From Forest to Framework
Exploring Temporary Disaster Shelters in Bamboo

Hirunjith Walisadeera

Chalmers School of Architecture
Department of Architecture & Civil Engineering
Master's Thesis 2025

Examiner: Liane Thuvander
Supervisor: Marco Adelfio
Co-supervisor: Flávia Lopes

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Chalmers School of Architecture
Department of Architecture and Civil Engineering
Architecture and Planning Beyond Sustainability [MPDSD]

Chalmers University of Technology
41296 Gothenburg, Sweden
Tel : + 46 (0) 31 772 10 00

CHALMERS
UNIVERSITY OF TECHNOLOGY

ABSTRACT

We bare witness to increasing climate-related disasters, and the need for rapid, cost-effective, and sustainable emergency shelters has become more urgent than ever. This study explores the potential of bamboo temporary shelters as a viable solution for displaced communities in Brazil, with a focus on the early stages of disaster relief (1–4 weeks post-disaster). By utilizing the Guadua and Bambusa species, a fast-growing and locally available material, the thesis investigates how bamboo can offer a lightweight, biodegradable, and easily assembled shelter alternative. Taking into account the principles of sustainability and humanitarian aid, the research aims to develop a shelter design that prioritizes ease of construction, environmental responsibility, and adaptability to the subtropical conditions of Região Serrana region in the State of Rio de Janeiro.

The methodology combines field visits, literature reviews, and hands-on design experimentation. Site visits in the Região Serrana region provide experience into local needs and environmental factors, while research into aid organization guidelines aligns the project with international standards for temporary housing. The study engages with contemporary bamboo construction discourse through literature and practical learning at TIBÁ (Institute of Applied Ecology and Low Impact Architecture), a center specialising in bio-architecture. The design process follows an iterative approach, employing physical modeling and full-scale prototyping of bamboo structures to evaluate structural integrity, assembly efficiency, and material performance.

This study contributes to the ongoing dialogue on sustainable disaster relief by exploring the feasibility of bamboo as a scalable, low-cost, and rapidly deployable shelter material. By focusing on self-assembly and biodegradability, the proposed shelter design minimizes reliance on specialized labor while reducing long-term environmental impact. The findings aim to inform both architectural practice and humanitarian efforts, offering a practical blueprint for integrating bamboo-based solutions into disaster response strategies in Brazil and beyond.

Key words: bamboo, disaster relief, emergency, sustainable, temporary shelter

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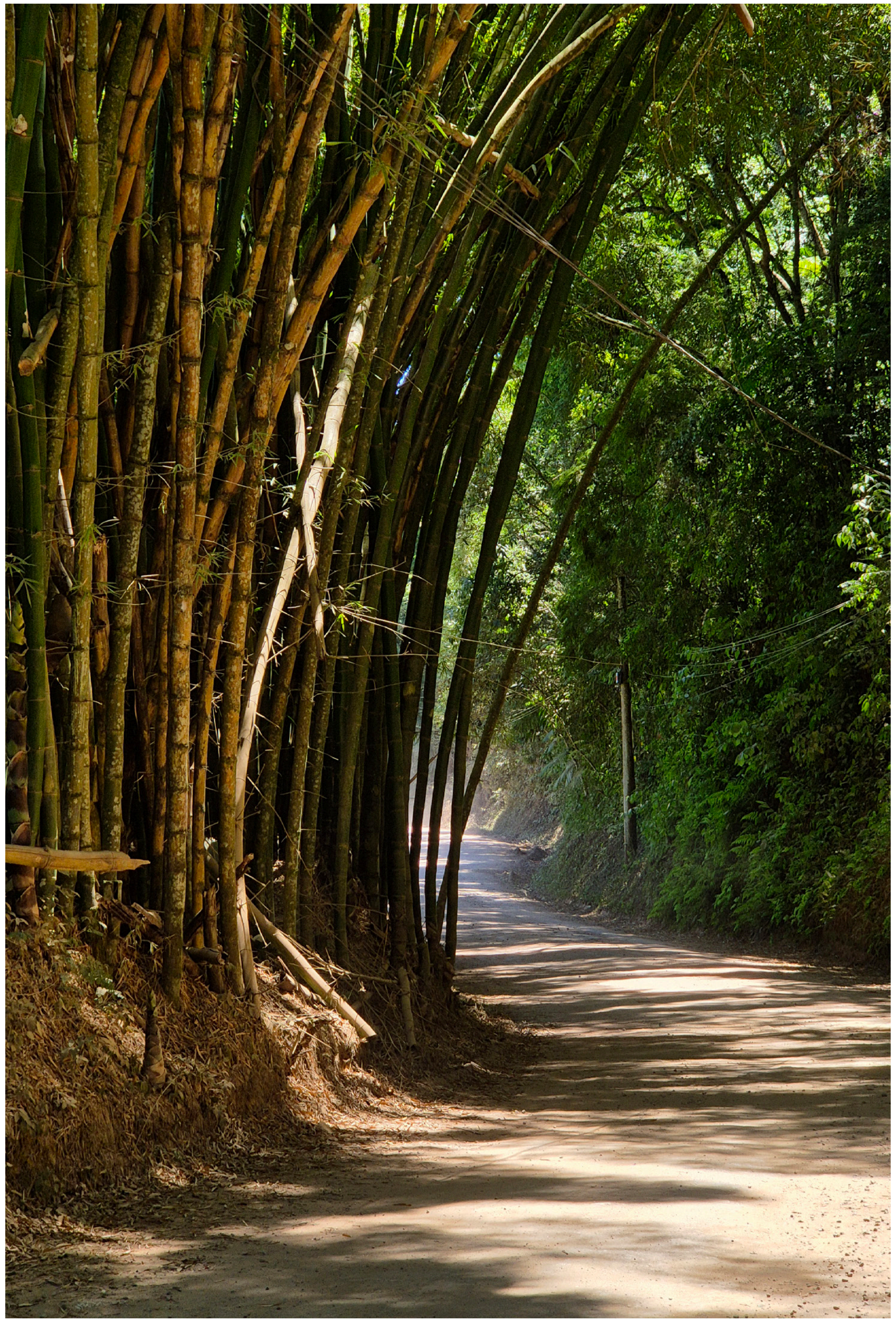
Fig. 1: Aftermath of 2022 flash floods and landslides, Nova Friburgo
Photo: Celso Pupo, editorial license



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← Fig. 2: Rural road on the outskirts of Bom Jardim
Photo: author

AUTHOR

Contact

Hirunjith Walisadeera
walisadeerahirunjith@yahoo.com
+46 737 12 96 55

Education

Architecture and planning beyond sustainability (MPDSD)
Chalmers University of Technology
2024 - 2025

Architecture for Sustainability (Erasmus+)
Politecnico di Torino
2023 - 2024

Architecture BSc
Chalmers University of Technology
2018 - 2021

Work Experience

Intern
Liljewall Architects
Gothenburg, Sweden
2021 - 2022

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CHAPTER 1

INTRODUCTION

PREAMBLE

A natural disaster is a drastic unforeseen event caused by natural forces, resulting in considerable harm to the environment, infrastructure and people's lives. The most common disasters are earthquakes, hurricanes, floods, wildfires, and tsunamis, each differing in scale and damage. The impacts of these catastrophic events stretch beyond the immediate destruction, often leaving hard long-term social, economic, and humanitarian problems for the affected communities.

Crisis management following natural and non-natural disasters is a concern affecting governments as well as communities around the world. Exploitation of land, war, and climate change have made disasters all the more common, and the current upward trajectory shows no signs f slowing down. According to FEMA (2024), the number of disasters associated with climate change has increased from below 50 in 1950 to over 400 in 2010, resulting in a serious loss of both the natural and built environment. Beyond human suffering, one of the harshest effects of these disasters is the destruction of housing, leaving large communities displaced. As a result, housing provision in post-disaster situations is a vital factor in reconstruction, as it addresses the fundamental human needs of security and well-being.

The impact of disasters extends beyond individual homes to entire city infrastructures, affecting millions of people globally. In 2014 alone, 373 natural disasters, which were mostly weather-related, caused the loss of nearly 300,000 lives and resulted in financial damages of approximately $110 million (FEMA, 2024). Events such as Hurricane Katrina in 2005 illustrate the scale of destruction, with over 214,700 homes damaged and more than 800,000 people displaced due to flooding (FEMA, 2024). While improvements in disaster preparedness have helped reduce death tolls in recent years, the frequency of disasters continues to rise. This increase is closely linked to climate change, rapid urbanization, and population growth, creating an urgent need for efficient disaster response and reconstruction strategies.

The most significant post-disaster problem is the provision of permanent housing for displaced people. FEMA states that it may take about five years to restore housing after a disaster, a period that can cause significant delays in the recovery of the afflicted areas. The accomplishment of the housing project depends on how effective the project is in avoiding long-term socio-economic consequences. At this point, the implementation of the strategies is critical because it determines the acceleration of the process of returning to normal living conditions or increasing the capacity to deal with the next disaster.

Temporary Housing

Temporary housing are initial stages of post-disaster housing, and provide the crucial first step in delivering immediate relief to displaced communities. It provides immediate shelter as its construction is fast and cost-effective. Temporary housing is built mostly with materials that are already available, like tents, prefabricated units, and re-purposed community spaces. The primary goal is to address the urgent need for shelter in the aftermath of a disaster, ensuring that affected individuals have a safe place to stay while more sustainable solutions are developed. However, due to logistical challenges and overcrowding, temporary solutions often face problems with sanitation, electricity, and insulation, making them unfit for long-term use.

Physical and satellite images reveal that despite being meant for temporary housing, shelters often stay in use for much longer, even for years (Quarantelli, 1991; Johnson, 2007). This issue is common in developing countries where housing shortages, and land speculation make reconstruction harder. Emergency housing, while essential during the disaster response process, needs to be brought into the reconstruction strategy and implemented quickly and efficiently so that the transition to more stable housing solutions can happen in a timely manner.

↑ Fig.4: Aftermath of the 2011 Catastrophe, Petrópolis
Photo: Focus Pix, editorial license

Situating the Project in Brazil

The field work for this project was conducted at TIBÁ, a bio-architecture institute located in Bom Jardim, in the state of Rio de Janeiro. Located in the Região Serrana highlands, the region faces yearly floods and mudslides. In January 2011, a catastrophic series of floods and mudslides swept through the mountainous areas of Nova Friburgo, Teresópolis, and Petrópolis. The catastrophe claimed at least 916 lives and caused extensive damage to infrastructure and homes. This specific disaster is one of the most weather related disasters in Brazil's history. These recurring incidents highlight the regions vulnerability to heavy rainfall and the critical importance of effective disaster preparedness and to lessen the impact of future natural disasters.

While the state of Rio de Janeiro was the specific context for the field work, a shelter designed for its sub-tropical climate will also be deployable in similar climates around the world. The scope of this project will be Brazil, but it is worth mentioning that a vast number of countries, specifically in South- and South East Asia, have a great proficiency in bamboo construction, and may be able to tweak and adjust the design to their needs.

RESEARCH QUESTION & AIMS

How can locally sourced bamboo serve as a more sustainable, low-cost alternative to conventional materials in the design of temporary shelters in Brazil?

AIMS

The aim of this thesis is to explore a design and implementation of a temporary shelter proposal in bamboo, with a dwelling area enough to house a family of four. The main focus of the design is to be sustainable, cost-effective and rapidly deployable without the access to skilled labour.

The main structural parts of the shelter was built with bamboo, a locally available material that is structurally strong in comparison to its weight, rapid growing, and biodegradable. The study also focused on designing a system that could be quickly assembled without specialized tools, ensuring that affected communities can participate in their own recovery process. The design of the shelter was dictated by a strict set of guidelines outlined by humanitarian organisations. The study also explored scalability and modularity, allowing for adaptability in different geographical and climatic contexts.

This thesis investigates the environmental aspects of using bamboo as a construction material, by examining their biodegradability, potential for re-purposing, and end-of-life disposal. By assessing various construction techniques, material treatments, and logistical strategies, the study proposes a model that minimizes waste and reduces dependency on non-sustainable temporary housing solutions. This study aspires to contribute to the broader discourse on sustainable disaster response, offering a cost-effective and environmental friendly alternative to conventional emergency shelter approaches.

THEORY

To gain perspective of the subject, existing guidelines from humanitarian aid organizations such as the UNHCR, Red Cross, and Shelter Centre were reviewed. These guidelines shaped the design criteria, ensuring that the proposed bamboo shelters align with international standards for emergency housing, including factors like space requirements, durability, and ease of deployment. Existing literature on the stages of disaster relief and appropriate solutions were also reviewed.

METHOD

To better understand both bamboo as a building material and the projects' context, the majority of this thesis was completed during a field study period in Bom Jardim, RJ, Brazil.

To ground the research in its real-world context, field visits were conducted in the disaster-prone Região Serrana region of Brazil. Two cities were visited and documented: Nova Friburgo (large city) and Bom Jardim (small city). These visits provided first-hand insight into the local climate, terrain, and building techniques utilised by the communities.

An in-depth study of bamboo construction was conducted through literature review and hands-on learning at TIBÁ. Books, academic papers, and case studies on bamboo architecture were analysed alongside practical experience gained at TIBÁ, a well-known research and training center for natural construction in Brazil. This combination of theory and practice strengthened the technical foundation for the shelter design.

The research includes an iterative design process using physical modeling and prototyping of bamboo shelters at TIBÁ. Small-scale models were built to explore structural efficiency, flexibility, and ease of assembly. Through full-scale prototyping, design, structural integrity and time were tested in real life conditions.

DELIMITATIONS

The study was conducted using only two species of bamboo. It is important to recognize that bamboo exhibits a wide range of structural characteristics depending on the species and the environmental conditions in which it grows. Different species from different geographical regions may perform very differently under stress or environmental exposure. Therefore, the results of this study may not be fully representative or applicable to shelters constructed using other bamboo species available in various parts of the world.

The project faced limitations in terms of both time and available resources, which restricted the ability to test certain critical components of the shelter. Specifically, the roof and floor materials proposed in the final design were not physically tested on the actual prototype. This results in a gap in understanding how these components would perform in real-world conditions, especially in terms of durability, water resistance, and ease of assembly.

Areas prone to landslides typically experience high levels of rainfall and strong winds, conditions under which naturally sourced roofing materials, for example thatch or palm leaves, are often unsuitable due to poor water resistance and limited durability. As a result, the design includes waterproof plastic tarpaulin or canvas as roofing material. While these are not entirely sustainable options, they are considered more reliable in providing temporary protection from the elements in emergency situations.

The bamboo shelter design was not tested using all the intended materials outlined in the conceptual plan. This means that the performance of the complete shelter structure, particularly under real-life environmental challenges such as heavy rain or strong wind, could not be fully evaluated during the short project duration at TIBA. Consequently, certain practical aspects such as water resistance, structural stability, and occupant comfort could not be verified.

Ventilation in the shelter was achieved primarily through the main entrance and a small perimeter gap at the bottom edge of the tent. While this allows for minimal air exchange, it does not provide sufficient airflow for occupant comfort in warm or humid conditions when the main opening is closed. A more effective ventilation solution, such as an operable window or vent, was not included due to the project's prioritisation of a lightweight, easily assembled structure that does not require skilled labor or complex tools.

Given the above constraints, the bamboo shelter, in its current form, may not be suitable for prolonged occupancy. In some disaster-affected regions, temporary shelters are often used far beyond their intended duration due to delays or failures in disaster response systems. Under such circumstances, this shelter may not provide adequate protection, comfort, or durability over an extended period.

CHAPTER 2

THEORY

THEORY PART 1:
POST DISASTER HOUSING

The first part of this chapter aims to provide context of the overarching aspects of post-disaster housing. The chapter will point out in which phase of disaster aid this study will operate in (the temporary shelter phase) as well as which design criteria that were considered when designing the proposal.

WHAT IS TEMPORARY HOUSING

Sufficient roof coverage equally contributes to the human living in the very first step of a disaster (The Sphere Project, 2011). Contrary to popular belief, a shelter only provides a roof, but living conditions must also be met first. To make a shelter livable, it must provide adequate clothing, blankets, mattresses, stoves, fuel, and access to the basic services like water and sanitation (Ashmore, 2004). Disaster relief (DR) shelters are very specific post-disaster accommodation structures for the secure, hygienic, and livable settings where displaced people temporally can stay until they can go back to their initial permanent houses. Many DRM sources are designed to be flexible, which means they can be quickly set up, taken down, and stored until the next time they will be used (Arslan, 2007). These light-built structures are multifunctional and could be in the form of plastic sheeting, tents, prefabricated housing, or repurposed public areas like community centers, university dormitories, places of worship, sports venues, and private rentals (AGOTS, 2007).

The main function of a shelter is different from that of a house. On the one hand, shelters are the first ones to shelter and protect the people from bad weather after a disaster has occurred while houses on the other hand are but elements to fostering good daily routines and their owners' long life time (Johnson, 2007b; Félix et al., 2013a). The United Nations Office for the Coordination of Humanitarian Affairs and European Space Bureau (UN/OCHA/ESB, 2006) and Hadafi et al. (2010) assert that a sufficient dwelling shelter is such "the immediate environment for all aspects of family life, providing protection from the elements, secure tenure, personal safety, and access to clean water and sanitation, proximity to places of employment and educational and health care facilities." While contrast, a house is generally said to be "lodging, shelter for human habitation," including both the actual living area and its environment. In addition, it even contains government programs that aim at providing housing for low-income families (UN/OCHA/ESB, 2006; Hadafi & Fallahi, 2010).

↗ Fig. 3: Paper tube temporary housing by Shigeru Ban

Source: Brett Boardman, courtesy of Sherman Contemporary Art Foundation

↘ Fig 4: Tierras Temporary Housing in Palenque by Manuel Cervantes Estudio

Source: César Béja, courtesy of Arqutectura Viva

STAGES OF DISASTER

According to Arslan and Ünlü (2008, p.2), the disaster period can also be divided into four stages:

Stage one: the first and most important one, a approximately 72-hour period, concerns the provision of emergency shelter until the emergency situation becomes stable.

Stage two: a 60-day period providing the survivors with temporary shelters along with essential needs such as food, water, and medical support while they are displaced.

Stage three: providing 'interim housing', for a longer period lasting a year or more, until suitable conditions for a permanent solution is met.

Stage four: the permanent move from temporary solutions to permanent housing.

It is important to state that the timeline for these stages may not occur in a linear manner and may change drastically according to the aftermath of the natural disaster and the context of where it takes place (see figure 5 and 6) (Johnson 2007). The length of the period between the occurrence of the disaster and people's response is a major determining factor in the stages not being the same. In most cases, survivors can even skip some of the listed stages or do some simultaneously. Some possess different capacities to rebuild, where having more resources at hand may yield a permanent solution faster. However, most people who reported to be significantly affected due to the natural disasters went through transitional or temporary housing stages for months or even years before they got the permanent place.

STAGES OF POST-DISASTER HOUSING

According to Johnson (2007, pp. 436-437), the four post-disaster recovery phases and the different stages of temporary housing occur in the following order:

1. Emergency Shelter - few days

This refers to the immediate, short-term accommodation that are given during a crisis. It includes public service shelters, staying with friends or family, or quickly crafting a makeshift cover from plastic sheeting as refuge for the night. This stage is very short and the access to food and medical supplies may be limited.

2. Temporary Shelter - few weeks

This phase is specifically for short-term accommodation after a disaster, most often in the form of tents or designated communal facilities. The shelters are to be used for the survivors of natural disasters. They are offered food, water, and medical assistance from the aid organization. The shelters' purpose at this stage is to provide a weatherproof, private resting space. Functional spaces for cooking, social interaction and recreation are not prioritised due to the size and short-lived nature of the shelter.

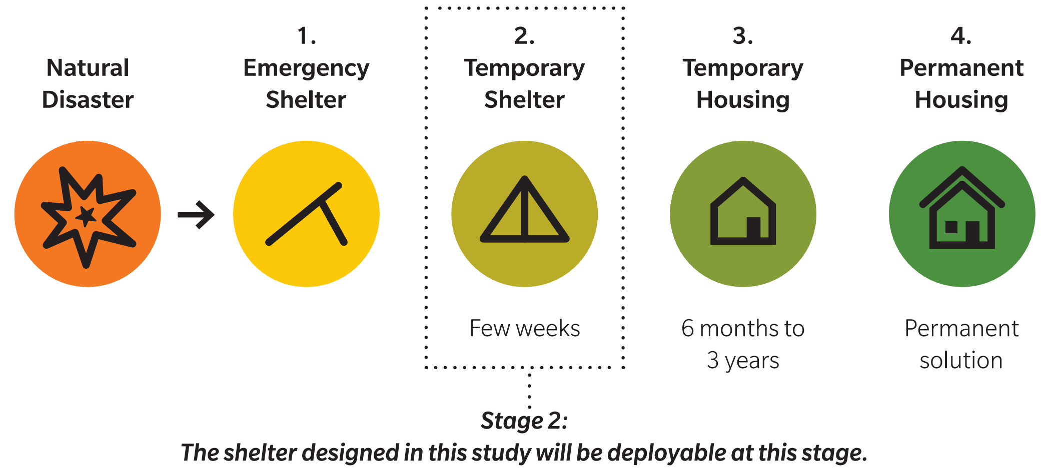
3. Temporary Housing - 6 months to 3 years

At this stage, the transition to permanent housing becomes a reality as displaced people gradually adopt their previous lifestyles, such as returning to work and school, and their daily home life. Depending on the situation, the temporary housing may involve moving to rented apartments, living in prefabricated homes, or using makeshift shelters such as containers or shacks. People will often have access to food, water and medical support provided by aid organisations.

4. Permanent Housing - permanent solution

A permanent housing solution that may stem from flexible transitory forms like a progressive shelter, core shelter, or an entirely new house. The houses are meant to be resilient and resistant for future disasters and provide security for people exposed to disaster. To minimise future risk, the housing should factor building with proper structural integrity, choosing a safe site, and following disaster-resistant construction norms (Quarantelli, 1991; Johnson, 2007).

STAGES OF POST-DISASTER HOUSING



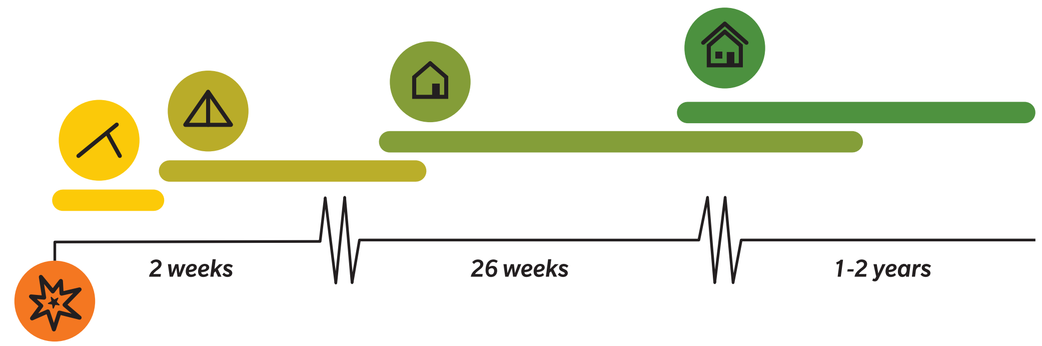


Figure 5: An optimal sequence of disaster recovery

Each stage is built in a timely manner and the inhabitants can move from one solution to the next.

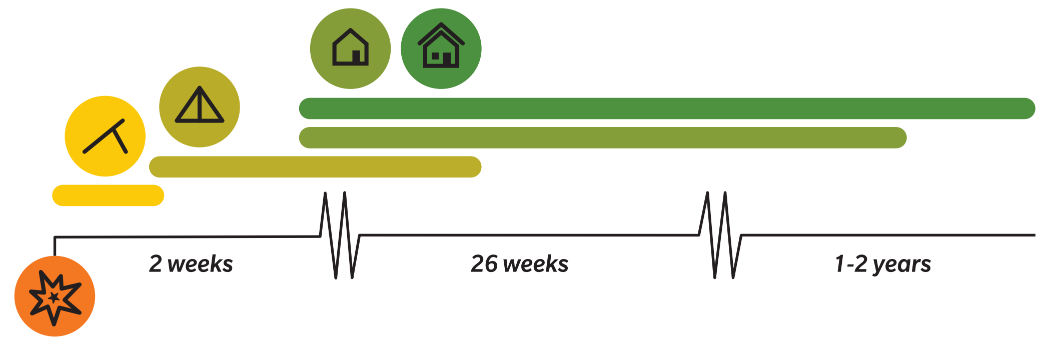


Figure 6: An irregular sequence of disaster recovery

Several different stages happening simultaneously, as survivors have different means to solve their needs, or an unfair distribution of disaster aid. Some may get access to permanent solutions quickly, while others are left in temporary solutions far too long.

DESIGN CRITERIA

The key problems that the temporary shelter aims to solve are tied to basic needs, such as basic physiological needs and security. Alongside a forgiving temperature range, there is an opportunity to answer these needs with a lightweight structure using local biodegradable materials. Further criteria such as cost and transport were added to the equation due to their relevance for a context centred approach.

Design criteria for the this study were chosen from the UN's requirements for emergency shelters, as well as The Shelter Centres guidelines (UNHCR, 2011) (Shelter Centre, 2010). As detailed in figure 7, the criteria were sorted into three levels of detail, macro, meso, and micro. This helps determine at which stages of each criteria is to be considered when designing.

Colour

Colors affect the mind and behaviors, largely determined by the physiological, environmental, and sociocultural factors prevailing in that situation (UNHCR, 2011). Warm colors promote the mood for meeting other people, while cool colors create an effect of relaxation. For temporary shelters, it is advised to avoid green and brown tones that affiliate with military camps (UNHCR, 2011).

Light

Sunlight, which is the only natural light in the absence of electricity, is needed for indoor lighting. Opening windows and holes can increase safety by allowing visibility, but they must be placed cautiously because they can create both security and privacy problems (UNHCR, 2011).

Space

UNHCR 2007 stipulates that people in emergencies must have a minimum of 3.5 m² per person in tropical climates, and kitchen or cooking spaces are not included. Hence, the shelter should have a capacity of at least five people and should provide a minimum floor area of 14 m². Furthermore, at least 60 percent of the floor area should be with a ceiling height of 1.8 meters for sufficient livability space (UNHCR, 2011).

Transport

Temporary bases should be portable and simple for the transport to be done effectively. A packed shelter should not weigh more than 25 kg and should not take a volume of more than 0.4 m³. The shelter package should be easily transportable by a smaller lorry, or even better, in the back of a pick-up truck or large car (with trunk opened). The dimensions should not exceed 500x500 mm, with the maximum height of 2100 mm (Shelter Centre, 2010). Since all components of this shelter are sourced within Brazil, global shipping logistics can be disregarded. However, the dimensions still allow multiple shelters to fit on a 1200x800 mm EUR pallet, should international shipping become necessary.

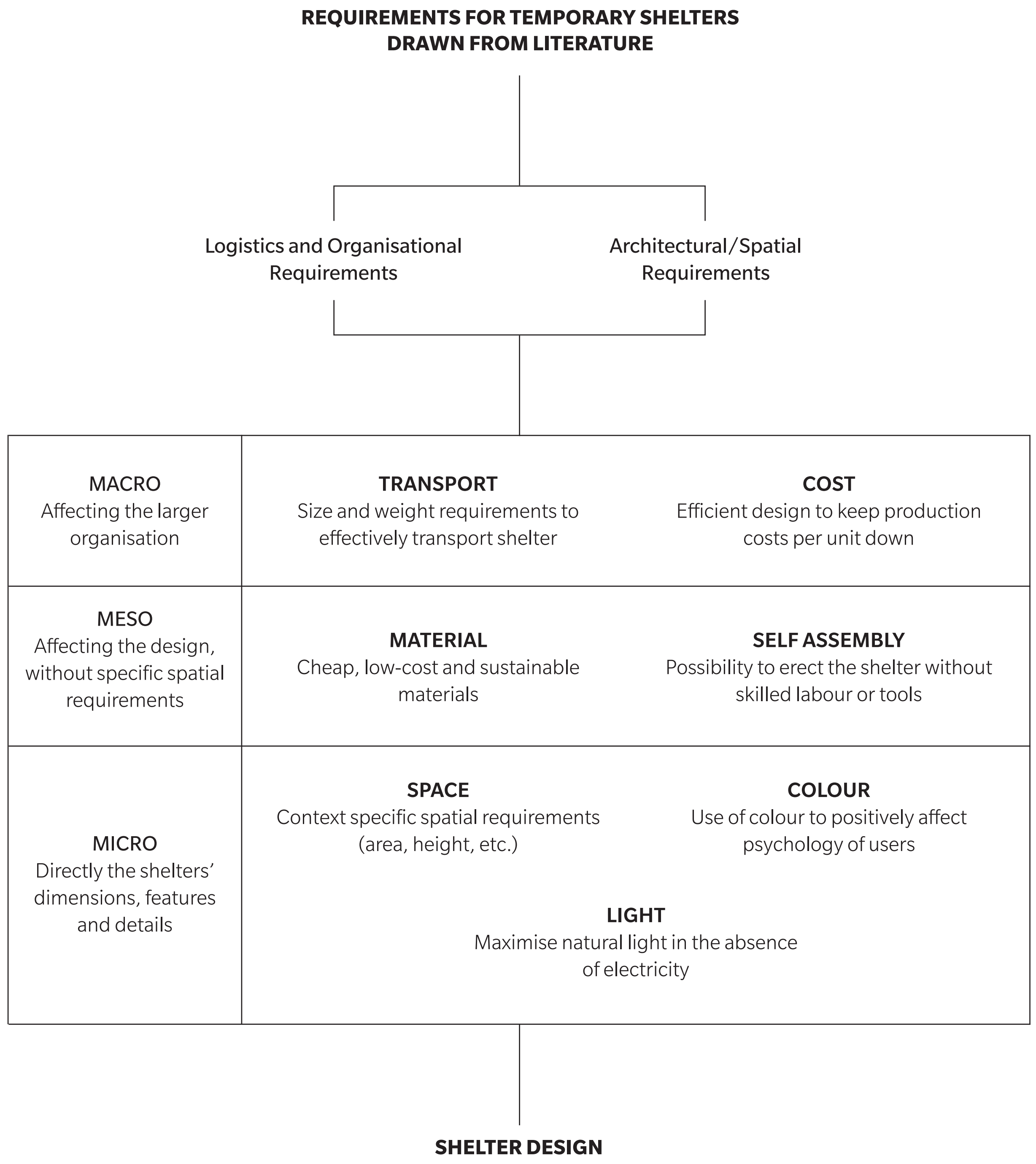
Cost

The amount of funding allocated per shelter can vary depending on the type of disaster, making it essential to keep the cost per unit low to ensure all situations can be effectively accommodated. Keeping costs down is also in the interest of shelter agencies, as using low-cost materials helps prevent shelter components from being stolen or resold.

Transport expenditures can dramatically alter the total costs: the airfreight costs for a 50 kg tent can accumulate to 1000 USD per unit, while the ocean freight only costs 20 USD per unit (Axelsson 2012). This further stresses the importance of local sourcing and production to keep costs down. The speed of production and the logistics of delivery also are critical factors when considering shelters.

Self Assembly

A small group of people with little technical skills must be able to easily assemble the shelter in unfavourable conditions. In the assembly phase, time is equally critical. While a temporary shelter may only take a few hours to set up, the sheer number of displaced individuals and a limited workforce can cause delays. Since immediate shelter is a top priority, the initial solution should prioritize ease of installation with minimal tools required.



↑ Fig. 7: The central design criteria in this study

REFERENCE PROJECTS

← Fig. 8: UNHCR Family tent

→ Fig 9: Algerian Two Pole tent

Source: UNCHR Shelter Design Catalogue 2016

UNHCR FAMILY TENT

The Family Tent is a ridge-style double fly tent featuring elevated walls. It has a total usable area of 23m^2, which consists of 16m2 of main floor area plus two 3.5m2 vestibules. For additional insulation the tent has a double fold ground sheet. For enhanced stability, the outer tent is supported by a frame consisting of 3 upright poles, 1 ridge pole, 6 side poles, 4 door poles, 3 guy ropes on each side, and 2 guy ropes at each end.

Dimensions

The external dimensions of the tent are 4 m in width and 6.6 m in length, including the vestibules. The central height is 2.2 m. When fully assembled with guy ropes, the tent occupies a footprint of approximately 61 m².

Package

The components: double-fly tent, poles, pegs, and hammer, are all securely packed with the groundsheet and wrapped around to prevent damage. Important to ensure that metal components do not puncture the packaging. Each tent package includes illustrated assembly instructions of setup.

Materials

The tent's outer roof and inner canvas are made from a polyester-cotton blend and the groundsheet follows the plastic sheeting standard. (UNHCR, 2016)

ALGERIAN TWO POLE TENT

The Framed Tent is used by UNHCR, ICRC and IFRC and suitable for a family of 5 people, it is heavier and more expensive as compared to the standard Family tent, and meant for situations where the standard Family Tent is not the appropriate solution, being ideal to be used in urban areas. This self-standing frame tent allows easy set up on hard surface, offers more inner volume, and requires a reduced surface area for erection, as compared to the standard Family Tent. Nevertheless, to assure a good wind resistance, the tent needs to be securely anchored to the ground with the provided guy ropes and pegs. The symmetric flaps offer the possibility to join 2 tents together lengthwise to create larger units.

Dimensions

4.15 m in width, 4 m in length, and a central height of 2.4 m.

Package

All components, including the tent and its accessories, are packed together in a single bundle for ease of transport and storage.

Materials

The outer roof and inner tent canvas are made from a durable polyester-cotton blend, while the groundsheet conforms to the UNHCR's standard for plastic sheeting (UNHCR, 2016).

→ Fig. 10: Tuareg Shelter

← Fig 11: Tuareg Tent

Source: UNCHR Shelter Design Catalogue 2016

TUAREG SHELTER

The Tuareg shelter initiative was set in motion in Burkina Faso, with a specific focus on supporting the nomadic refugees who had escaped from northern Mali. The initiative was aimed at extending the shelter support to the Malian refugees who have been residing in camps, with the main objective being the reduction of their vulnerability to protection-related and settlement-associated challenges in the temporary settlements.

The project features a vernacular shelter design, which implements traditional materials and is based on the cultural practices of the Tuareg people. One of the main points emphasized is the prominent role of the Tuareg female gender in the construction of shelters.

The nomadic structures allow the shelters to be easily moved and reassembled according to the traditional way of life. The delivery of materials was done through existing social and tribal structures in the refugee communities. The special shelters kits were created in order to integrate various sizes of the families, thus providing the materials for building a shelter of the right scale (UNHCR, 2016).

TUAREG TENT

This emergency shelter project was developed in Sahrawi refugees' camps in Tindouf. The design not only servies the cultural but also the climatic needs. The tents were made up of a combination of canvas, blended cloth, bamboo poles, iron pegs, and cotton rope, which is why the constructed tents had an internal area of about 49 m² and a total footprint of 121 m².

Materials

Canvas Sheet: Each family was given 70m x 1.5m high-quality canvas for the building of the Sahrawi tents. The tent users have been very satisfied with the canvas due to good properties like durability, weather capability and waterproofing. Cotton sewing thread was also used to reinforce the points of stress, such as the joints between wall, roof, door, and window.

Blended Cloth: An additional 70x1.5 meters of the blended cloth were provided to each family.

Bamboo Poles: Every bamboo pole was equipped with a 12 cm metal pin rivet on the top that made assembly easy and provided strength.

By these materials, shelters were built that in their design still followed the cultural tradition, while at the same time, providing effective protection in the extreme desert conditions (UNHCR, 2016).

THEORY PART 2:
BUILDING WITH BAMBOO

The second part of this chapter aims to provide an introduction to bamboo as a constuction material, featuring techniques used South America and Asia. It will touch upon the biology of the plant, and havesting and treatment. The chapter will focus on the species used in the study, namely Asper, Guadua and Vulgaris.

BAMBOO IN BRAZIL

The history of bamboo in Brazil reaches back to the times of its indigenous cultures before the arrival of the Portuguese, and the plant was called taboca and taquara. The first scientific studies on bamboo in Brazil were developed during the 19th century, between 1829 and 1835. Nees Von Esenbeck, a German biologist and physician, made significant contributions to the taxonomy of bamboo and wrote a chapter on grasses, bamboo included, in Flora Brasiliensis no Brasil. Later, he published a separate study exclusively on Brazilian bamboos, and it is recognized as the first dedicated work on Bambusoideae species.

A 2001 study identified 17 genera, 137 species, and 2 subspecies of bamboo in Brazil, with the highest concentration found in the states of São Paulo, Minas Gerais, Santa Catarina, Bahia, and Paraná. The Atlantic Forest, stretching from Pará to Rio Grande do Sul, hosts the greatest diversity of Bambusoideae species. However, exotic bamboo species introduced during Portuguese colonization have played a more significant economic role and have received greater attention than native species. The study highlights Guadua and Bambusa as the most valuable bamboo genera in Latin America, with the most commercially important species being Guadua angustifolia, Guadua amplexifolia, Bambusa vulgaris (introduced/exotic), Bambusa tuldoides (introduced/exotic), and Phyllostachys aurea (introduced/exotic).

BIOLOGY

Bamboo culms emerge directly from underground rhizomes (stalks). In species with pachymorphic rhizomes, the thick, segmented underground stems grow in a clustered, zigzag pattern, creating a dense, three-dimensional network that can reach a height of up to two meters. The other , for plants that have leptomorphic rhizomes, the development is from underground stems that spread horizontally which creates a more spaced-out pattern of growth. Some bamboo species like this show traits of both types (Minke, 2016).

Bamboo has an unusual growth form in which everything is set - all nodes and internodes of the culm, which has grown up to, are already created in the sprout. When growing, only the internodes elongate, whereupon the node diameters stay constant. The internodes lengthen; starting from the bottom, and the node diameters remain the same. It is the specific wavering or cone-shaped form of the fully developed culm which comes out of this. The “mother” plants of the first generation are smaller, have a diameter of less thickness, but each next generation is thicker than the previous one (Londoño, 2003).

One of the species that grows quick is Guadua Angustifolia Kunth, which grows on average around 21 cm a day. In a month, it grows to about 80% of its actual height and can grow in total up to between 15m and 30m in five months. Every year, this species gets to produce 1,200 to 1,350 crop of culms on an area of one hectare. It, however, becomes construction-ready usually four to six years after the lignification process. This time is taken for the vascular bundles to dry and mature, and thus the finished structure is suitable for cutting and building due to becoming hardened (Minke, 2016).

In the initial growth stage, bamboo culms can have moisture content as high as 80%, but the moisture level decreases to around 20% after four to six years of maturation. Interestingly, the bamboo that is grown on slopes, with water scarcity being an issue, develops tougher and more fibrous tissue which makes it stronger in compression compared to the bamboo in flat, wet regions (Minke, 2016).

SPECIES IN THIS STUDY

Dendrocalamus Asper

The largest of the species used in this project. Even though it is a native plant of East Asia, Dendrocalamus asper is now grown and found wild in some states in Brazil, such as São Paulo and Rio de Janeiro, since it was first introduced in the country in the 1930s.

Use in this project:
Used in the dome frame. Cane cut vertically into slats, 30 mm wide and 2100 mm long. As one of the larger bamboo species, its cane can be cut into smaller parts and still hold structural integrity.

Guadua Angustifolia Kunth

A species native to South America. Abundant in the states of Sao Paolo and Rio de Janeiro, it is a fast growing yet strong species. Can be used for structural components such as pillars and beams.

Use in this project:
Anchors: 300 mm pieces of cane hammered down into the ground and used to anchor the dome frame. This species was chosen for its inner diameter, which is around 100 mm.

Bambusa Vulgaris

Like other bamboos, Bambusa Vulgaris develops directly from its rhizome. Its pachymorphic rhizomes create a compact, three-dimensional network conducive to forming dense clusters of culms. This species was used as a substitute for Guadua during early prototype development, as it offers comparable structural properties.

Use in this project:
Vulgaris served as an alternative for the shelter feet during the prototype phase.

↑ Fig. 12: Species of bamboo used in this study, grown and harvested at TIBÁ. From above:

1. Dendrocalamus Asper
2. Guadua Augustifolia
3. Bambusa Vulgaris

Photo: author

↑ Fig. 13: A plethora of wild bamboo species growing in the states of Rio de Janeiro and Sao Paolo, encountered by the author during site visits and trips.

Photo: Author

HARVESTING & TREATMENT

According to Minke (2016, pp. 17-20), the process of harvesting and preparing bamboo for construction can take many paths. Below are different methods that suit the context of this project situated in Região Serrana, Brazil. Bamboo contains a large quantity of starch, which attracts insects, especially when the level of sap is high. Also the presence of humidity can cause the appearance of fungus and lichens. To guarantee durability in bamboo construction elements, it is important to take into account good procedures for cutting, drying and treatment.

Cutting

Bamboo is usually harvested with a machete or saw, and the cut is usually made just above the first or second node(raw bamboo). The cut must be made at an angle so that rainwater will not flow down into the rhizome, which could cause rot. Dry season is the best time for bamboo harvesting because bamboo has low water content at this time. It is worth noting that both lunar cycle and the time of day affect the humidity level inside the plant. The moisture content is at its lowest during the waning moon and in the early morning, the time before the sun rises. For construction purposes, the cane is supposed to be cut at the age of three to five years, when the tissue has been fully lignified and hardened (Minke, 2016).

Cleaning the Surface

Lichens and surface residue on bamboo can be taken off with steel wool, however this method is very expensive, takes a lot of time and is possibly harmful to the respiratory health of the workers. Metal brushes or sponges are also to be avoided since they can cause damage to the outer protective layer (the culm sheath), thereby weakening the bamboo. More profitably, a safe and affordable way is to wash it with high-pressure hydrowash, which does not compromise the structural integrity of the bamboo while effectively cleaning the surface (Minke, 2016).

Air Drying

The simplest way of drying bamboo is by arranging the culms in a tripod-like formation that opens them to the maximum sun and wind. Controlled drying can be done in plastic-covered greenhouses that should be opened at night to allow drier wind in and should be closed during the day to trap solar heat (Minke, 2016).

Preservation by Immersion

In order to protect bamboo from insect and fungal attacks, the most effective preservation method is immersion in a biocidal solution which works both as an insecticide and a fungicide. For better absorption, it is necessary to perforate the culms at each internode, in a staggered pattern (to prevent cracking) or through a longitudinal bore with an iron that pierces all the nodes, the culms are then submerged in the solution for several days. It is very important that during the whole process bamboo is not dry because if it is completely dried the preservative salt will not get through the culm wall. Osmotic absorption occurs only when the culm has moisture to some degree, which enables the salts to come in along the water.

Commercially available preservatives typically contain copper sulfate, sodium dichromate, or zinc chloride, but an environmentally friendly and cost-effective alternative is the use of pentaborate which is a mixture of 5% borax and 5% boric acid in water (Minke, 2016).

Storage

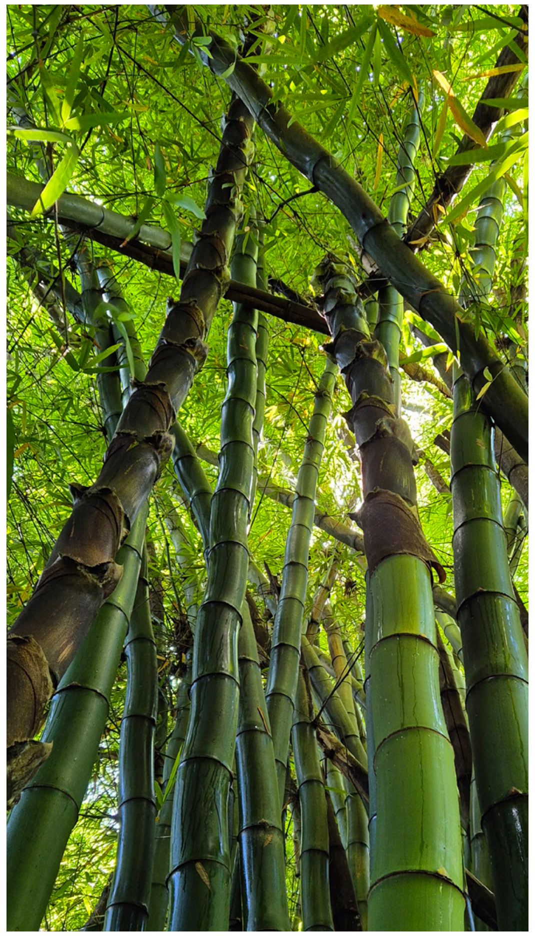
As a hygroscopic and porous material, bamboo readily takes in moisture vapor and in liquid form. The swollen outer shell of the culm when wet is the cause of mechanical strength deficiency. Because of these reasons, bamboo must be kept in places that are dry and tightly covered with enough ventilation so that it does not drink water and stay durable (Minke, 2016).

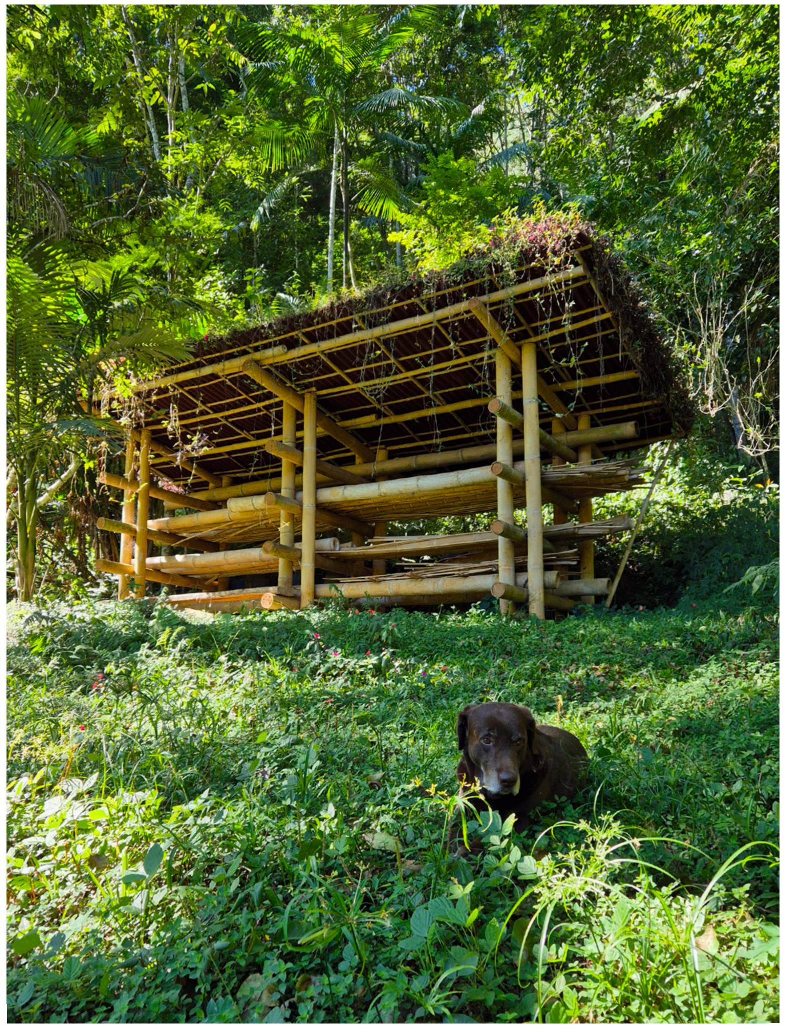
Sustainable agricultural practices

This thesis aims to provide a sustainable alternative to unsustainable materials, which is why it is paramount that sustainable practices be upheld when sourcing bamboo,

Just as any other agricultural resource, bamboo must be grown and harvested with respect to its natural context. Clearing natural forest for growing bamboo should be avoided as there is more than enough grasslands in the region to support the scope of this project.

As bamboo is fast growing and can be harvested within 6 years, the total land used per material produced is very efficient (Londoño, 2003). It is also important to state that bamboo's fast growing nature can also be a pitfall, as it has the tendency to take over if not kept in check.





↑ Fig. 14: Bambusa Vulgaris at TIBÁ
Photo: Author

↖ Fig. 15: Cutting Phyllostachys Aurea for model-making
Photo: Author

↖ Fig. 16: Canes of cut Bambusa Vulgaris
Photo: Author

↘ Fig. 17: Harvesting Bambusa Vulgaris with chainsaw
Photo: Author

↙ Fig. 18: Bamboo storage at TIBÁ
Photo: Author

STRUCTURAL ELEMENTS

SELECTING CANES

The selection of canes for construction is of great importance due to the natural variation of the material. According to Minke (2016, pp. 17-20), these factors should be considered when choosing suitable canes for construction:

1. Only mature and correctly dried bamboo should be used, preferably culms between four and six years of age. This age range offers the best balance of strength and durability. Canes with visual cracks should be thrown away due to the lack of the structural integrity.

2. The selected canes must be straight or bent slightly, without internal bends. For use as columns that transfer large forces, the eccentricity of the axial load should be 0.33% of the axial total length to avoid any instability, or buckling under pressure.

3. Bamboo culms infested by insects or fungi are unsuitable for construction as such degradation weakens the internal fibers and may lead to structural long-term collapse. A visual inspection for discoloration or surface damage is necessary.

4. Canes with fungal growth pollution, lichen, or other surface contaminants must be cleaned thoroughly before the use. Surface growths can sometimes depict internal damage. If not treated, it may indicate a deeper biological problem.

5. For columns, the lower third of the culm should be used. This part typically has thicker walls and closely spaced nodes that provide compressive strength and resistance to buckling more than upper sections.

6. When picking bamboo for beams, culms that have longitudinal cracks should be avoided, particularly along the neutral axis as these reduce down the flexural strength significantly and lead to premature failure under load.

7. Bamboo raised at higher altitudes or in drier soil conditions have shorter internodes and node space spacing. The tissue is denser and has more mechanical strength which makes these canes more reliable for use in construction.

COMPONENTS IN THIS STUDY

This study features bamboo used in two basic forms: canes and slats. Six 1.2m canes cut from Guadua were used as anchors for the dome frame, which in turn was constructed with bamboo slats made from Asper.

CANES (ANCHORS)

The steps detailed to the left should be followed when canes for the anchors of the shelter. The anchors serve a straightforward purpose: act as stabilising anchors to which to dome can be anchored in.

BAMBOO SLATS (DOME)

Bamboo slats are strips of bamboo cut longitudinal. For this study, slats of th Asper species was used. The length of the slats depends on the cane it was cut from, usually about 75% of the base canes size. Slats used in this study were 30 mm wide and 15 mm thick.

Slats excel as a material when working with curved structures due to the fibres running along the curves. The porousness of the material aids in creating a lightweight but rigid structure when put together.

→ Fig. 19: The Bambuzeria
- a bamboo workshop at TIBÁ
Photo: Author

CHAPTER 3

CONTEXT

CONTEXT

This chapter focuses on the specific context that the shelter is designed for and will hopefully be deployed in, namely the mountainous region of Região Serrana in the State of Rio de Janeiro, Brazil. The emergency shelter is a response to the flash floods and mudslides that have hit the region harshly for the past decade. The project bears a sense of urgency as harsher weather patterns become more frequent.

With beautiful mountains, a mild climate, fertile soil, and many rivers, the Região Serrana region began its occupation in the 19th century, primarily by Swiss and German settlers (Pacievitch, n.d.). Petrópolis was also chosen as a residence by the Portuguese Court in 1845 and even served as the capital of Brazil from 1893 to 1902. Over the years, these characteristics have made the region an important tourist destination, leading to the establishment of a vast network of hotels and restaurants. Additionally, an industrial sector developed, with fashion production and a strong metal-mechanical industry, which, alongside agriculture, helped boost the regional economy (Busch & Amorim, 2011).

The regions climate is predominantly humid subtropical (Cwb and Cfa in the Köppen classification), characterized by mild summers, cool winters, and high annual precipitation. Due to the region's elevation, which ranges from approximately 600 meters to over 2,000 meters, temperatures can vary significantly, with colder areas experiencing occasional frost and even rare snowfall at higher altitudes (Pacievitch, n.d.). Orographic precipitation is common, as moist air from the Atlantic Ocean rises and condenses over the mountainous terrain, contributing to high humidity and frequent rainfall. The vegetation is primarily composed of Montane and Cloud Forests, which are part of the Mata Atlântica (Atlantic Forest) biome. This ecosystem is characterized by dense, evergreen forests with high biodiversity.

The largest city in the Região Serrana region is Petrópolis, with a population of around 300,000 people, followed by Nova Friburgo with approximately 190,000 and Teresópolis with around 185,000 (Pacievitch, n.d.). While these cities serve as economic and cultural hubs, many smaller towns and rural communities are scattered throughout the mountainous region. Despite its economic advantages, the region has always been highly vulnerable to natural disasters. Located in the Serra do Mar, it is composed of rocky formations covered by a thin layer of soil and dense Atlantic Forest vegetation (Busch & Amorim, 2011). The steep slopes and heavy summer rainfall make the soil unstable and prone to landslides.

This natural fragility was worsened by human activity. Over the years, deforestation and irregular settlements spread across the hillsides and riverbanks, further increasing the region's vulnerability. As a result, heavy summer rains frequently led to erosion, flooding, and landslides. The Regional Engineering Council of Rio de Janeiro (Crea-RJ) had already warned about the risks of construction in hazardous areas two years before the disaster (Busch & Amorim, 2011).

According to media reports, surveys conducted between 2008 and 2009 in the three largest cities of the region revealed that around 42,000 people were living in 230 high-risk areas, where 10,000 houses had been built (Busch & Amorim, 2011).

↑ Fig. 20: The project's context: the Regeao Serana of Rio de Janeiro State
Map made in ArcGIS

← Fig. 21: Outskirts of Bom Jardim
Photo: Author

↗ Fig. 22: A house on the outskirts of Bom Jardim
Photo: Author

↘ Fig. 23: Bom Jardim and its surrounding mountains
Photo: Author

↑ Fig. 24: Aftermath of 2022 flash floods and landslides, Nova Friburgo
Photo: Celso Pupo, editorial license

LANDSLIDES - THE MAIN CULPRIT

Landslides are a type of mass movement characterized by the sliding of solid materials, such as soil, rock fragments, and other debris, down a slope (cit). This type of movement commonly occurs in areas with rugged terrain and is triggered by the presence of fissures in the soil or rock, along with the combined action of external factors, which can be both natural and anthropic (human-induced).

Natural causes of landslides
Soil type: Loose soil types, which allow high water infiltration, are more susceptible to landslides. The likelihood increases when these soils sit atop impermeable rocks. In such cases, water accumulates, leading to excessive saturation or water-logging, increasing the chances of the soil breaking apart and sliding downhill (cit).

Rugged terrain and slope inclination: The angle of mountain and hill slopes plays a key role in mass movements like landslides. A steeper slope will naturally decrease the stability of the top layers of earth. Slopes with angles above 20° are considered steep.

Intense rainfall: Heavy rain concentrated over a short period makes slopes prone to landslides, especially those without vegetation cover. The sudden increase in water volume in the soil leads to stronger surface runoff, which causes flash floods. This movement destabilizes the soil, reducing its cohesion and causing it to slide down the slope. In countries with frequent earthquakes, tremors can also trigger landslides.

Anthropic causes of landslides
Removal of vegetation cover on slopes: Vegetation helps reduce the impact of raindrops on the soil and has a root system that absorbs part of the infiltrating water, preventing soil saturation. Deforestation eliminates this protective function (cit).

Construction on slopes: Occupying steep terrains, such as hillsides—common in large urban centers due to uncontrolled urbanization—along with building houses and other structures in these areas, adds weight to the soil. This extra load can disturb the soil's equilibrium, leading to landslides.

Irregular waste disposal: In addition to clogging drainage pathways, improperly discarded waste, such as trash dumped directly on the soil, releases gases like methane, which contribute to mass movements. In rare cases, methane-related explosions can also trigger landslides.

Preventative measures
Mitigating the risk of landslides is challenging, as many contributing factors are already in place, including existing infrastructure and broader environmental influences like climate change (cit). Therefore preventive measures become all the more important to reduce the possibility of these disasters. Preserving vegetation on the hills and mountain slopes is absolutely vital, as the roots of the plant help to stabilize the soil and absorb excess water. Not all trees are made equal though, it is important to avoid planting large, heavy trees, such as banana trees in steep areas, as their high water demand can contribute to brittle soil. Proper waste disposal is also important, as the accumulated garbage adds weight to the ground and can disrupt the drainage routes, further enhance the risk of landslides.

Infrastructure planning plays an important role in preventing slope instability. New infrastructure should be carefully thought through with awareness of positioning on the slope, soil-stabilising vegetation, weight, wastewater management. Construction of effective drainage channels ensures proper water runoff, reduces excessive soil saturation. Sewage and waste water should be dealt with in specified areas rather than directly into the ground instead of preventing unnecessary erosion. Homes should repair the water leaks immediately to avoid long infiltration that can weaken the soil structure.

Unauthorized slope modifications, such as irregular cuts in the hills, must be strictly avoided, as they can compromise stability. If the soil exposed on a weak slope is detected, the residents should report it to civil security officers, which can apply protective barriers such as plastic sheets to reduce the erosion from rainfall. Applying these precautions is a start, but come with no guarantees due to the unpredictable nature of natural disasters.

Future prognosis
In 2024, the world experienced a record number of landslides, highlighting the growing effect of climate change on extreme weather events and natural disasters. Rising global temperatures have accelerated the weather patterns, causing heavy and more frequent rainfall in many areas (cit). This increase in rainfall makes the soil more quickly, reduces its stability and makes landslides more likely. Prolonged drought, which is another result of climate change, can dry and weaken the soil, causing a sudden risk of falling in case of heavy rains. These shifting weather extremes create the right position for more frequent and severe landslides, especially in hilly or mountainous regions .

Beyond the rainfall, climate change is also intensifying other factors that contribute to landslides and extreme weather. Permafrost melting in cold areas is destabilizing the slopes of the mountain, increasing the risk of rockfall and land collapse (cit). Sea levels and strong storms are causing more coastal erosion, causing the foundation of rocks and hills to weaken. The increasingly common wildfires burn the dusty vegetation that keeps the soil in place, creating new opportunities for erosion and landslides of bare slopes. As climate change intensifies, these interconnected environmental changes will continue to carry forward more frequent, destructive landslides and other extreme weather events worldwide.

THE 2011 CATASTROPHE

The mudslides in the Região Serrana region of Rio de Janeiro in January 2011 were one of the deadliest natural disasters in Brazil's history. Triggered by intense rainfall, the disaster caused massive landslides and flash floods that devastated towns such as Nova Friburgo, Teresópolis, and Petrópolis (cit news). The unprecedented scale of destruction overwhelmed local authorities and highlighted critical weaknesses in Brazil's disaster preparedness and response systems.

Between the night of January 11, 2011, and the early hours of January 12, intense rainfall struck the region, affecting the municipalities of Nova Friburgo, Petrópolis, Teresópolis, Bom Jardim, São José do Vale do Rio Preto, Sumidouro, and Areal. The affected area covered approximately 2,300 km^2, home to over 713,000 inhabitants (Pacievitch, n.d.).

Although the region experiences floods and landslides annually, it had never faced a disaster of this magnitude. Entire neighborhoods were buried within seconds, prompting the declaration of a state of emergency and public calamity (Busch, Amorim, 2011). A massive support network was mobilized, involving local, state, and federal authorities, private organizations, and volunteers. Despite these efforts, the losses were devastating, with over 900 fatalities, around 350 missing persons, thousands left homeless, and severe damage to the infrastructure, economy, and geography of the affected areas.

The National Institute of Meteorology recorded 130 mm of rainfall per day, more than twice the normal level of 60 mm for that time of year. Experts estimated that, in some areas, the rainfall likely exceeded 200 mm in just 24 hours, meaning that half the expected precipitation for the entire month fell in just one day. A total of 32 hours of continuous heavy rain led to catastrophic flash floods, landslides, and rockfalls across the region. Rivers quickly overflowed, forming powerful waves that swept away rocks, trees, and entire houses. The relentless downpour also triggered massive landslides, burying entire neighborhoods under thick layers of mud and debris. Additionally, rockfalls dammed small rivers, creating temporary barriers that eventually collapsed, unleashing torrents of mud and water that surged through valleys, further amplifying the destruction (Busch, Amorim, 2011).

A geological report from the Department of Mineral Resources of Rio de Janeiro, titled "Megadisaster of the Serra", revealed that the landslides reached speeds of 180 km/h, with massive amounts of earth covering 1 km in just 20 seconds. The report also identified five types of landslides, two of which had never been recorded in the region before. In Nova Friburgo alone, over 3,000 landslides were documented.

The magnitude of the disaster was so severe that it altered the region's geography, leaving a lasting impact on the landscape. Rivers, streams, and canals changed course, reshaping the natural flow of water through the valleys. Bridges, roads, and streets were completely destroyed, cutting off access to entire communities and complicating rescue efforts. Entire neighborhoods were buried under thick layers of mud and debris, erasing homes and infrastructure and forcing thousands of residents to flee or rebuild from nothing (Busch, Amorim, 2011).

↗ Fig. 25: Aftermath of the 2011 catastrophe, Petrópolis
Photo: Focus Pix, editorial license

↘ Fig. 26: The seven cities hit hardest by the disaster, Rio Janeiro State
Map made in ArcGIS

BAMBOO:
A NATURAL ALTERNATIVE

As a local and naturally abundant resource in the region, bamboo carries a slew of benefits that make it interesting not only for building shelters but also for supporting ecological resilience, especially in the highlands of Rio de Janiero State.

One of the strongest cases for using bamboo is its status as a local material. Cultivated in various parts of Brazil and particularly suited to the climate of Rio de Janeiro State, bamboo does not require international shipping or importation. This is important in times of crisis when global supply chains may dwindle. By sourcing, processing, and building with bamboo locally, entire shelters can be produced within the country, ensuring faster response times, reduced costs, and increased self-reliance. This local solution reduces foreign dependencies and empowers local communities, which is vital during emergencies.

Benifical properties

As a building material, bamboo is remarkably flexible, both in its material qualities and in the range of applications it supports. Its natural fibers provide a unique combination of strength and bendability, which makes it highly resistant to tension and movement (Londoño, 2003). These qualities become extra useful in harsh weather conditions. At the same time, bamboo can be used in countless ways: as structural supports, wall cladding, roofing, furniture, and even in woven panels. Its adaptability encourages creative, site-specific design while also allowing for modular construction techniques that can be easily scaled.

Bamboo is lightweight which makes it suitable for this project, making it easy to transport. Unlike heavier conventional materials like concrete or brick, bamboo can be moved with minimal equipment, even in hard-to-reach or remote areas. This is especially important in Rio de Janeiro's varied topography, where transportation infrastructure may be limited or damaged. Its lightness aids faster assembly and requires fewer hands on site, making it ideal for temporary shelters, emergency housing, or community-built projects.

Equally important is bamboo's biodegradability. Unlike artificial materials, bamboo returns to the earth without leaving a lasting environmental footprint. In sensitive biodiverse regions like those in the Serra do Mar range, this characteristic is extra important. Post-use, temporary bamboo structures can be thrown after serving their purpose and decompose naturally without harming local ecosystems.

Rapid expansion and simple growth are also the fundamental properties that make bamboo distinctive. Some varieties can reach up to one meter per day and can live for only a few years. Consequently, bamboo is a preferred product for the production of materials. It offers year-round harvest opportunities and supports local agriculture while contributing to a sustainable construction supply chain (Londoño, 2003).

The combined effect of all these factors is that bamboo becomes an incredibly cheap material to use, particularly concerning the industrial alternatives. It is a means of cutting back on the requirement for sophisticated equipment or energy-demanding processes. The use of bamboo for construction, both locally and in its unprocessed or semi-processed state, brings down the production costs to a greatly. This affordability is important for underprivileged communities and for making disaster recovery interventions where budget constraints are a key issue. (Minke, 2016).

BAMBOO IN LANDSLIDE CONTROL

Beyond construction, bamboo has the potential to play an unexpected yet critical role in landslide prevention and slope stabilization. Rio de Janeiro state, with its iconic mountainous terrain and densely inhabited hillsides, faces a constant threat from landslides—especially during the heavy rains of the wet season. These natural disasters pose severe risks to human life, infrastructure, and the environment.

Planting bamboo on vulnerable slopes offers a natural method of erosion control. Its root system, which grows densely and spreads widely, binds soil together, helping to prevent the downward movement of earth during intense rainfall. The structure of bamboo roots is particularly effective in stabilizing loose or sandy soil, which is commonly found on deforested or overdeveloped hillsides. In areas where native vegetation has been cleared, bamboo can quickly reestablish ground cover and reinforce the terrain.

In addition, bamboo canopy intercept rainfall, reducing the speed and impact of water hitting the soil. This helps lower the rate of surface runoff and minimizes erosion. In this way, bamboo functions as a living infrastructure element, complementing engineered solutions like retaining walls or drainage systems. It offers an eco-friendly, low-maintenance approach that works with nature rather than against it.

Using bamboo for slope stabilization not only addresses environmental risks but also provides social and economic benefits. Communities involved in planting and maintaining bamboo can generate income while contributing to local resilience. Over time, harvested bamboo can even be used for construction, creating a self-sustaining cycle of environmental care and material production.

↑ Fig. 27: Wild bamboo in field, Bom Jardim
Photo: Author

CHAPTER 4

METHODOLOGY

RESEARCH APPROACH

LEARNING THROUGH EXPERIENCE

The experiential learning theory of John Dewey is fundamental to the prototyping phase in which the building of bamboo shelter models allows for the hands-on engagement of materials and methods (Dewey, 1938). The cyclical process of the trial, error, and refinement resembles Dewey's theory that action and reflection are the core processes of knowledge development. Each prototype serves as a learning tool, providing immediate feedback on structural performance and self-assembly techniques.

Observing bamboo structures at TIBÁ further supports Dewey's "situated learning" theory, where encounters with real-world examples, in the same way, promote the understanding of the principles of understanding. The study of joinery and the reaction of materials to environmental factors encourages inquiry and practical insight, thus ensuring the research is based on lived experiences and not just abstract theory.

TACIT KNOWLEDGE

Tacit knowledge is another type of learning which is derived from hands-on experience. Michael Polanyi's theory from The Tacit Dimension (1966) emphasizes that knowledge is acquired by personal engagement and experience, not formal teaching. This was evident during the learning process under Marc van Lengen's guidance at TIBÁ. Bamboo construction involves many subtleties that cannot be fully understood through books alone, such as the material's bending, the strength of different joints, or the method of assembling a structure. Practical experience is a source of knowledge not only through direct instructions but as well through observations made on Marc's techniques, gestures, and approaches to problem-solving. According to Polanyi, this is also consistent because we "know more than we can tell," as most of the knowledge is obtained indirectly through the practice of doing, failure and success, and physically working with the material (Polanyi, 1966).

DESIGN METHODOLOGY BASED ON DIGITAL AND PHYSICAL MODELS

This study adopts a prototyping-based design methodology, as outlined by Kim (Prototyping-based design methodology; 2019). It incorporates digital and physical models to improve the efficiency, correctness, and creativity of planning buildings. Digital tools are used in the early design stages to explore form, test performance, and to optimize spatial and structural systems. While virtual models offer rapid iteration and data-based analysis, these methods are often limited in terms of replicating the reality of material performance and construction challenges.

The parallel work of testing physical prototypes is to fill these gaps by checking the viability of materials, assessing the construction techniques, and seeing how they perform in a real environment. By making smaller or full-sized models, aspects like connections, stability, and interaction with users can be observed and amended. The ongoing exchange between digital and physical modeling enables continuous refinement, reduces design risks, and ensures constructability. Applying this methodology to shelter design results in a sturdy workflow that combines virtual precision with physical insights, ultimately resulting in a more balanced outcome.

FIELD STUDIES IN BRAZIL

To gain essential first-hand experience with the context and the material bamboo, the author spent approximately three months at TIBÁ (description below) in Bom Jardim, RJ, Brazil. The field studies consisted of learning through literature and observing bamboo structures, site visits, a workshop, and full scale prototyping.

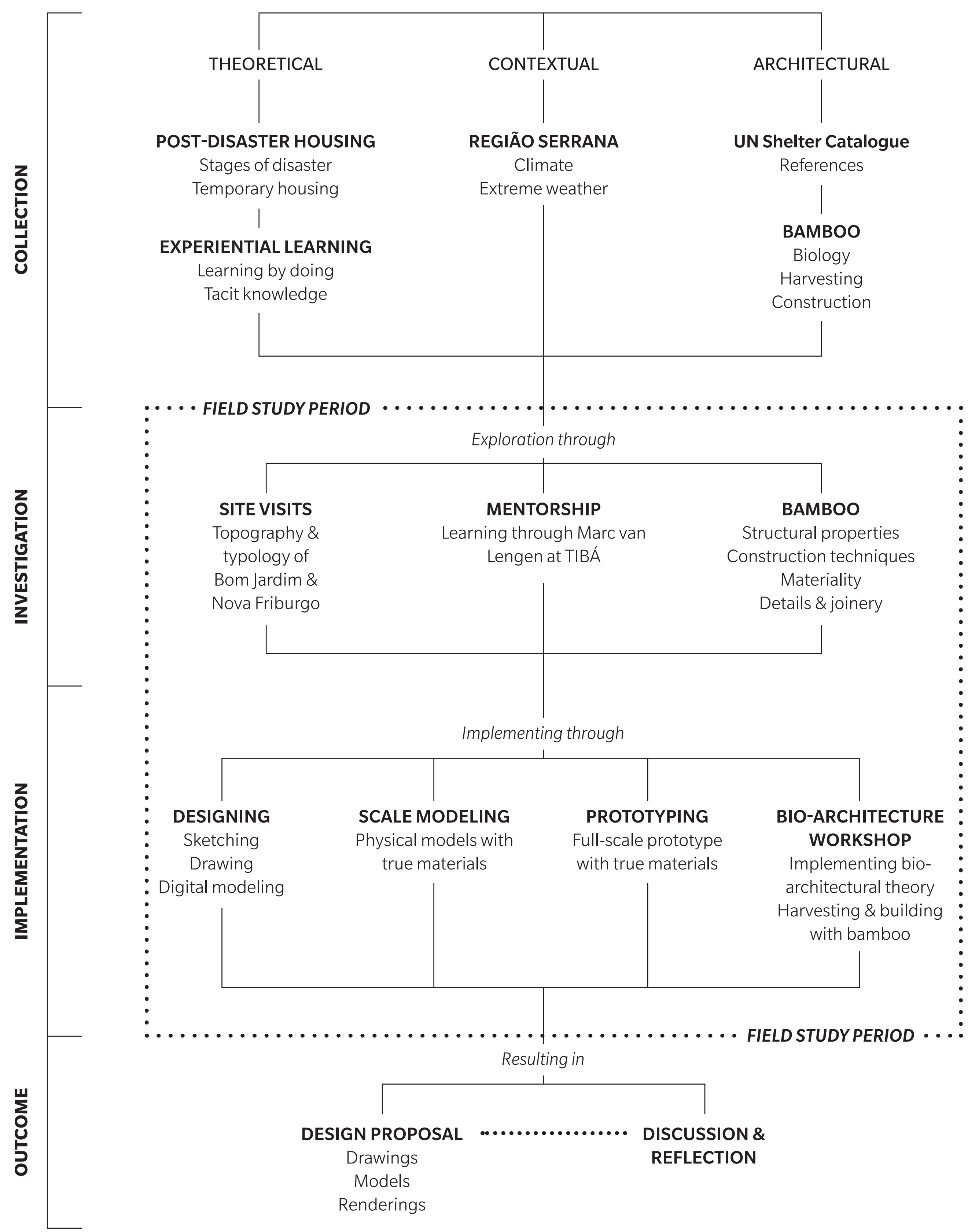
TIBÁ

TIBÁ (Instituto de Tecnologia Intuitiva e Bio-Arquitetura) is an educational center located in Bom Jardim, in the state of Rio de Janeiro, Brazil. Founded in 1987 by Dutch architect Johan van Lengen, author of the renowned Barefoot Architect, the centre is dedicated to eco-friendly construction and living. The institute offers hands-on courses and workshops on bamboo building, bio-architecture, and agroforestry. Its campus features ecological buildings and natural surroundings that provide immersive experiences that blend theory and practice.

FIELD DESIGN DIARY

The design diary aims to detail the methodology of the field studies in chronological order.

METHODOLOGY OVERVIEW



Part 1: Laying the groundwork at TIBÁ

After traveling to Brazil, an integrated approach combining literature review, observation, hands-on experience, and mentorship was used to develop a comprehensive understanding of bamboo as a construction material. Additionally, a bio-architecture workshop held at TIBÁ provided both hands-on experience and theoretical knowledge about bamboo.

LITERATURE

An initial understanding of bamboo as a construction material was established through the study of Gernot Minke's Building with Bamboo. This source provided essential knowledge on the biology of bamboo, as well as techniques for its harvesting, treatment, and use in architectural applications. The material's structural properties and design potential were further explored through Heino Engel's Tragsysteme, which offered a detailed examination of tensile and form-active structures, relevant to lightweight and flexible bamboo architecture.

OBSERVATION

Practical insights were gained through direct observation of bamboo structures at the Instituto TIBÁ. Interaction with the built environment allowed for a tactile and visual assessment of the material's qualities, including its surface texture, rigidity, flexibility, and overall aesthetic. These observations contributed to a deeper understanding of bamboo's capabilities and design possibilities in real-world applications.

Further understanding of bamboo's material behavior was developed through participation in the maintenance of a bamboo greenhouse at TIBÁ. This hands-on involvement revealed the natural wear and aging processes of the material, such as splitting, weathering, insect damage, and joint deterioration. Observing and addressing these issues in an existing structure provided insight into the limitations and vulnerabilities of untreated or poorly treated bamboo over time. It also highlighted the importance of proper detailing, species selection, and consistent upkeep in extending the material's lifespan. This experience reinforced the need for thoughtful design and maintenance strategies when using bamboo in long-term architectural applications.

WORKSHOP

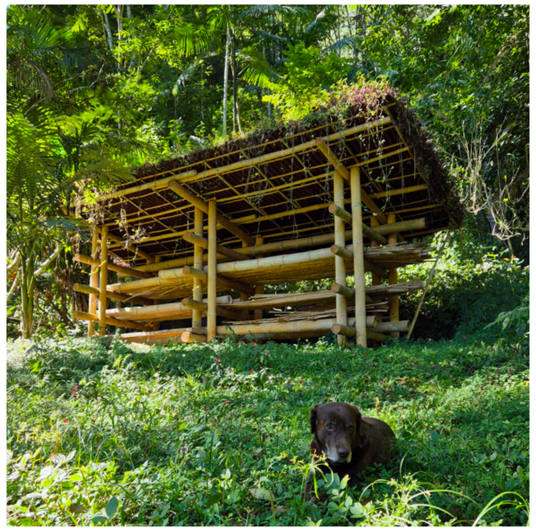
A three-day bio-architecture workshop held at TIBÁ led by Marc van Lengen and Aga Probala provided hands-on experience with alternative materials and methods, one of which was bamboo. Participants were introduced to sustainable harvesting methods and traditional as well as modern treatment techniques aimed at enhancing the material's durability. The workshop served as an applied learning environment, reinforcing the theoretical knowledge with practical implementation.

MARC VAN LENGEN

Conversations with Marc, a specialist in bamboo construction, offered valuable insight into the characteristics of different bamboo species. His expertise guided the evaluation of species most suitable for use in shelter construction, taking into account structural performance, availability, and environmental adaptability. This phase helped inform material selection for future design considerations.

↑ Fig. 28: Bamboo gridshell constructed from slats of Dendrocalamus Asper, harvested and constructed at TIBÁ
Photo: Author

↑ Fig. 29: The Twisted Tower, built with Dendrocalamus Asper, during several workshops with Jörg Stamm at TIBÁ
Photo: Author



↑ Fig. 30: Bamboo storage shed at TIBÁ
Photo: Author

↑ Fig. 31: The Bambuzería - a bamboo workshop built with Guadua Augustifolia at TIBÁ
Photo: Author

↑ Fig. 32: Bamboo gridshell domes, constructed from slats of Dendrocalamus Asper, harvested and constructed at TIBÁ
Photo: Author

↑ Fig. 33: Interior of the Twisted Tower,constructed from slats of Dendrocalamus Asper, harvested and constructed at TIBÁ
Photo: Author

Part 2: Bio-Architecture Workshop at TIBÁ

A three day bio-architecture workshop led by TIBÀ's Marc van Lengen and Aga Probabla, together with Caio Martins, an architect dedicated to exploring low-impact alternatives. The workshop is based on methods outlined in The Barefoot Architects Handbook by Johan van Lengen, and delves into adobe, bamboo and rammed earth construction techniques, as well as theory supporting sustainable practices.

RAMMED EARTH

Rammed earth construction involves compressing a damp mixture of subsoil, sand, and occasionally a stabilizer like lime or cement, into sturdy, monolithic walls. We learned to build form-works and methodically layer and compact the earth to form dense, durable structures. To achieve an aesthetic look, soils mixed with different pigments were layered during the ramming process. The bottom and top layers were done in concrete to the form a much needed stability (fig. 42).

This technique offers excellent thermal mass, regulating indoor temperatures naturally, and creates an aesthetically striking, striated texture. The use of local earth reduces environmental impact and promotes a strong connection to place, making rammed earth both sustainable and architecturally expressive.

ADOBE

Adobe brick making at TIBA emphasized the importance of working with the land by using soil sourced directly from the surrounding region. This soil was mixed with water, then shaped into bricks and left to cure in the sun. The workshop put emphasis on the consistency required for making bricks, and how to properly use a wooden mould (fig 35 and 36). The result is a biodegradable, low-energy material with excellent breathability and thermal performance.

Superadobe

A similar method, namely utilising adobe filled was also taught. Superadobe utilises sacks (in our case, plastic mesh sacks were used), which are filled with adobe and rammed. The width of the rammed bag defines the final thickness of the wall, as the compacted material conforms to the bag's original dimensions. This construction method can be both monolithic or masonry.

EARTHEN WALLS WITH BAMBOO FRAME

This workshop used bamboo slats and adobe infused with hay. Earth walls were constructed using a framework of bamboo slats, which acted as reinforcement and helped bind the earthen material together (fig. 37 and 38). This hybrid technique enhances the wall's tensile strength and resistance to seismic forces, while still retaining the ecological and thermal benefits of earth construction.

WEAVING BAMBOO SLATS

Bamboo slats were split as shown in figure 37, and then weaved into a tunnel shape. After erecting a structural base frame, thinner slats can be weaved into place, providing more stability and aesthetics.

Fig. 34: Preparing earth for adobe bricks, from water and red soil from the region.

Fig. 35: Leader of workshop Caio Martins explaining how to properly place the adobe mixture into the mould.

Fig. 36: Finished adobe bricks left for air drying.

Fig. 37: Splitting bamboo into slats by pushing it into a special circular tool. This can be repeated with smaller species of bamboo, larger ones require a saw.

Fig. 38: Bamboo and adobe infused with hay used for construction of walls.

Fig. 39: A different construction method using the bamboo slats: weaving them into geometrc shapes, in this case a tunnel.

Fig. 40: Mould for rammed earth sample. The workshop was split into three groups, each making their own sample.

Fig. 41: Adding different colourings to the earth to gice the sample a design.

Fig. 42: Finished rammed earth sample, featuring earth mixed with different pigments and a layer of compacted concrete on top and bottom for stability.

Fig. 43: Marc van Lengen, leader of the workshop, teaching the stability of rammed earth constructions.

Fig. 44: Caio teaching the correct consistency of earth. A careful balance between dry soil and water.

Fig. 45: Fun, social events after dark are a part of sustainable community building!

Part 3: Site visits

Site visits were conducted in the cities of Bom Jardim and Nova Friburgo, both located in the Serra do Mar mountain range. The aims were to gain a deeper insight into urban planning, existing infrastructure, and identifying potential risk zones. A combination of experiential walking, photographic documentation, and anecdotal note-taking formed the core of the observational methods used to develop a comprehensive understanding of each site.

BOM JARDIM AND NOVA FRIBURGO

Sites visits were conducted in Bom Jardim and Nova Friburgo, two cities located in the Serrra do Mar range.

Bom Jardim was visited three times and Nova Friburgo once. The objectives with the site visits where to deepen the understanding of the city planning and existing infrastructure, as well as identifying potential risk-zones.

METHODS

Experiential Walking

The primary method of engaging with the site was through direct exploration on foot. Walking allowed for a first-hand experience of the urban fabric, offering an embodied understanding of spatial relationships, circulation patterns, materiality, and atmosphere. This approach emphasized a sensory engagement with the site: sounds, smells, and textures, while also allowing for spontaneous interactions with locals and the discovery of informal uses of space. By navigating the area at different times of day, a more nuanced understanding of temporal shifts and patterns of occupation emerged.

Photography

Photographic documentation was employed as both a recording and analytical tool. During each site visit, a wide range of photographs were taken to capture not only physical elements such as buildings, infrastructure, and vegetation but also ephemeral aspects like light conditions, signage, and human activity. These images were later used for comparison across visits and to support critical reflection in the design process. Photography also facilitated remote analysis and served as a visual archive that could be revisited to reassess details that may have been overlooked in person.

Anecdotes

Informal note-taking played a vital role in capturing spontaneous thoughts, observations, and emotional reactions during the site visits. These anecdotal records included sketches, snippets of overheard conversations, unique encounters, or personal reflections prompted by particular spatial experiences. Though less structured than formal field notes, these entries provided a rich, qualitative layer of understanding that complemented the more objective methods. Over time, these small notes accumulated into a narrative of the site that informed both conceptual thinking and design decisions.

← Fig. 46: Downtown Bom Jardim, looking up to the surrounding mountains
Photo: Author

Part 4: Design through model-making

To investigate design strategies and the structural behavior of bamboo, a series of physical models were constructed using a smaller species of bamboo: Phyllostachys Aurea. Physical modeling gave a direct understanding into joinery, flexibility, and stress distribution, offering a more tactile and accurate understanding than digital simulations. These hands-on experiments led to the development of two preliminary shelter designs.

PHYSICAL MODELING

To explore design possibilities and better understand the behavior of bamboo in construction, physical miniature models were created using a smaller species Phyllostachys Aurea of bamboo. Physical models were preferred to digital ones as the strengths and weaknesses of each design became evident when modeling.

A cane of Phyllostachys Aurea was cut, ad later sawed into smaller pieces of about 30 cm. These were later split into small strips with a machete.

The bamboo strips were built into smaller experimental models using string for joints and hot glue for anchoring the feet onto the baseplate.

TRUE MATERIALS

The smaller bamboo species Phyllostachys Aurea was used to build the models. This approach was chosen to replicate the natural properties of the material as closely as possible at a manageable scale. By working with actual bamboo rather than substitutes, the models retained the inherent qualities of the material—such as grain direction, surface texture, and natural curvature—allowing for a more authentic exploration of structural form and assembly techniques.

The process of modeling revealed important insights into the flexibility of bamboo, particularly how it bends, where stress tends to concentrate, and how different joinery methods respond to tension and compression. These hands-on experiments provided a clearer understanding of how bamboo behaves under various structural conditions, offering a valuable preview of the challenges and opportunities that might arise when working with full-scale members. In addition to informing design development, the modeling experience also contributed to a deeper material sensitivity, bridging the gap between conceptual ideas and practical construction realities.

INITIAL DESIGNS

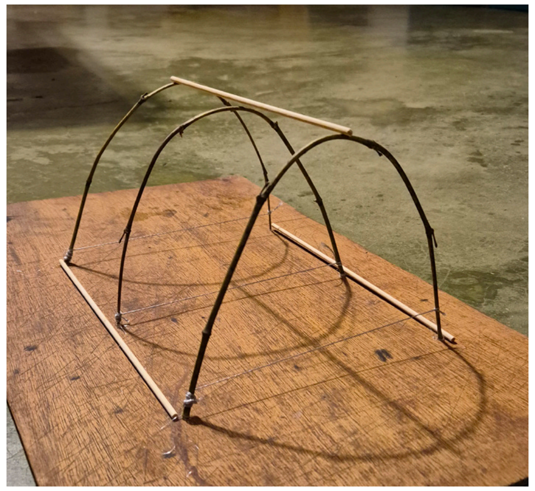
The miniature model phase resulted in two distinct designs: the traditional dome and the tunnel.

The Traditional Dome

A classic four corner dome tent structure consisting of four arced bamboo slats, all connected together with a horizontal strip.

The Tunnel

A tunnel-shaped shelter consisting of three bamboo slats which form their arc shape when pushed together.



↑ Fig. 47: Harvesting Phyllostachys Aurea at TIBÁ
Photo: Author

→ Fig. 48: Splitting the cane
Photo: Author

↙ Fig. 49: The Tunnel Model
Photo: Author

↘ Fig. 50: The Dome Model
Photo: Author

↑ Fig. 51: Bambusa Vulgaris at TIBÁ
Photo: Author

← Fig. 52: Harvesting Vulgaris
Photo: Author

→ Fig. 53: Picking slats from storage
Photo: Author

↓ Fig. 54: Sawing slats
Photo: Author

Part 5: Full-scale prototyping

The construction process began with the harvesting of Bambusa vulgaris for structural poles and the preparation of treated Dendrocalamus asper slats for the grid-shell dome. Slats were cut, overlapped, and tied with wire to create long flexible members, while the poles were anchored directly into the ground. The dome prototype was then erected by inserting the slats into the poles and securing the structure with rope tensioning, resulting in a stable and self-supporting form.

HARVESTING

A cane of Bambusa Vulgaris was cut about 40cm above ground with chainsaw, and later cut into 120cm pieces. The upper section of the cane, about 9m above ground was unable to be used as its cane diameter and thickness was lacking. This part was cut into smaller pieces and lft to decompose in the bush.

PREPARING SLATS

Bamboo slats from TIBÁs storage were used for the gridshell dome. The slats were made from Dendrocalamus Asper, ranging from 3-5m in length, 3cm wide and about 1,5cm thick. The slats had been treated with a boric acid bath, years prior to the use in this study.

The slats were then cut to 1,8m lengths and tied together with metal wire. Due to its efficiency and assembly time, metal wire was preferred to drilling holes and fastening with nuts and bolts. The slats overlapped 50cm, and each overlapping joint was tied together with three separate wires. The finishhed slat was 6,8m long, and three of them were made.

ANCHORING POLES

The bamboo poles that would support the dome were harvested from the species Bambusa Vulgarisas detailed above in "Harvesting". These bamboo canes were hammered into the ground to a depth of 20cm.

ERECTING THE PROTOTYPE

After the poles had been anchored, the dome could be raised by sliding the slats into the culms of the poles. The slats slide in about 20cm and do not need to be fixed with rope or nail as the tension of the arc holds it fixed.

The centre of the dome was tied together with rope to prevent the slats from misaligning.

To further strengthen the general shape, rope was strung between the halfway points of the arc. This stabilised the structure and irregularities and bowing/buckling.

Unfortunately, the plastic roof could not be prototyped, which would certainly yield further improvements.

ITERATIONS

To find a suitable height, the length of the arcs were iterated twice, each time shortening the length. The final length for the prototype landed on 6,5m. Shortening the arc was done by dissembling the four slats making up the arc and cutting off an equal amount on all four.

↖ Fig. 55: Testing different heights with arcs of different lengths

↙ Fig. 56: Main frame of shelter erected, centre tied together

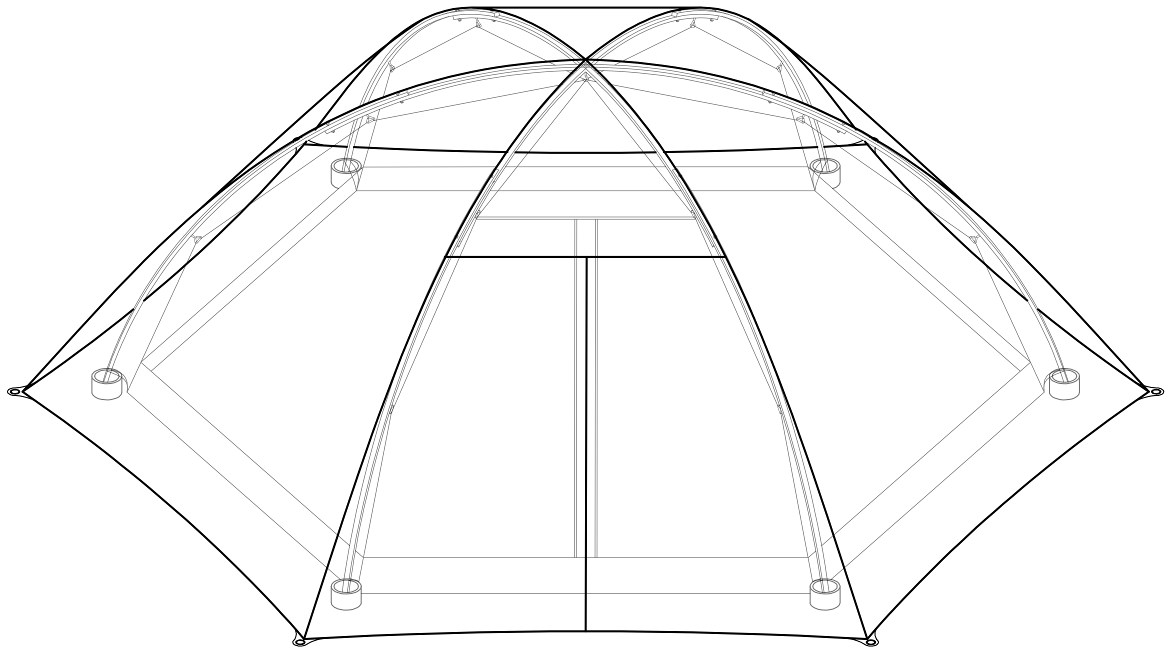
↗ Fig. 57: Completed structure of shelter

↘ Fig. 58: Different angle
Photo: Author

CHAPTER 5

PROPOSAL

↑
Fig.59: Deployed shelters in the outskirts of Bom Jardim



The proposal is a simple dome shelter featuring three slats of bamboo bent into arcs. The slats are anchored by six canes of bamboo, sunk into the ground. Designed according to UNs disaster relief requirements, this shelter incorporates basic principles of tent design with bamboo components and canvas sheet roofing.

OVERVIEW

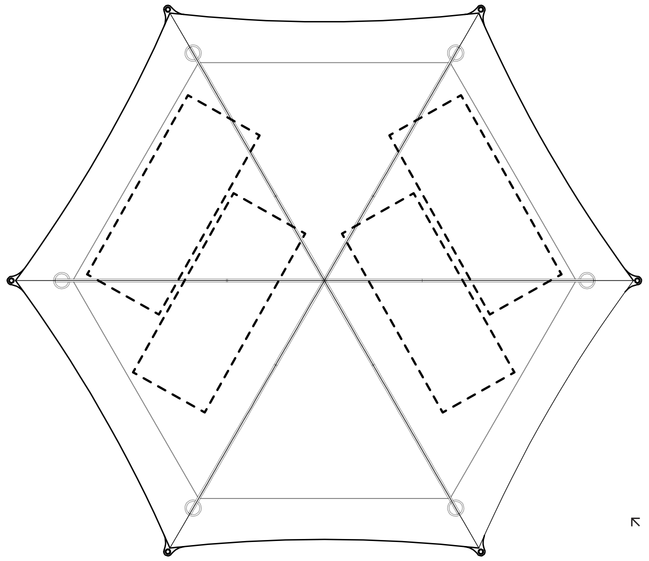
The hexagon dome shelter features structural elements made from two species of bamboo, namely Guadua Angustifolia and Dendrocalamus Asper. Asper bamboo slats form three arcs which are anchored 100 mm into the Guadua canes. White canvas sheet is used for the roofing providing a cover against the elements. The shelter has an inner tent made from a cotton mesh to keep out insects and animals, as well as a ground sheet in tarpaulin plastic.

INSTANCE OF USE

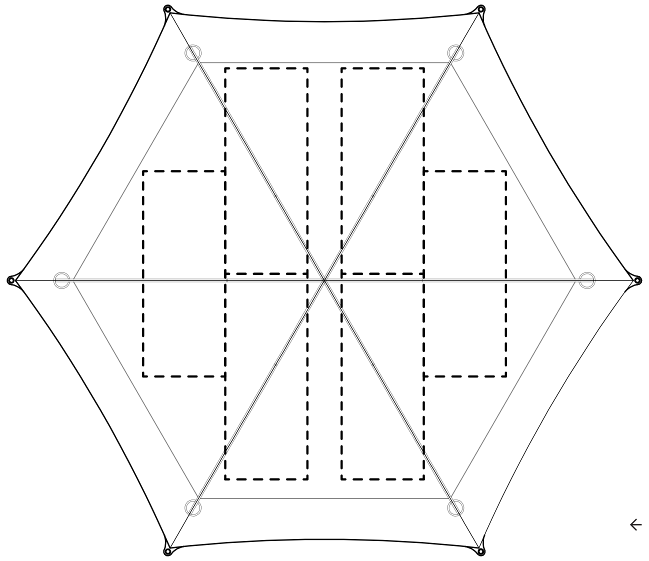
The shelter is specifically designed for emergency situations, providing immediate protection from the elements, a degree of privacy, and a secure space for rest and sleep. Its lightweight construction and quick setup make it ideal for rapid deployment in post-disaster contexts.

The structure is intended to be assembled on relatively flat ground. While the flexibility of the bamboo frame allows it to accommodate minor surface irregularities, significant unevenness can distort the shape of the dome. This may lead to structural imbalances, uneven load distribution, and in severe cases, compromise the stability of the shelter, increasing the risk of collapse.

↗ Fig. 60: Wireframe view

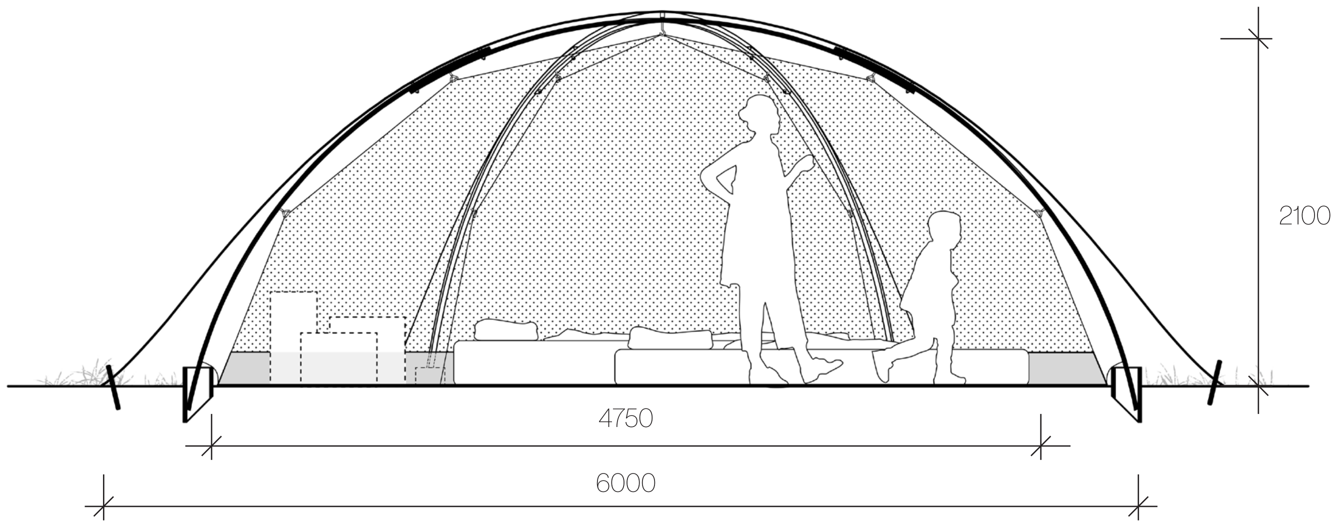


↖ Fig. 61: Plan featuring four beds



← Fig.62: Plan with six beds

↘ Fig. 63: Cross section of shelter



APPLYING THE DESIGN CRITERIA

Cost

To keep costs per unit low, cheaper and readily available materials were prioritised. The canvas roofing and mesh inner tent are both standardised materials in shelter construction, used by the UN.

The structural parts were all designed in bamboo, a low-cost local material. Bamboo is more cost-efficient than the commonly used steel for shelters, whilst also being less carbon intensive.

Weight also plays a role in the total cost per unit, as heavier packages have an increased transport cost. By keeping the total weight low, transport costs will also be minimised.

Transport

The shelter was designed according to strict weight and size guidelines for ease of transport. The mountainous region where the shelter aims to be deployed can be somewhat inaccessible, especially after heavy rains. The weight was kept below 30 kg, and the dimensions of the shelter package to a maximum of 2200 mm, enabling it to be transported by smaller lorries and even pickup trucks. These specifications allow the shelter to be carried by two people to its pitching location.

Light

White was chosen for the canvas roofing as it lets in the most light during daytime. Sunrise and sunset times are not extreme, so dark colour to block out light are not necessary.

The entrance to the tent can also be tied open, allowing for a sufficient flow of natural light if needed.

Colour

To promote as sense of light and calmness, white was chosen as the colour for the canvas roofing. The brown tarpaulin ground sheet mimics a natural colour, taking inspiration from nature and its proven calming properties.

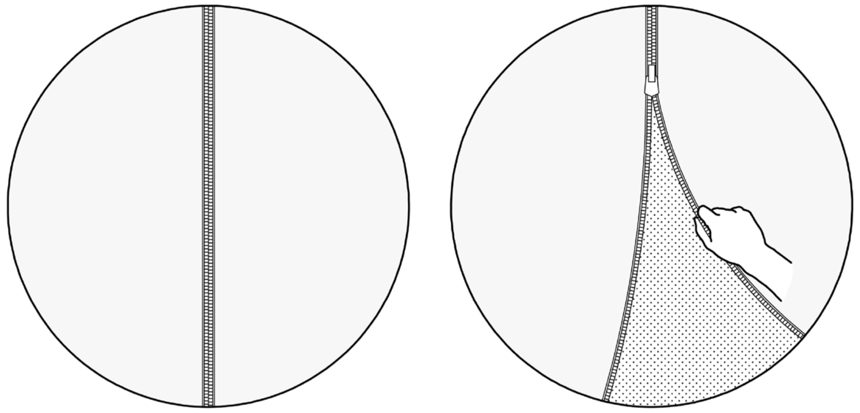
Space

The decision behind the hexagonal shape was to provide more than sufficient room for a household of four. As a result of this shape, there exists space in the front of the shelter for by the entrance, and space in the back of the shelter for storage of smaller belongings.

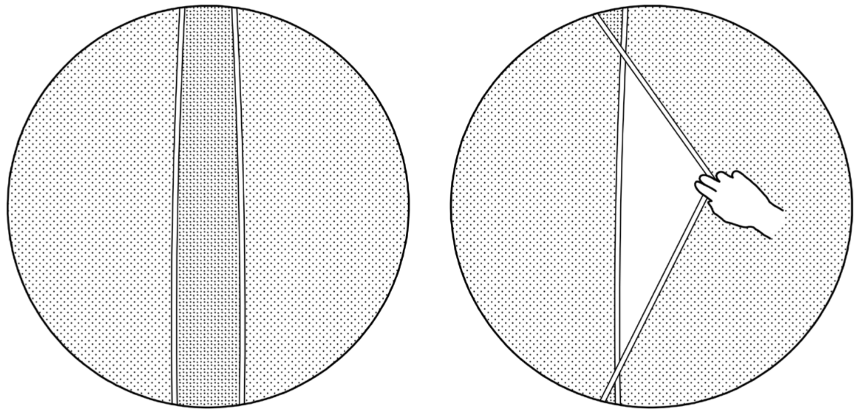
Self Assembly

The shelter comes packaged as a roll, ready for construction. A two-sided pamphlet illustrates the instructions, with the only tool required being a hammer (any object fit to deliver blunt force will suffice).

The shelter requires two people to erect, with additional help required for raising the tent by bending the frame into its dome-like shape.

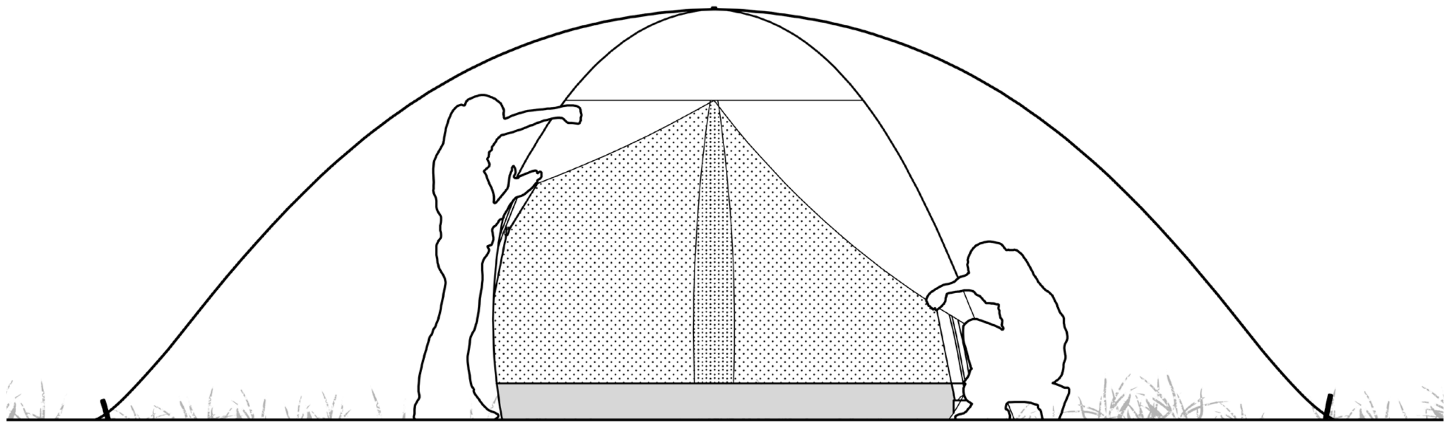


↑ Fig. 64: Zip opening of canvas roof



← Fig. 65: Elastic band opening inner tent

↓ Fig. 66: Front elevation showing entrance



THE ENTRANCE

1. Canvas Roof Zipper

The canvas roof features a waterproof zipper to open and close the opening of the shelter.

2. Inner-tent Elastic Opening

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The shelter requires two people to erect, with additional help required for raising the tent by bending the frame into its dome-like shape.

SPACE AND ADAPTABILITY

As seen in figure 48, the shelter is designed for a household of four (bed size 800W x 2000L mm). There is around a 3 m^2 space on the top side for storage of belongings. The plan shows a suggested layout of beds, which can naturally be rearranged according to its users wishes.

The maximum capacity of the shelter can extend to six people in the case of emergency, see figure 49 (bed size 800W x 2000L mm). This solution may become very warm and is not recommended.

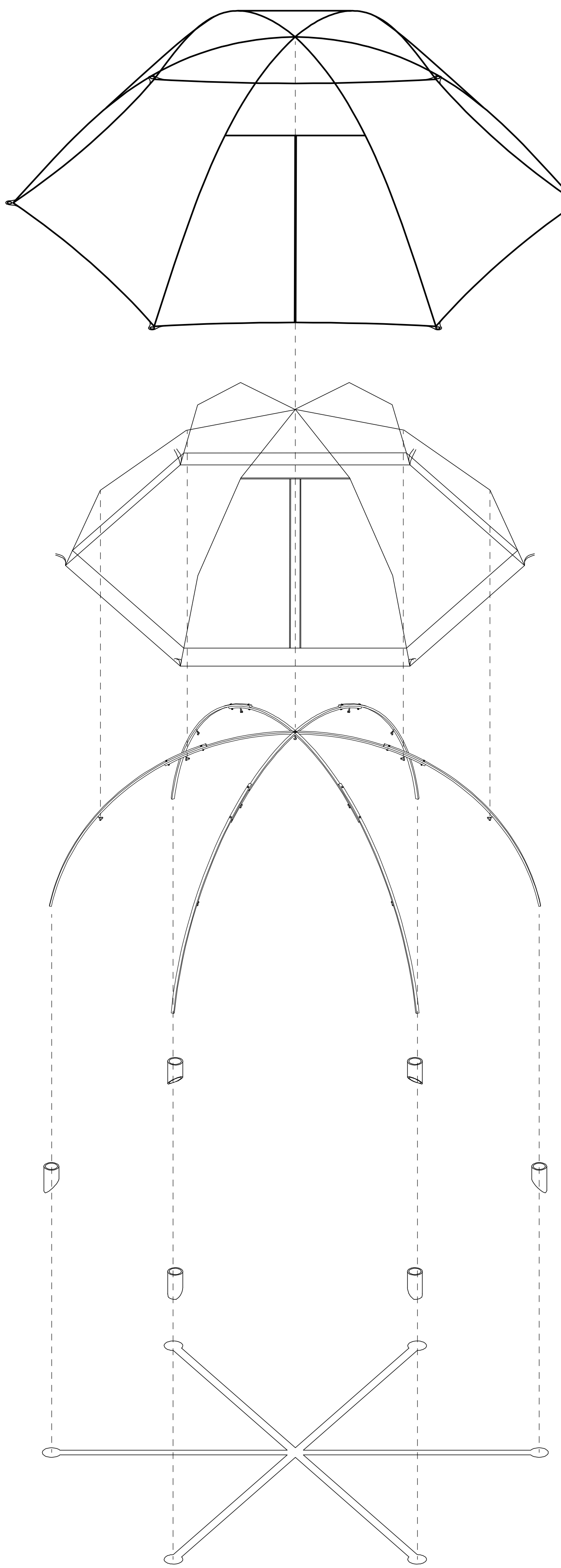
The shelter provides only a place to sleep for the night. Functions such as restrooms, water, food and social spaces must take place outside the shelter. These functions can be solved by setting up camp near a public building or close to neighbors, friends or family that may be able to provide access to such functions.

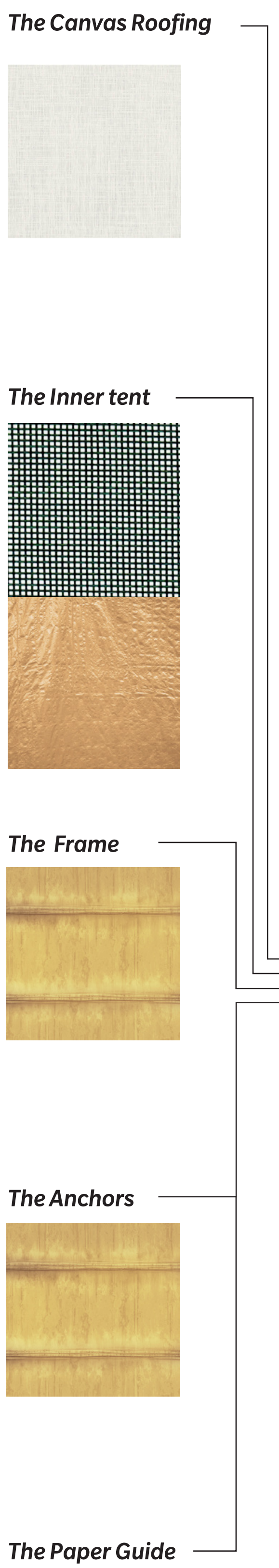
VENTILATION

A key limitation of the shelter design is the lack of ventilation openings near the top of the roof, which are essential for allowing hot air to escape. During warm, sunny days, heat naturally rises and accumulates in the upper sections of the shelter, potentially making the interior uncomfortable. Without upper vents to release this trapped heat, the shelter may retain excessive warmth, especially in hot climates, which can affect occupant comfort and usability.

The main entrance can be fully opened, providing a relatively large ventilation area of about 3.2 square meters. While this could, in theory, allow enough airflow to cool the interior, this configuration was not prototyped or tested during the project. As such, it remains unclear whether this method alone provides sufficient ventilation under real-life conditions.

There are also small gaps along the lower edges of the roof, where the structure doesn't sit completely flush with the ground. These allow for a minimal degree of cross-ventilation, enabling some cooler air to enter from below. However, the airflow they offer is quite limited and unlikely to compensate for the lack of upper-level ventilation, especially in hotter environments.





COMPONENTS OF THE SHELTER

The Canvas Sheet Roofing

The white canvas roofing has small loops which can be threaded by the three bamboo arcs, much like a modern camping tent. The six ends of the tent are to be pulled out and staked, creating necessary tension to prevent sagging.

The Inner tent

Cotton mesh attached to a brown tarpaulin ground sheet. Once the dome frame is up, the corners of the ground sheet can be tied to the anchors and the mesh inner tent hanged onto the hooks on the frame.

The Frame

The three tent poles consist of Dondrocalamus Asper slats. Each tent pole is made up of three 2000mm slats, when joined are a length of 5500mm. Similarly to the Guadua canes, the slats are treated with a borax submersion technique.

Thin hemp rope is strung between the hooks fixed into the slats for additional stability and to prevent the tarpaulin roof from sagging during heavy rain.

The Anchors

The feet of the shelter consists of six 200 mm canes of Guadua Augustifolia. The canes are treated by borax submersion. These are to be hammered 100mm down into the ground, and will serve as the anchors of the shelter.

THE SHELTER PACKAGE

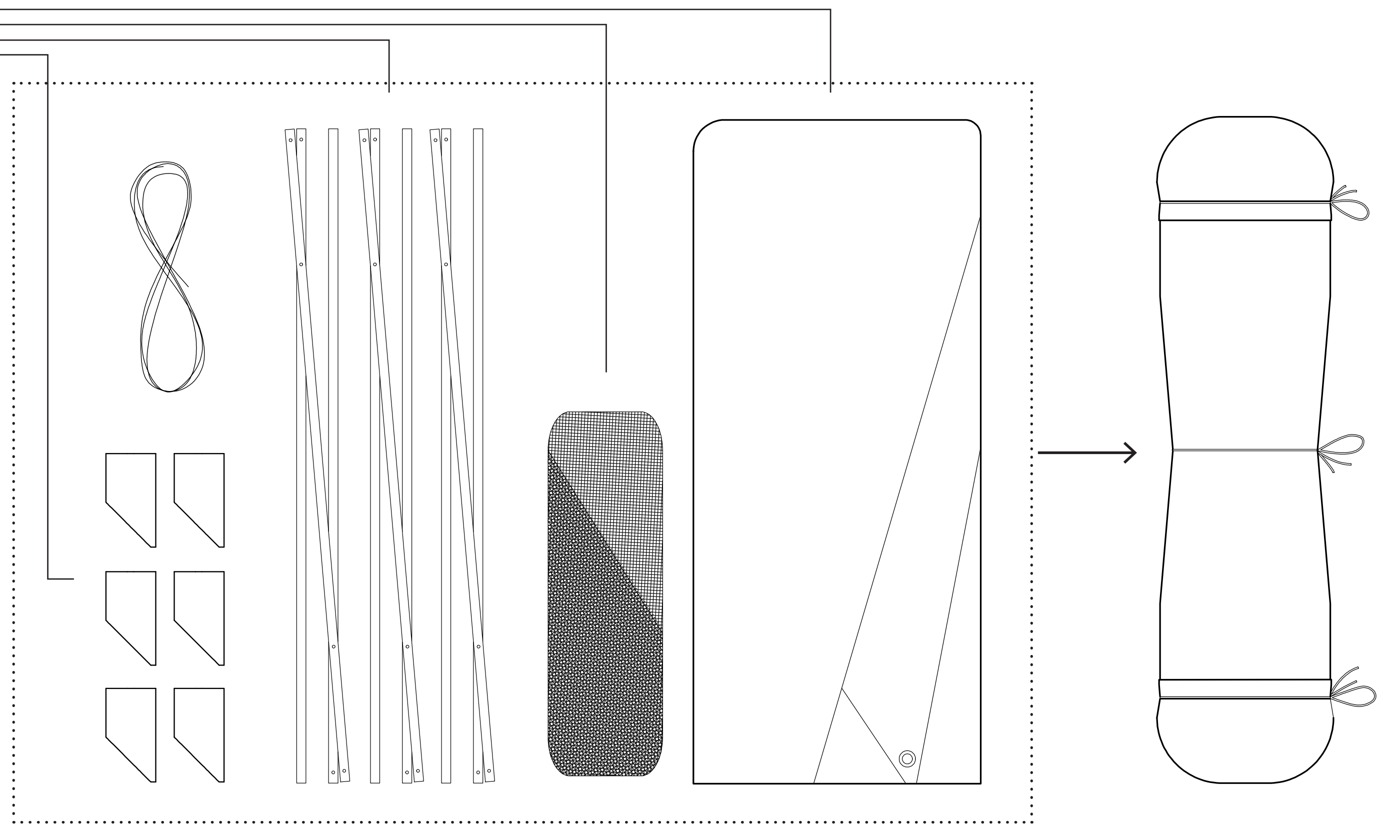
In the aftermath of natural disasters in mountainous regions like Brazil's Região Serrana, accessibility and ease of transport are often major obstacles in delivering emergency shelters to affected communities. The lightweight shelter developed in this project was specifically designed to address these challenges. With a packed size of just 2150 mm in length and 400 mm in diameter, the shelter can be conveniently carried by two people, even on foot, making it ideal for navigating the narrow trails and steep paths. Its compact dimensions also mean that it can be easily transported using small lorries, pickup trucks, or even larger passenger cars, significantly enhancing logistical flexibility in areas where road access may be limited or damaged by landslides.

Dry setup during rain

Additionally, the shelter's setup process is optimized for wet conditions, a crucial consideration in regions prone to sudden rainfall. The roof covering is erected first, providing immediate overhead protection. This allows the groundsheet and inner tent to be installed under shelter, ensuring that these interior components remain dry during assembly.

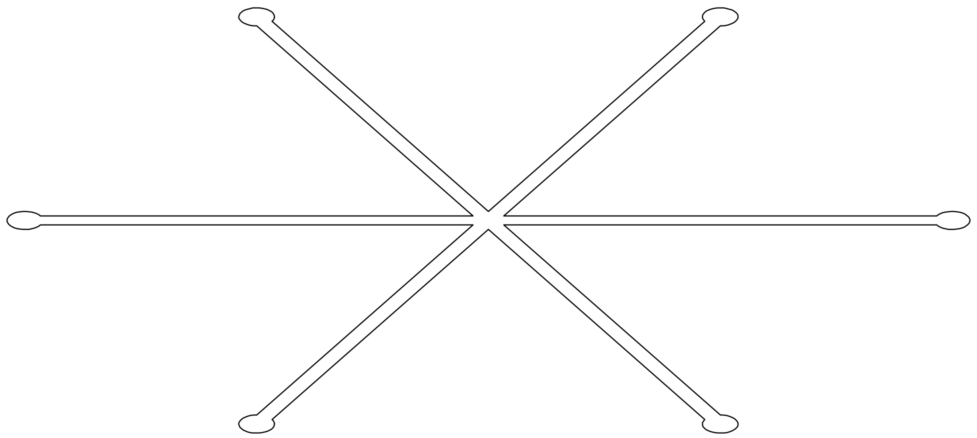
← Fig. 67: Axonometric view of shelters' parts

↓ Fig. 68: The shelter package

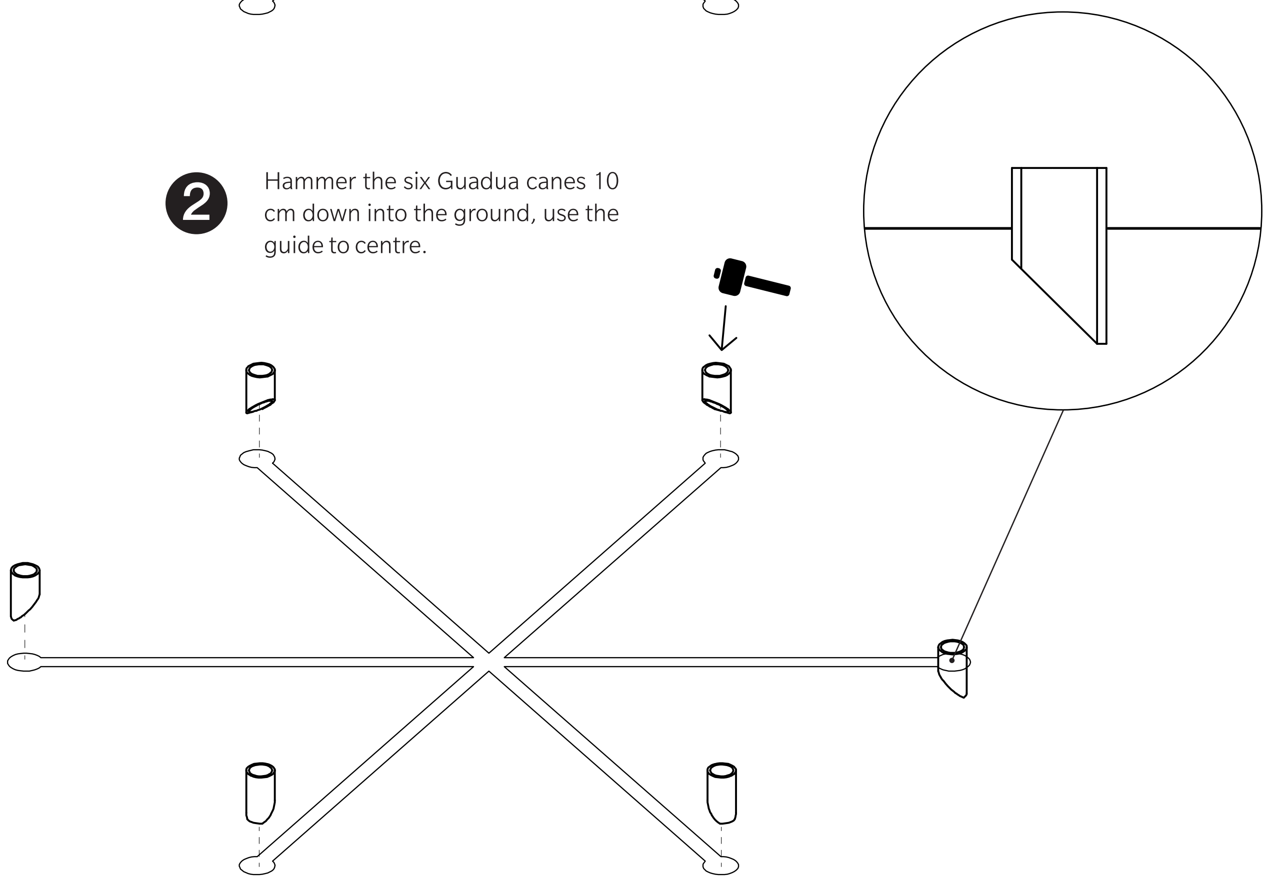


ASSEMBLY

1 Set up the paper guide on a flat surface.
The guide will give an estimation of the shelters size.



2 Hammer the six Guadua canes 10 cm down into the ground, use the guide to centre.



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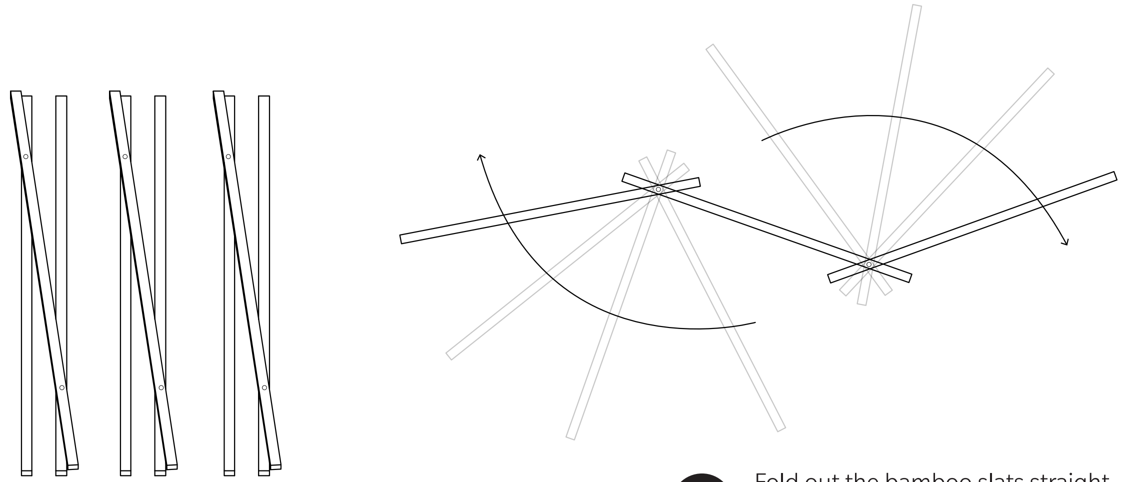
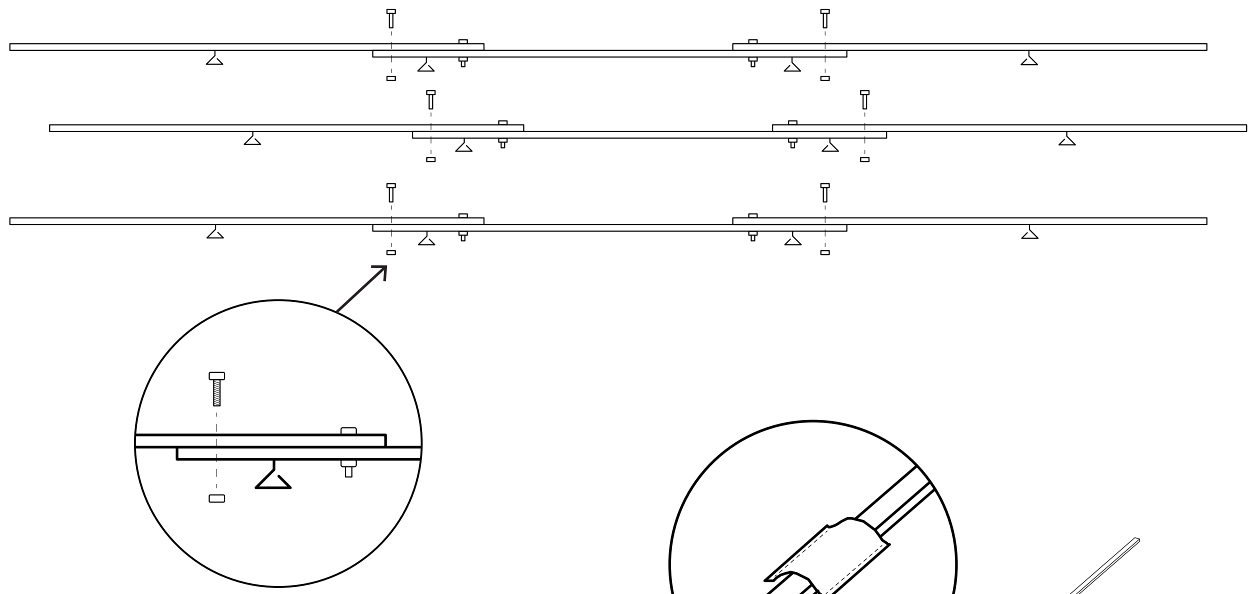
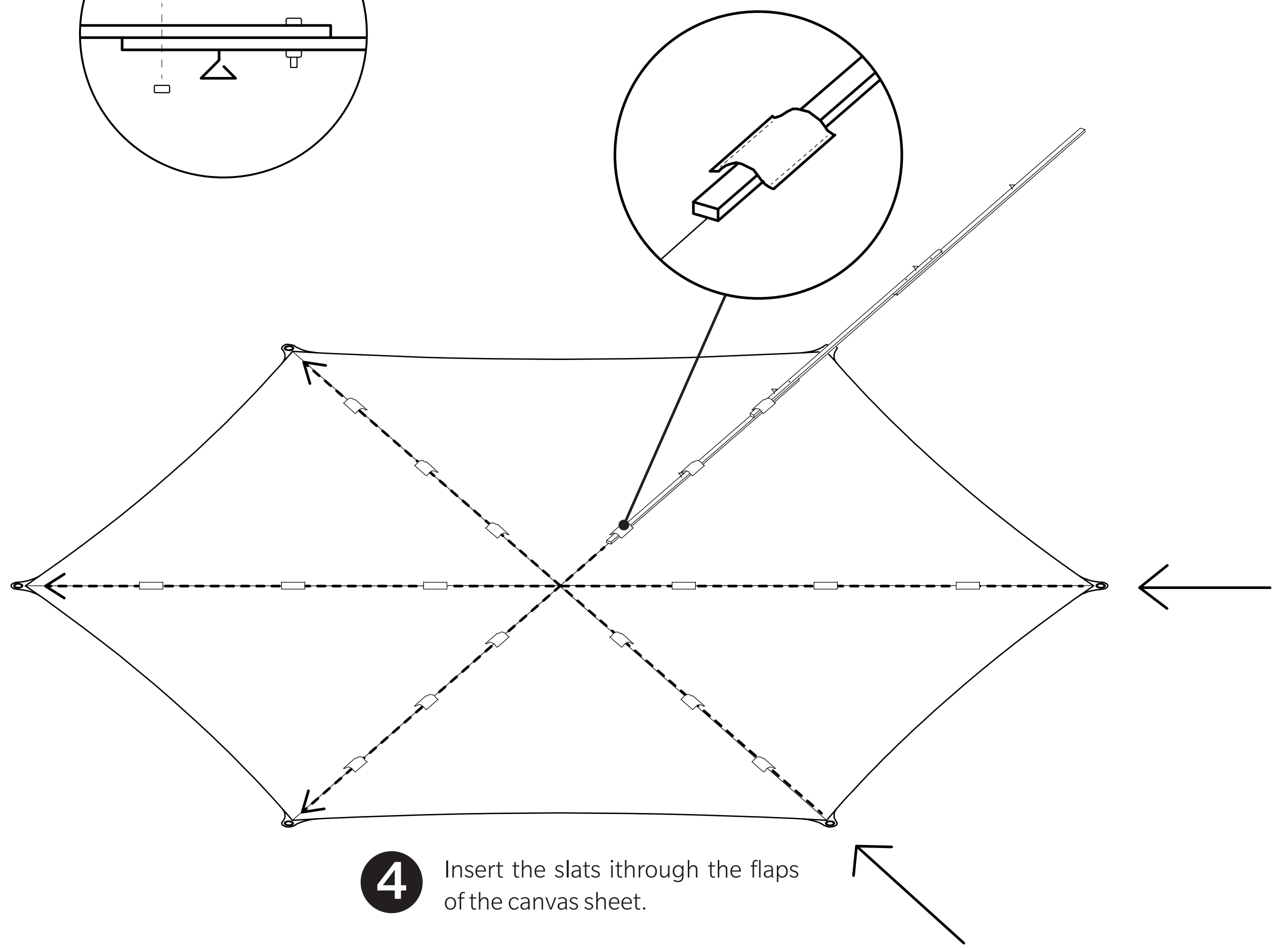
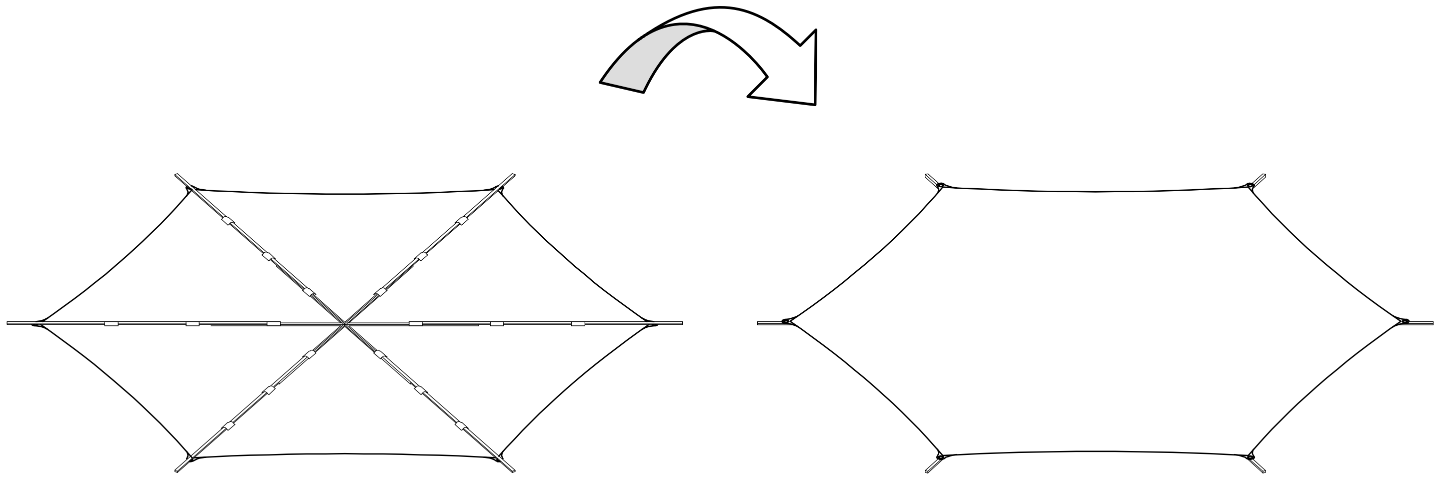


3 Fold out the bamboo slats straight and lock them with a nut and bolt through the pre-drilled holes.

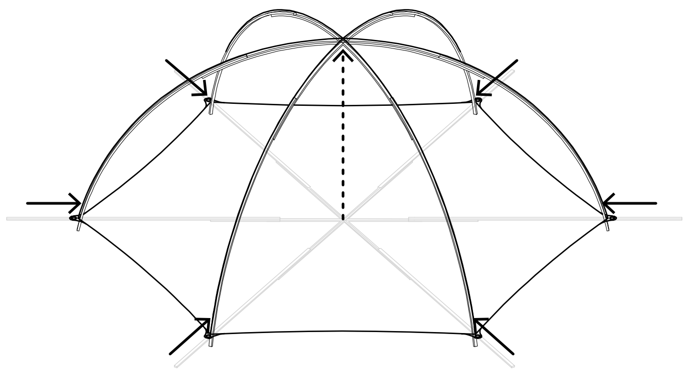




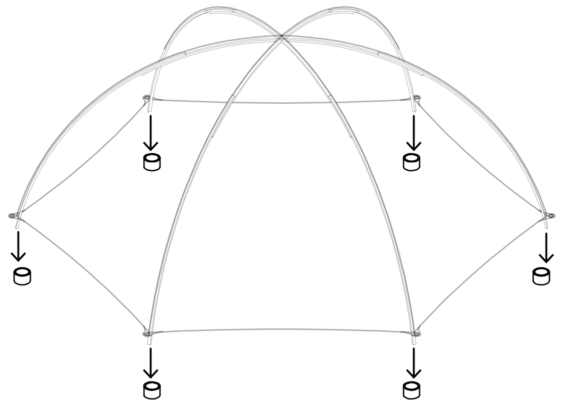
4 Insert the slats ithrough the flaps of the canvas sheet.



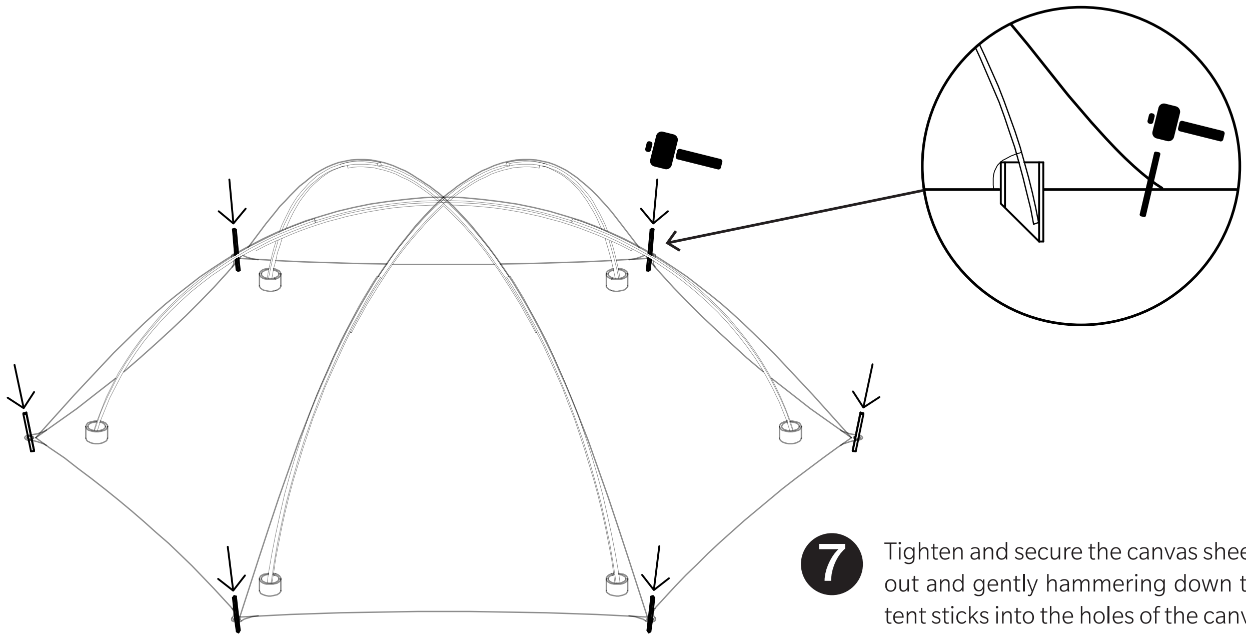
❹ Once all three slats are in, flip the canvas sheet roof so that the slats face downward.



❺ Push towards the centre to form a dome.

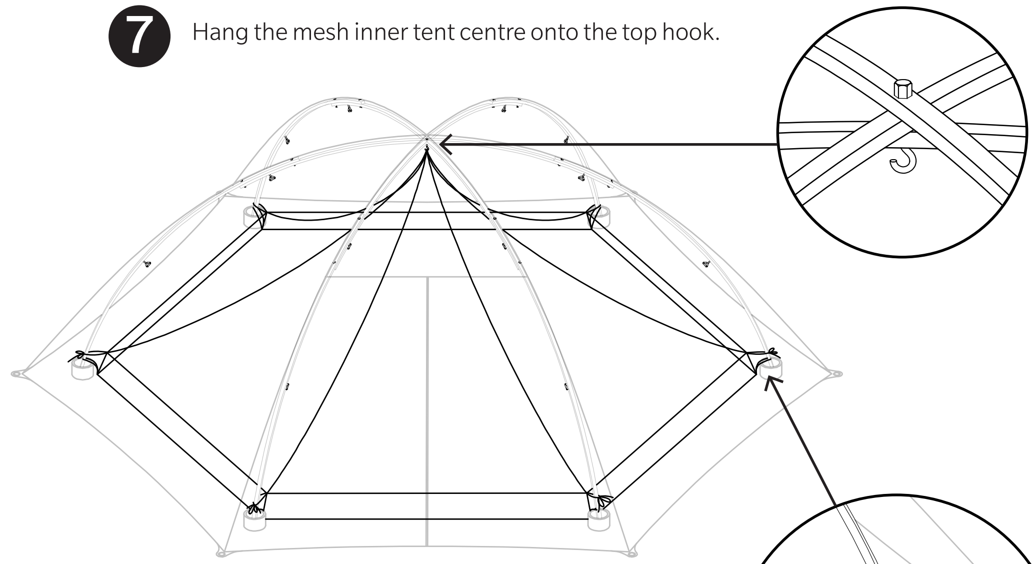


❻ Insert the ends of the slats into the anchored canes. Insert 10 cm down into the cane.

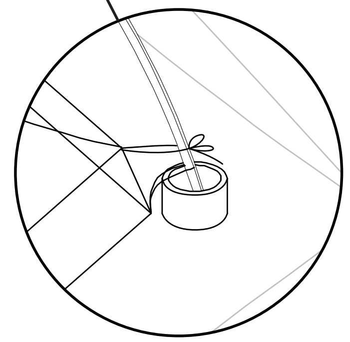


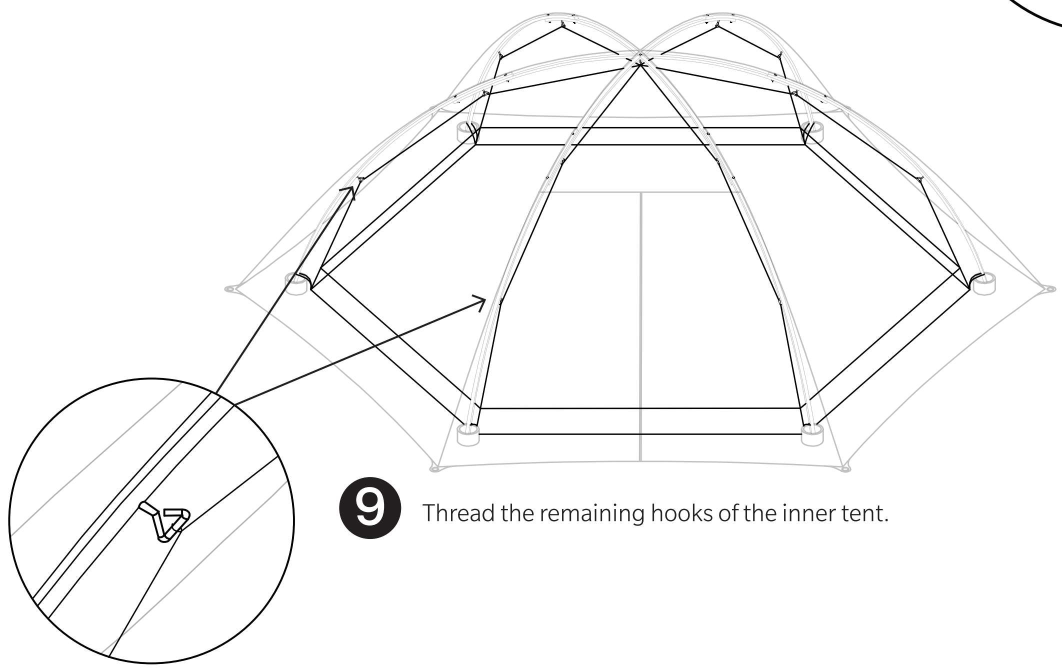
❼ Tighten and secure the canvas sheet by pulling out and gently hammering down the bamboo tent sticks into the holes of the canvas roof.

❼ Hang the mesh inner tent centre onto the top hook.

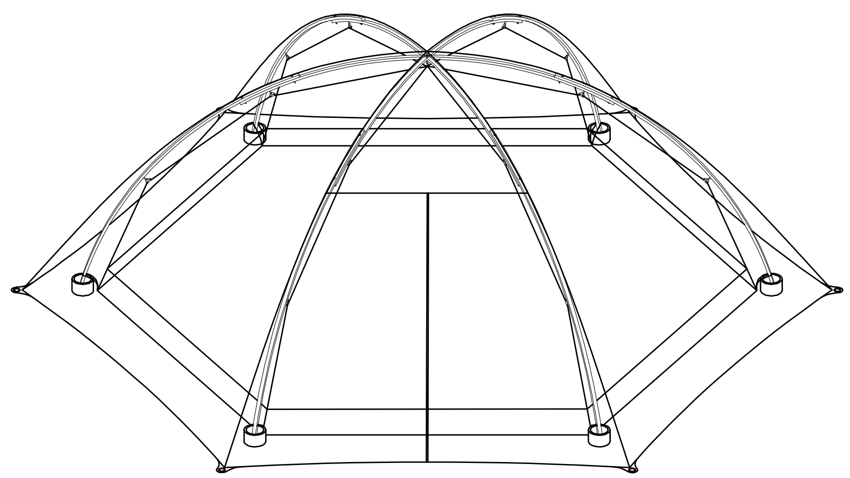


❽ Bring in the inner tent and tie the ends of the ground sheet to the corners of the frame.





❾ Thread the remaining hooks of the inner tent.



❿ Complete!

SCENARIO

An examination of the logistics and planning involved in deploying the shelter in a post-disaster scenario in the Região Serrana, touching on manufacturing to a deployment strategy during emergencies.

A POST DISASTER SCENARIO

Disasters in the Região Serrana, such as mudslides and flash floods, are frequent and often devastating. The region's steep terrain and heavy seasonal rainfall make it particularly vulnerable to rapid-onset natural hazards. These events can cause severe damage to infrastructure, including roads, bridges, and utility lines, isolating communities and making access to affected areas extremely difficult. In past disasters, major transport routes have been blocked for days, delaying the arrival of critical supplies and assistance.

Given these conditions, timely delivery of emergency relief becomes a significant logistical challenge. Emergency shelters, in particular, must be deployed as quickly as possible to provide immediate protection for displaced individuals and families. Any delays can leave people exposed to the elements, without adequate shelter, food, or medical care. This underscores the importance of pre-positioning shelters in strategic locations throughout the region, ensuring that they can be distributed promptly even when major roads are compromised.

To address this, a resilient and responsive logistics plan must be in place, with shelters stored in easily accessible regional hubs like Petrópolis, Teresópolis, and Nova Friburgo. From these points, shelters can be transported via alternative routes, smaller vehicles, or even on foot if needed. The shelters' lightweight and compact design makes them suitable for deployment even in areas with limited access, helping ensure that emergency aid reaches those in need without delay, regardless of infrastructure damage or geographic challenges.

LIFESPAN

The shelter is intended for short-term use, with a designed lifespan of approximately 2 to 10 weeks. While it can physically last longer, extended use is not recommended, as it lacks essential features required for long-term habitation for example, dedicated restroom facilities, cooking areas, and social spaces. These limitations make the shelter unsuitable for prolonged stays, particularly in situations where displaced individuals remain without permanent housing for extended periods.

DISPOSAL

The bamboo frame is fully biodegradable and can be disposed of as organic waste, making it an environmentally friendly component. Once no longer needed, it can be composted or naturally decomposed, reducing environmental impact.

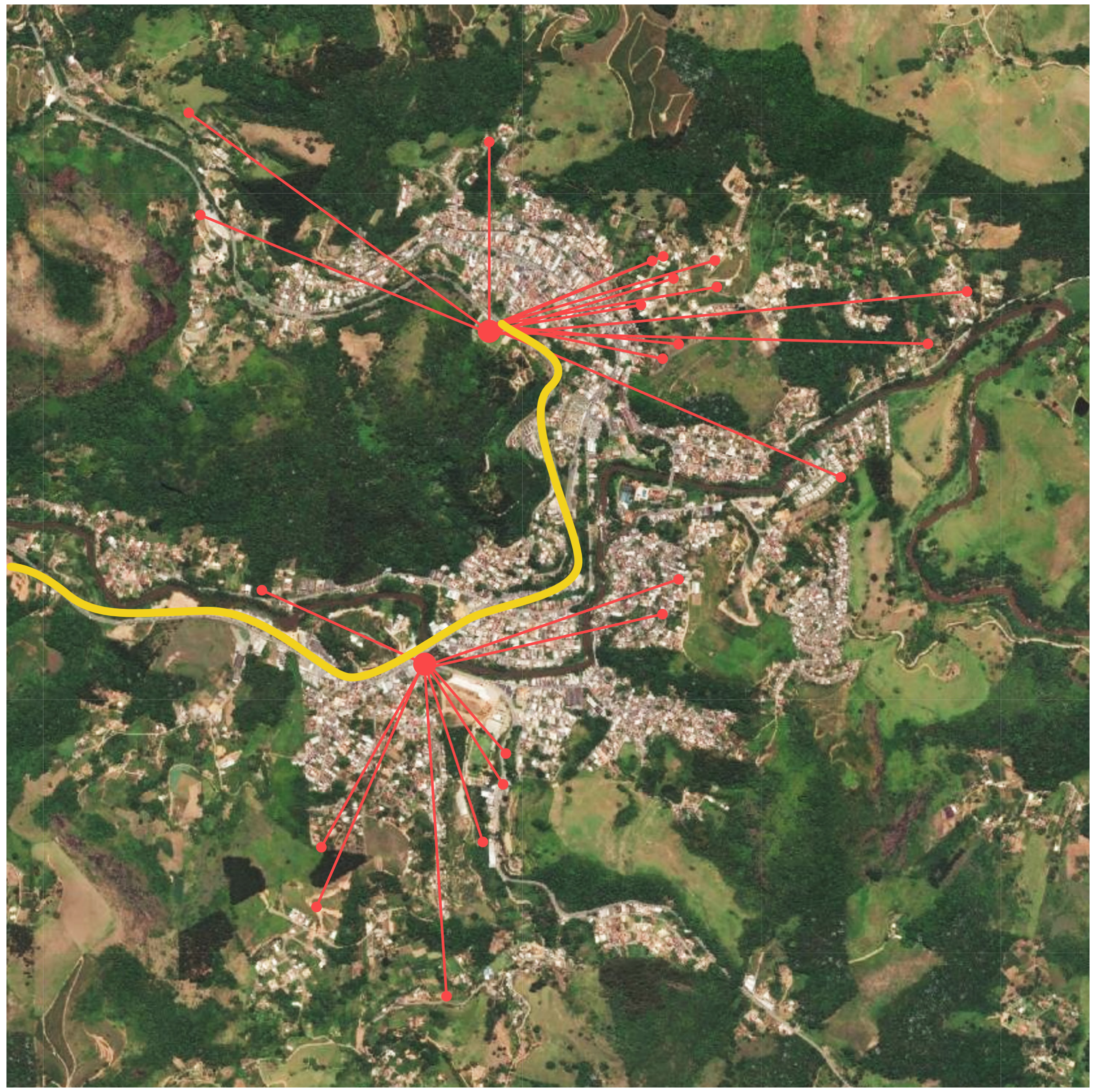
The inner tent can be re-purposed as insect netting, useful for covering windows or sleeping areas to protect against mosquitoes and other pests, especially in regions with insect-borne diseases.

The tarpaulin groundsheet, being waterproof and lightweight, is ideal for reuse in temporary roofing or waterproof covers. Its durability makes it useful in a range of emergency or makeshift applications.

The canvas sheeting can also be reused as temporary roofing or wind barriers, offering decent weather protection. While not fully waterproof, it remains functional and versatile.

One of the projects early ambitions was to develop a fully biodegradable shelter, but this proved impractical. Natural alternatives like woven bamboo were too heavy and lacked sufficient water resistance, unlike synthetic materials such as canvas and tarpaulin, which better met the shelter's performance needs.

↑ Fig. 69: Collage visualising the aftermath of a mudslide and early disaster relief efforts



MANUFACTURE AND ASSEMBLY

The bamboo used for the shelter structure can be sourced locally in the regiao Serrana, where the two species of bamboo naturally grows or can be cultivated. This approach allows for on-site harvesting and processing, reducing transportation costs and supporting local economies. Bamboo is a fast-growing, renewable material that can be cut, treated, and shaped into structural components using relatively simple tools, making it highly suitable for community-based production in rural or disaster-affected areas.

The mesh inner tent, made from cotton, is a commonly used material in both tent production and insect control applications. This material can be manufactured within Brazil, which not only simplifies the supply chain but also enhances the potential for local job creation and rapid deployment during emergencies.

The tarpaulin groundsheet and canvas roof covering are standard components used in the United Nations' shelter programs worldwide. These materials are sourced directly through the UN, ensuring consistency with established humanitarian aid standards. Using these pre-approved components also supports interoperability and logistical efficiency in disaster response efforts, particularly when working alongside international organizations and NGOs.

While both canvas roofing and tarpaulin sheeting are commonly used materials that are likely available within Brazil, the project's time constraints did not allow for a full exploration of local sourcing options. Ideally, sourcing these materials domestically would be the most effective solution. Producing the entire shelter using Brazilian-made components would significantly reduce transportation costs and enhance resilience to global supply chain disruptions. This becomes particularly important in disaster response scenarios, where speed, availability, and logistical independence are critical for effective shelter deployment.

↖ Fig. 70: The three proposed hubs of disaster relief storage in the region

↙ Fig. 71: Possible transport route of shelter in Bom Jardim after disaster

STORAGE IN REGIAO SERRANA

In disaster relief, time is critical. Every hour can significantly impact the well-being and survival of affected populations. To deliver rapid and effective assistance, it is essential that emergency shelters be pre-positioned within the affected region, rather than stored in distant locations such as Rio de Janeiro, which is several hours away. Transporting shelters from Rio to the mountainous Região Serrana is not only time-consuming but also vulnerable to road blockages or delays caused by landslides or flooding which are common after severe weather events.

A more efficient approach would be to store the shelters locally, in one or more of the region's largest and most connected cities: Petrópolis, Teresópolis, and Nova Friburgo, see fig 57. These urban centers serve as regional hubs and are well-connected to many smaller surrounding towns and rural communities. By relocating storage facilities to these cities, transport times can be reduced by up to four hours, enabling a much faster response during emergencies. This localized strategy greatly enhances logistical readiness and ensures that shelter materials can reach affected areas when they are needed most.

EMERGENCY TRANSPORT

Once dispatched from the local storage centers in Petrópolis, Teresópolis, or Nova Friburgo, the shelter packages are delivered to large, accessible public spaces within the affected cities and towns. Schools, football fields, and other open community areas (which are present in virtually every municipality) serve as ideal locations for this purpose. These spaces can be quickly converted into disaster relief hubs, where shelters are distributed directly to those in need, and where medical assistance, food supplies, and basic services can also be coordinated and provided efficiently.

Thanks to their compact size and flexible design, the shelters can be set up in a variety of environments, including dense urban areas, suburban neighborhoods, or rural settings, depending on what best suits the needs of the users. This adaptability ensures that families can remain close to their communities or places of origin, which is often vital for emotional and social recovery after displacement. (See Fig. 58 for an example of setup.)

CHAPTER 6

FINAL REFLECTIONS

DISCUSSION

This thesis has attempted to answer the question:

How can locally sourced bamboo serve as a more sustainable, low-cost alternative to conventional materials in the design of temporary shelters in Brazil?

To answer this, the research focused on evaluating the potential of bamboo as a viable construction material for disaster relief shelters, with a focus on the specific region of Região Serrana, in the state of Rio de Janeiro. The aim was to not only analyze the material's structural and environmental performance but also to comprehend the way its use could promote more sustainable and local solutions in a country that often experiences floods, landslides, and other natural disasters.

Following the UN´s internationally recognised humanitarian architecture principles, the project aimed to meet key criteria for sustainability, cost-effectiveness, and ease of assembly. These benchmarks were integrated with knowledge gained from TIBÁ, a Brazilian bio-architecture institute, renown for its teaching of natural building techniques and practical hands-on education. The resulting shelter proposal was designed for a household of four, a number common in emergency situations. Structurally, the design employed Guadua Augustifolia and Dendrocalamus Asper bamboo species, both regionally cultivable. These were selected for their properties, and availability, which are attributes that support long-term feasibility and reduce reliance on global supply chains.

The central research question of whether bamboo can be effectively used as a primary material for disaster shelters in Brazil was addressed through fieldwork at TIBÁ. This phase of the project was essential, allowing the design process to be influenced by directly working with bamboo as a living and tactile material. Through techniques of splitting, joining, bending, and modeling with bamboo, the project adopted a material-first approach based in learning through experience. These methods were supported by theoretical frameworks, such as Michael Polanyi's concept of Tacit Knowledge and John Dewey's Learning by Doing, both of which validate the role of practical work in problem-solving. At first, the project planned to develop and test a number of full scale prototypes. However, time limitations and unplanned circumstances of field work made it inconceivable. The access to several species of bamboo and the possibility to explore the material thoroughly shifted the focus of the project to structural components, while more holistic aspects like roofing, thermal comfort, and weatherproofing were put aside. Although this change in the plan altered the original ambition of the thesis, it, however, provided important information on the structural integrity of bamboo and its implications for future development stages.

As extreme weather events become more frequent and severe, a slight change in our architectural response to disaster may be necessary. The current reliance on specialised parts in plastic and steel come at environmental cost, especially when discarded after use. While emergency shelters may constitute a small fraction of global building emissions, they serve as examples of a larger contradiction: that post-disaster response and sustainability are mutually exclusive goals. To address both humanitarian and ecological challenges, the building industry must adopt a more flexible mindset that considers local resources, post-use, and carbon footprint. This becomes even more important in regions highly vulnerable to climate risks due to the high cost of imported materials and frequent disruptions in transportation. In such contexts, using local, renewable materials improves the responsiveness of disaster architecture but also informs the local community of viable alternatives. This way of thinking can be extended to the permanent building sector as well, pushing for a system that prioritise sustainability at every scale of construction.

Over the course of the investigation, bamboo's adaptive nature as a construction material became evident. The combination of its mechanical properties-lightweight yet high tensile strength, combined with a fast growth rate and renew-ability, proves that bamboo a compelling alternative to more carbon-intensive materials. Additionally, the variety of bamboo species opens up the possibilities for a wide spectrum of structural and aesthetic uses, enabling use in different architectural roles depending to treatment and processing. Despite these advantages, bamboo is not considered a viable material in mainstream construction, with reasons ranging from a lack of standardisation to regulatory hurdles. Its association with being a cheap temporary material in many parts of the world continues to hinder its adoption, even in regions where it grows abundantly. This highlights a larger issue: unless alternative sustainable materials become socially acceptable and standardised, a shift away from extractive and unsustainable practices may be too late, or happen not at all. Therefore, bamboo's potential is not just its ecological benefits, but its ability to re-frame how we value natural materials in contemporary architecture.

This thesis has represented both a personal and professional journey. Exploring a new material in a setting far from my previous experiences came with its triumphs and challenges. Having previously worked within a European architectural context, alternative low-tech materials and techniques was fascinating. I was drawn to bamboo due to its potential, but had yet to work with it directly. This study became a way to address that gap.

Spending approximately two and a half months conducting fieldwork alone at TIBÁ was a great introduction to bamboo, and broadened my understanding immensely. The process was structured around a task-oriented schedule, which made the schedule easier to follow. This method was far from perfect, and led to more engaging tasks being prioritised over essential design development. Substantial time was spent to understand bamboo's physical characteristics and joinery methods, leaving less room for exploratory design. In retrospect, more time could have been dedicated to designing more versions and prototyping alternative shelter configurations.

An additional point of contemplation during the thesis process concerned the broader acceptance of alternative materials. While concrete and steel dominate perceptions of quality and permanence, the question arises whether it is fair to suggest that those living in vulnerable conditions adopt materials traditionally linked with poverty. Even if bamboo and earth constructions can meet modern standards of safety and comfort, there remains hesitation around their legitimacy.

Looking forward, a logical continuation of the project would involve completing the prototype including all its parts and testing the it under real conditions, such as living in it and monitoring durability as well as weather performance. Another aspect to test would be the accessibility of the self assembly, which could be done by facilitating a community-led assembly. This thesis merely took the first steps of shelter design in bamboo. Through a more iterative and collaborative design process, a highly functional and context-appropriate shelter could emerge.

As a young designer committed to environmentally responsible architecture, I hope this thesis widens the perspective of regionally grounded solutions, especially in contexts of urgency and vulnerability. Working closely with bamboo in the specific setting of Região Serrana allowed me to engage deeply with a material that is often undervalued, yet incredibly capable. The hands-on work brought a depth of understanding that theory alone could not offer. This experience has shaped my thinking about how local, renewable materials like bamboo can inspire disaster resilience, not just as a technical solution, but as a cultural and ecological re-evaluation of what architecture can and should be.

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