co-production of design scenarios.

4. Bamboo-Based Housing Proposals in Latin America: the resulting NOVAVIDA scenarios

A series of workshops and focus groups were developed with local experts and NGOs to evaluate the best material and housing typologies, for future sustainable and resilient neighborhoods. The consultation demonstrated that key principles for future design would include the use of local materials, passive thermal strategies and the adoption of an incremental typology. The initial proposal was also re-verified against the local urban development policy, the building regulations (26) and the seismic standards. Four different housing typologies (Figure 4), were combined in the urban environment in order to alternate residential buildings to public spaces and amenities. Green areas, parking lots and small public buildings such as community centres, nurseries and shops, are all integrated to foster a healthy social development and attract people from the surrounding areas to increase connectiveness with the consolidated city. During the research on the right material to choose for the design proposal, Bamboo was selected for its abundance and for the great opportunity to work as trigger on the development of local economy. The adoption of *bahareque encementado*, largely present in Manabí vernacular architecture, was chosen as a strategy to empower the local labour and give them the opportunity to work with their skills on a system familiar for them.

Therefore, one typology, the incremental house type A, was further developed, conceived with Composite Bamboo-based Share Walls (CBSW) System, and with the opportunity to be extended on the side. In order to guarantee the durability of the houses, the foundation was designed in reinforced concrete, with an upstand at least 400 mm high on the ground level to preserve the bamboo walls from water and dampness (18). The roof was designed as a double pitch with a gap at the ridge to favour natural ventilation inside the house, with bamboo trusses structure completed with corrugated metal sheets outside, chosen as alternative to roof tiles to contain the weight and facilitate the anti-seismic behaviour of the building. Proposals for future reconstructions in Portoviejo were based on a contemporary (re)contextualization of the *vivienda-comercio*. Specifically, recurrent elements, such as the *galería*, a covered porticus, aiming to protect from the sunlight and the heavy rain, during the rainy season, the patio to facilitate any cross ventilation, and in many cases, a hybrid structure made of wood and bamboo (Figure 5). The four typologies of housing were conceived as flexible systems, able to accommodate a variety of uses, to expand in future, and to be built in phases. They are all two storeys high, with the opportunity to grow on the side, according to the incremental housing hypothesis discussed previously. The housing layouts and their flexible use, which is capable to integrate small commercial activities, were well embraced by the experts and inhabitants, who recognised in them a potential solution to the needs claimed of the existing resettlements. More details of the design project can be found in Iuorio et al. 2022 (23).

To verify the local acceptance of the proposed urban settlements and the housing typologies in bamboo a series of interactive engagements, including focus groups and Virtual Reality (VR) workshops were hold in Ecuador. Specifically, Virtual Reality (VR) was chosen from the beginning as an innovative tool capable of engaging people across different age groups—not only under normal conditions but also in challenging, emergency contexts, as demonstrated by several studies (27). Its effectiveness lies in its ability to help non-technical people to experience both indoor and outdoor spaces, moving beyond conventional/two-dimensional representations of the built environment. Indeed, VR has demonstrated to be a valuable resource for involving the Manabí communities in the co-design and evaluation of scenarios at both urban and domestic scales. The VR sessions brought together a diverse range of stakeholders, including local

architects, risk managers, builders, and members of the local community, to assess the feasibility, sustainability, and social acceptance of bamboo-based construction solutions. A particularly notable outcome of these discussions was the overwhelmingly positive reception from both technical experts and local residents. The enthusiasm from experts underscored the architectural and structural potential of bamboo as a resilient, lightweight, and locally sourced material. Meanwhile, community members expressed appreciation for its affordability, adaptability, and cultural relevance. This shared optimism highlighted the immense value that a well-integrated and sustainable bamboo supply chain could bring—not just in terms of housing, but also in fostering local employment, economic growth, and environmental benefits through regenerative forestry practices. Based on the focus group discussion, also hypothesis of future scenarios of re-appropriation of the voids in the designed neighborhoods were developed to demonstrate the opportunities that could be offered to the growing local communities (Figure 6).

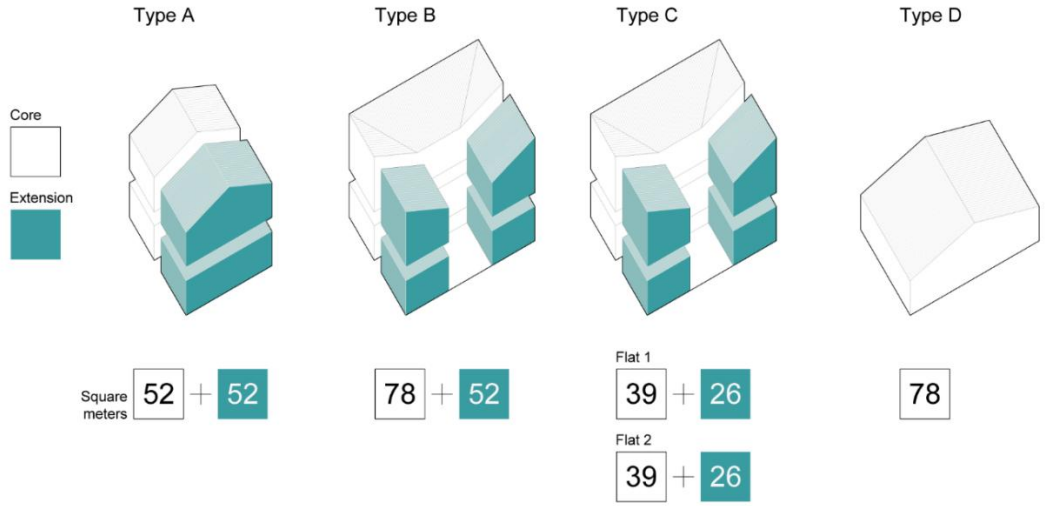

Figure 4. The incremental housing system developed to integrate the *vivienda-comercio* in the fabric unit.

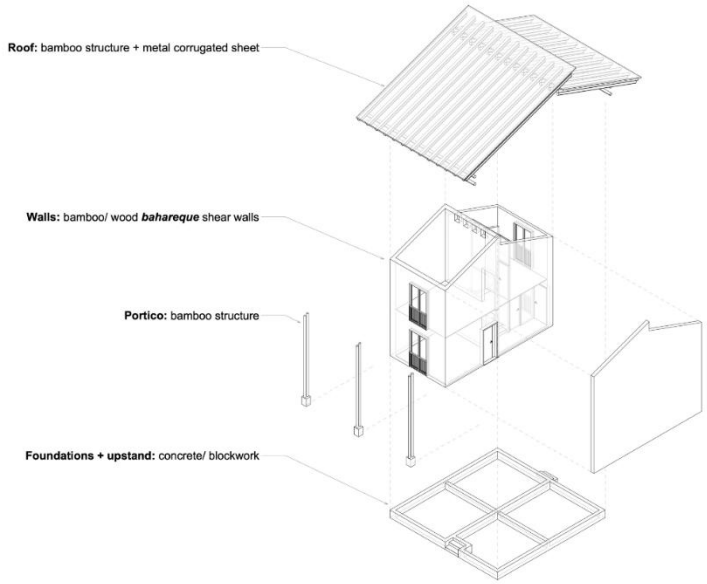

Figure 5. Construction system developed for the basic unit of Type A housing system.

Figure 6. Illustration of a line of Type A housing with hypothesis of reappropriation of the designed voids.

5. Conclusions and general remarks

In Ecuador as in many other areas of the world, the use of bamboo as a valuable construction material, faces several challenges. The most common is the cultural misconception that a bamboo house belong to poor communities. Addressing these perceptions requires advocacy and determination in showcasing bamboo's potential through good practice. Additionally, standardisation and certification processes must be established to ensure quality and safety in particular for the most vulnerable areas of the world.

The use of bamboo in climate and seismic-resilient housing presents a unique opportunity to address pressing challenges in Latin America. By leveraging bamboo's structural properties, ecological benefits, and socio-economic potential, communities can build neighbourhoods that are not only resilient but also sustainable and empowering. The interdisciplinary and participatory approach outlined in this study demonstrates how local materials can have a global impact, when is integrated in bottom-up approaches for housing constructions that aim to the long-term wellbeing of the inhabitants.

Further studies would be conducted to explore the long-term behaviour/performance of bamboo structures under climatic and seismic events. Interest is now paid to the opportunity of scaling up bamboo-based housing built with Composite Bamboo-based Share Walls (CBSW) System. With the right investments in local supply chains and in training for both design and construction stages, bamboo can become the trigger for a more resilient and sustainable development, not only in Latin America.

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