Contemporary Bamboo Housing in South America

Challenges & Opportunities for Building in the Informal Sector

David Witte

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Brian McLaren

Elizabeth Golden

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Abstract

Contemporary Bamboo Housing in South America
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David Witte

Chair of the Supervisory Committee:

Brian McLaren

Associate Professor

Department of Architecture

The greatest challenge of our time is to provide resilient, affordable housing solutions to rapidly increasing urban populations across the world. In Low and Middle Income Countries, local and national governments cannot provide affordable urban housing quick enough. The informal building sector has filled the void, but unsafe building practices leave communities vulnerable to natural disasters.

In the past seventeen years, three devastating earthquakes destroyed close to 150,000 homes across Colombia, Peru and Ecuador. Homes constructed of brick and concrete collapsed, while bamboo homes proved resilient to these natural disasters. The giant bamboo species Guadua is native to the continent and while this material has been used to build structurally sound housing for thousands of years, its potential has not yet been realized. In recent years, non-profit, academic and regional bamboo experts worked with the national governments in Colombia, Peru and Ecuador to legalize bamboo building, becoming the first South American countries to do so (2001, 2012 and 2017 respectively).

This thesis argues that while bamboo is an ideal material to build with, there are major cultural, technical and economic roadblocks that must be addressed to increase acceptance and use in the low-income and informal building sector. This research highlights how unprecedented public/private partnerships are working to fix the bottlenecks of the bamboo value chain, but are struggling to change attitudes toward the bamboo often associated with rural poverty and impermanent structures.

This thesis uses an anthropological approach through conducting interviews of a diverse group of bamboo experts and direct observation of bamboo reconstruction projects. This thesis promotes avenues in which bamboo can become a more viable material for building homes in the informal building sector by better understand typical building strategies of low-income communities. Brick and concrete will not likely disappear in the near future, therefore a hybridization of natural and industrial materials may be the only way to increase acceptance and use of bamboo in the informal building sector.

ACKNOWLEDGMENTS

To Brian and Elizabeth - Thank you for your continual support on my academic journey. Your feedback and guidance allowed me to develop a meaningful body of work.

To my family - Thank you for a lifetime of listening, support and freedom to pursue my passions. All of my successes came from a loving foundation that strengthens everyday.

To the Informal Urban Communities Initiative team - Thank you for allowing me the opportunity to continue working in Perú. I have no doubt that the participatory design projects with Eliseo Collazos started me down a path that led to this thesis. I appreciate your support and look forward to future collaboration!

To my friends - Thank you for reminding me to enjoy the world outside of architecture, and occasionally laughing at my jokes. You helped me maintain balance within a field of study that is known for its intense deep dive into coffee and sleepless nights.

To the countless invaluable people of Perú and Ecuador - Thank you for your amazing and boundless hospitality. Never in my wildest dreams did I expect you to take hours out of your busy days to drive me to see your projects, asking (and accepting) nothing in return. I am impressed and inspired by the dedication you put into the work you are advancing. Thank you for letting me be a part of it!

PREFACE

FIG 0.1 Un Techo Para mi Pais, Argentina

FIG 0.2 Host-family during Peace Corps, Piura, Peru

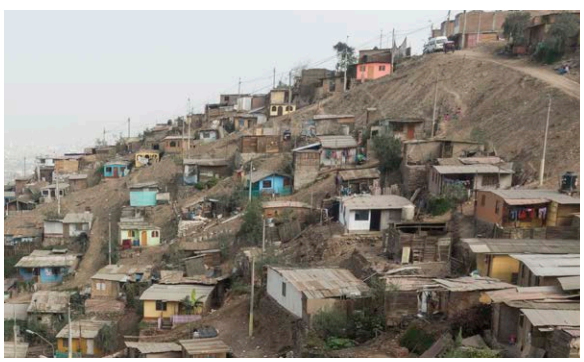

FIG 0.3 IUCI partner community, Eliseo Collazos, Lima, Peru

This body of work stems from a chain of events dating back to 2009, when I first visited South America. I was awarded the Raoul Wallenberg Summer Travel Award which funded my trip to Buenos Aires, Argentina. Through working with Plan Techos, I experienced first hand the hardships of informal settlements and the quagmire of complex political and social issues that lead to their formation. Two months later, I was back at the University of Michigan, wondering how I could do more than painting a few prefabricated wooden boxes. There had to be a better model.

In 2011, I returned to South America, this time to Perú, for a 27 month commitment with the Peace Corps. The cultural immersion was strengthened through my amazing host family and the projects I worked on were developed with community partners, addressing hygiene and access to clean water in small rural towns in the foothills of the Andes. During those two years, I formed a strong connection with my community and with the country.

When I moved to Seattle, I reached out to The Informal Urban Communities Initiative (IUCI) at the College of Built Environments, expressing interest in joining their work in Lima, Peru. In 2015, I was able to do so, working with a multi-disciplinary team to develop a fog-collection system to irrigate a community park and sports court. Working alongside the community members in the informal urban settlement showed me the power of grassroots efforts as well as the amazing wealth of talent and ingenuity.

The above set of experiences allowed me to increase my understanding of the issues that people face in rural and urban poverty in a way that my cultural anthropology classes and ethnographic studies could never do. Granted, there is nothing I can do to change the fact that I am a privileged outsider, but I feel that the relationships and connections that I formed were instrumental to the success of the following research. My approach to community development becomes more refined with each interaction and while this thesis does not culminate in a building design, I have no doubt that it will be helpful to someone down the road who will be building in an informal context. To them, I will say that while projects can spur positive change, it is the process of inclusion that will yield sustainable results and that true participatory design requires relinquishing the power of decision to those who will be most impacted by it.

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CHAPTER 1: HUMANITY'S GREATEST CHALLENGE

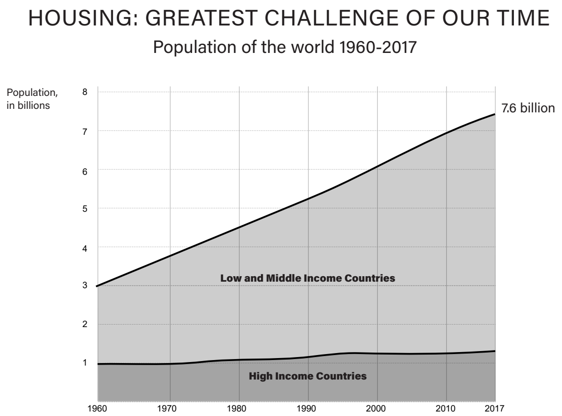


Fig 1.1 - Global population 1960-2017

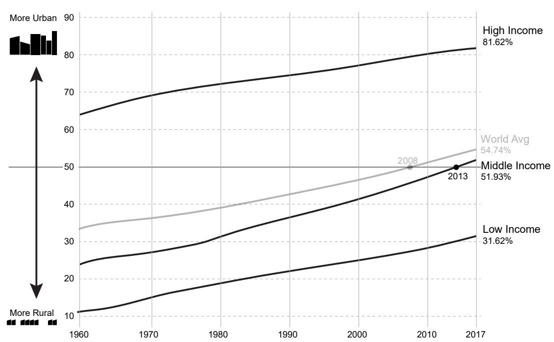


Fig 1.2 - Percentage of population living in urban areas

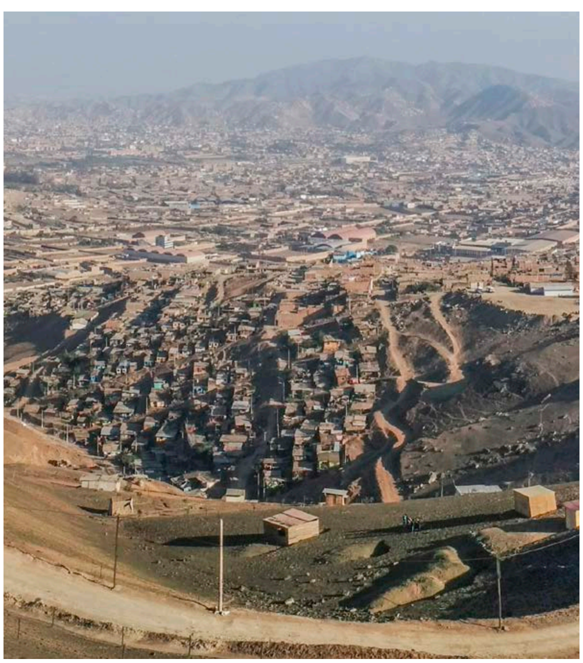


Fig 1.3: Vulnerable informal settlements in Lima, Peru, a country with over 10,000 squatter communities.

1.1 POPULATION GROWTH AND PRESSURES ON THE URBAN FABRIC

"In the past three decades, the urban population of developing countries has tripled to 1.3 billion. More and more populations are forced, through lack of choice, to expand into disaster prone areas such as flood plains, unstable hillsides and deforested lands, therefore causing disproportionate setbacks to the economies and livelihoods of the affected communities and nations when disasters strikes." - UN International Strategy for Disaster Reduction [1]

The global human population is growing at a rapid pace (fig 1.1). In order to keep up, we will need to build 95,000 homes per day; about 4,000 homes per hour.[2] Population growth is not happening uniformly across the world, as fertility rates in low and middle income countries are much higher than high income countries.

2008 marked the year that the world became more urban than rural. High Income Countries have historically been more urban than the Low and Middle Income Countries (LMICs). LMICs rapid rural-to-urban migration can overwhelm municipalities that do not have sufficient funds to regulate the large urban growth (fig 1.2).

1.2 INFORMAL SETTLEMENTS & VULNERABILITY OF THE URBAN REALM IN LMICS

One common strategy to obtain affordable housing in a city is to find untitled public land and lay claim to the plot with a temporary structure. This municipal land squatting or "invasion" is often coordinated by a large group of families, creating a settlement overnight. These families are often poor and cannot afford qualified builders, resulting in communities living in high risk situations: unsafe structures

Fig 1.4 - Informal builders = cheaper construction costs

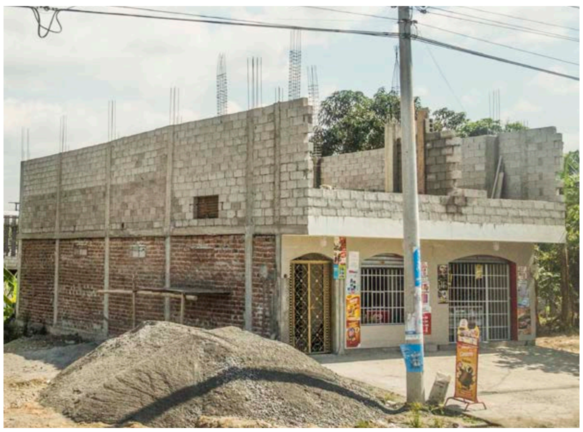


Fig 1.5 - Incremental growth, phased as funds are available

Fig 1.6 - Searching for survivors, Ecuador 2016 earthquake

Local and regional governments are inundated by invasions and have been relatively unsuccessful in their attempts to keep urban migrants off of their unused or undesirable land (fig 1.3). Once an informal settlement has been established, communities slowly develop a means to access basic infrastructural services. Roads begin as compact earth, water is delivered by trucks and stored in tanks at each home, and electricity is illegally connected to a “formalized” neighboring settlement. Over time, the community will petition the government for improved services, which are often obtained in return for political support.

Individuals homes are also slowly improved from a wooden paneled structures to single story, brick homes. In order to build economically, community members often work together to build someone’s home, knowing that when they are ready to upgrade, similar services will be provided for them (fig 1.4). Homes in low-income communities are in a constant state of construction, with exposed steel reinforcing rods poking out of columns while funds are saved for the next phase of building. Due to this incremental building practice, building materials may change from one story to the next (fig 1.5). (Plastering the front facade of homes results in a uniform appearance).

This process of continual home improvement is a common strategy in low-income communities world-wide, and as facilitated by the relatively easy-to-learn masonry building technology. Unfortunately, these families cannot access architectural or engineering services (fig 1.7) and the resulting homes are often vulnerable to catastrophic failure during seismic events (1.6).

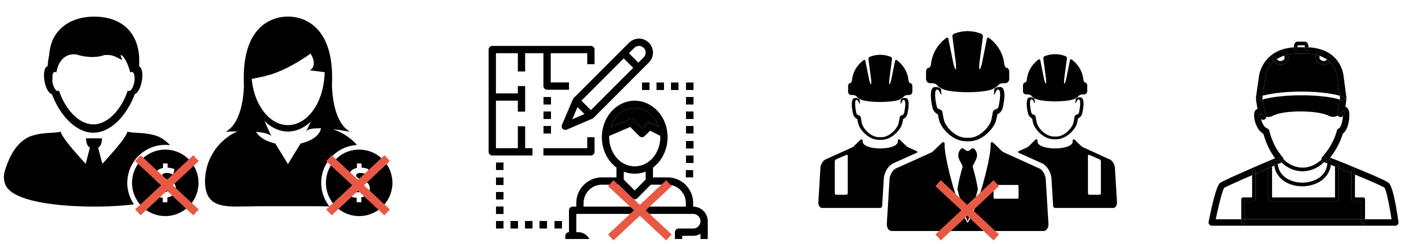
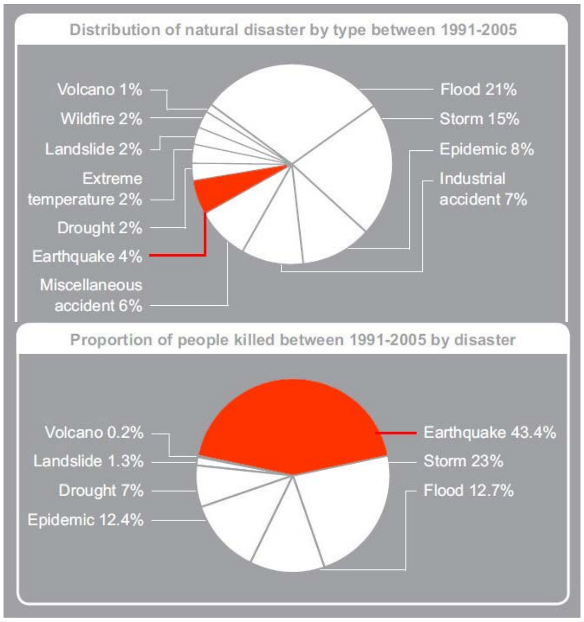


Fig 1.7 - Families do not have resources cannot afford architects, engineers and often rely on the informal building sector for construction services.



Source: EM-DAT: The OFDA/CRED International Disaster Database

Fig 1.8 Statistics on fatality of natural disasters by category

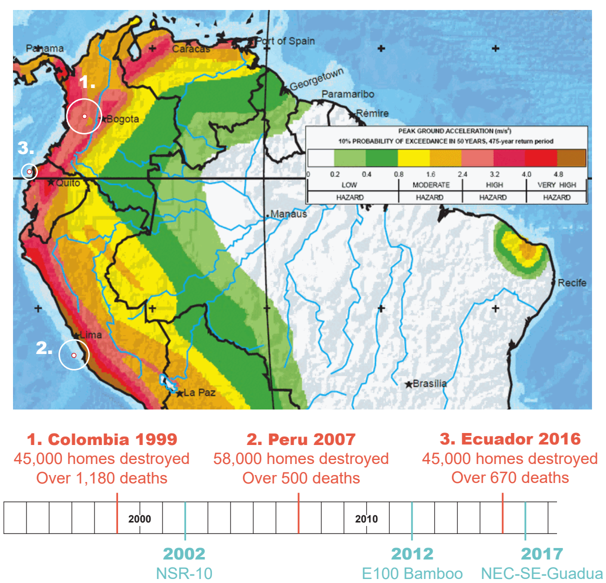


Fig 1.9 Relationship of large seismic disasters & subsequent introduction of bamboo into national building codes

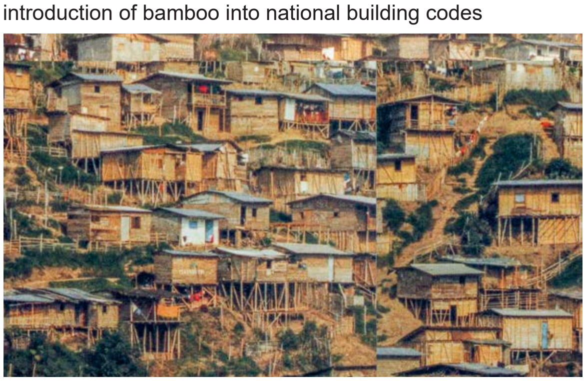


Fig 1.10 Bamboo resilient homes, Manizales, Colombia

1.3 SEISMIC EVENTS IN SOUTH AMERICA

The most deadly natural disasters are earthquakes, accounting for 43.3% of disaster mortalities from 1991-2005, with only 4% of the distribution of disasters in the same time period (fig 1.8). While the informal building sector is filling the void by providing housing for the urban poor, the homes are susceptible to collapse, especially in areas of frequent seismic activity.

Post-earthquake reconstruction is not always as simple as relocating communities to safer areas. In large cities, safe vacant land is typically on the outskirts, removed from the livelihood and services for which the community migrated in the first place. Relocating impoverished communities away from their cultivated social support networks and employment opportunities, often exacerbates economic disparities.[4] Unfortunately, while bulldozing slums has been condemned by human rights groups, its practice has continued and it is estimated that 5 million people are forced to relocate every year.[5] Ignoring or moving urban slums have had disastrous results, so the strategy of slum upgrading has been the most recent logical solution to decreasing the vulnerability of communities that have migrated to cities in search for a better life.

In terms of earthquakes, the pacific coast of South America is highly vulnerable, as it lies along the boundary of two tectonic plates. In just the past 20 years, there have been many major earthquakes in Colombia, Peru and Ecuador, each destroying thousands of homes (fig 1.9). After the 1999 earthquake in Colombia, an assessment found that 90% of the casualties occurred in non-bamboo homes.[6] Bamboo tends to perform well in earthquakes due to the fact that it is a light-weight material, giving it a high strength-weight ratio, and it is traditionally built with ductile connections (fig 1.10).[7]

1.4 EMERGENCY SHELTER TO PERMANENT HOUSING


Fig 1.11- Rudimentary emergency shelter

After each disaster, the country affected had a large housing deficit and an abundant, seismic-resistant building material. The problem arose because there were no legal building codes for using bamboo for structural purposes, making it illegal for the state to rebuild permanent housing using bamboo, and impossible for residents to obtain credit for building back with bamboo. Universities, NGOs and ecologically focused professionals championed the development of standardized bamboo building codes so that structural details that perform well in seismic events could be promoted and disseminated.


Fig 1.12- Emergency shelter with plastic privacy screen

After the most recent disaster (Ecuador, 2016), bamboo played an instrumental role in providing emergency shelter to the 45,000 families whose homes were destroyed. Innovative organizations found ways to use bamboo to provide emergency housing in ways that the material could be reused into transitional housing (fig 1.11 through 1.14). The traumatic experiences of brick and concrete building collapse, coupled with the strong track record of bamboo houses has improved the acceptance of the material among those living in high-risk zones.[8]


Fig 1.13- Enclosed, panelized transitional shelter

"We developed a do-tank...We realized what people really needed... At the moment of the emergency, you don't need to spend that much money. You just go ahead and put the families together...The only way to go through this mourning is to be in your family system. It's the only way to get active again and to be able to process the emotions and what you lost... People can't do that in these huge refugee camps, it's impossible..." [9] - Cristina Latorre on CAEMBA's shelter response.

(for more information on CAEMBA, see Appendix D: Build Back Better)


Fig 1.14- Transitional home interior

1.5 BAMBOO'S POTENTIAL

Bamboo is an ideal material to address the massive need for earthquake resilient urban housing along the west coast of South America for many reasons.

Abundance: The species native to the study area is a variety that has been used to build structurally-sound housing for thousands of years, and its rapid growth and abundance shows the materials capacity to address the large scale housing need.

Resilience: Based on historical evidence, bamboo's flexibility and seismic resistance could reduce the chances of losing a lifetime of investment in one's home.

Local Economy: There is also an economic opportunity to revitalized both urban and rural livelihoods, as investments in durable urban housing would directly benefit rural bamboo farmers, potentially slowing urban migration.

Renewed Investment: The unprecedented political support and international collaboration between Peru, Ecuador and Colombia marks a momentous opportunity for the bamboo building industry. The public/private partnerships that are investing in improving the bamboo value chain illustrates that bamboo housing shows promise. (See Appendix B, project 17C)

Fig 1.15 Dendrocalamus Plantation, Los Bancos, Ecuador

1.5 BAMBOO'S POTENTIAL continued

Material Versatility: While hard-wood and soft-wood species are grown to serve specific industries, bamboo's versatile strength in compression, tension and hardness lends itself to a wide variety of applications. Advancements to traditional housing techniques using minimally processed culms (low tech) as well as an increase of engineered bamboo building products (high tech) illustrate that bamboo's mechanical properties are ideal for future development. (See Appendix B, project 7)

Adaptable Building Systems: Bamboo is a light weight material, that can easily be disassembled and relocated (See Appendix B, project 18b and 18c). Housing is often an incremental process in low-income neighborhoods, therefore the lightweight characteristic of bamboo lends itself to this familiar process (if detailed correctly).

Impact on Climate Change: Bamboo tends to have very low embodied energy, as it is locally sourced and typically is not highly processed. Additionally, its rapid growth and large bio-mass sequesters high amounts of carbon.

1.6 CONCLUSION

The current model of urban growth in LMICs has left low-income communities vulnerable to natural disasters. Bamboo has proven to be a resilient alternative to brick and concrete housing for a myriad of reasons. This architectural thesis will therefore investigate two fundamental questions:

- Is bamboo in Colombia, Peru and Ecuador a viable material to provide resilient housing?
- If so, what can increase the acceptance and use of bamboo in the informal building sector?

The document is organized by chapters:
Chapter 2 will explain the resources and methodology of the research project.
Chapters 3 will introduce the reader to bamboo's material strength, weaknesses.
Chapter 4 will educate the reader on the historical use of bamboo in the study area.
Chapter 5 will explain how the earthquakes have catalyzed improvements to the bamboo value chain, explaining the exciting development of the bamboo building industry, ultimately answering the first thesis question.
Chapter 6 addresses the second thesis question through taking advantage of opportunities of bamboo's structural properties and applying them to existing informal building strategies.
Finally, chapter 7 will revisit arguments made throughout the document and conclude with final thoughts on how the bamboo housing industry can move forward in the years to come.

CHAPTER 2: FRAMEWORK

2.1 LITERATURE RESOURCES

Bamboo has been used as a building material world-wide and there are a plethora of resources that are tailored to the cultures and techniques in which they are produced (fig 2.1 through fig 2.4). The literature shown here and listed in the works cited build off each other, a compilation of decades worth of university research coupled with professional innovations in South America.

This project would not be possible without these rich, contextually specific documents, as the research is specifically focused on the structural bamboo varieties found in South America (Guadua and Dendrocalamus). The referenced literature generally structures the content in similar formats, first discussing the bamboo plant, its growth cycle, physical/mechanical properties as well as organic vulnerabilities. They go into varying depth on the vernacular use in the specified region and introduce new techniques that have been developed in regards to protecting the material from insects and fungus. Finally, each publication promotes the latest structural innovations and architectural details, disseminating best practices of building with bamboo.

These works provided invaluable insight into the evolution of building techniques over time, as well as clear diagrams that illustrate how bamboo is processed and assembled. The reference documents helped shape the organizational strategy of the following thesis, as they proved to be efficient ways of teaching a novice about the basic and intricate use of the material.

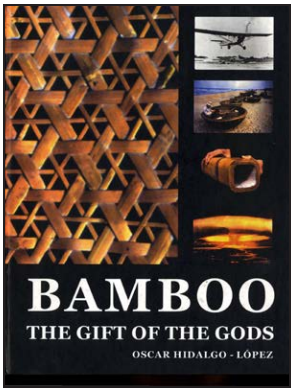


Fig 2.1- Colombian Source[1]
This publication is referenced constantly, as it provides a comprehensive and in-depth exploration into all aspects of bamboo, specifically in the South American context. Examples include: Plant growth, mechanical properties, historical uses, industrial development, case studies and dozens of crisp, axonometric details illustrating various bamboo construction techniques.

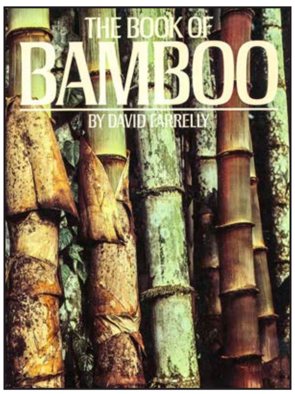


Fig 2.2 - US Source[2]
This 1984 publication reviews the global use of bamboo, listing 1,000 uses of the plant. Farrelly does little to hide his opinionated view of contemporary architecture, often quoting Bernard Rudofsky, lamenting the disregard of lessons learned from vernacular building techniques. A useful reference for understanding the global proliferation and cultural uses of the material.

Fig 2.3- Peru Source[4]
Jorge Morán Ubidia is a well-known bamboo pioneer in Ecuador. He is consulted often, with more than 40 years experience working with the material. This construction manual is filled with step-by-step photographs showing how to grow, harvest, treat and build with bamboo, adapted to follow the Peruvian Building code and Peruvian building culture.

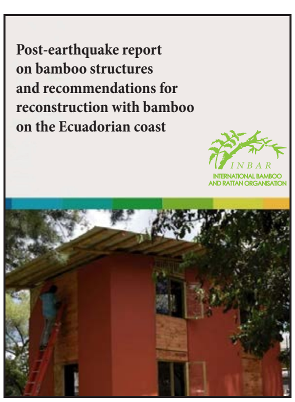


Fig 2.4- Ecuador Source[3]
This report is published by the International Network of Bamboo and Rattan (INBAR), a Chinese NGO whose Latin American regional office is based out of Quito, Ecuador. A detailed overview of how bamboo houses are resilient to earthquakes in response to the 2016 disaster. It explains challenges of and recommendations for bamboo reconstruction.

2.2 METHODOLOGY

To investigate the modern advancements in bamboo construction technology, literary resources could only go so far. In order to obtain up-to-date and diverse perspectives, personal investigation was a necessity.

The John Morse Research Travel Fellowship funded a 10-week expedition across Peru and Ecuador to investigate how the respective countries' bamboo housing market progressed after earthquake reconstruction. The research travel divided into four facets:

- In-person interviews with a diverse set of actors who are improving the bamboo value chain (fig 2.6)
- Photographic documentation of bamboo building techniques/details through site-visits to re-construction projects and other buildings discovered along the way
- Attending conferences and visiting Universities
- Participation in hands-on bamboo building workshops

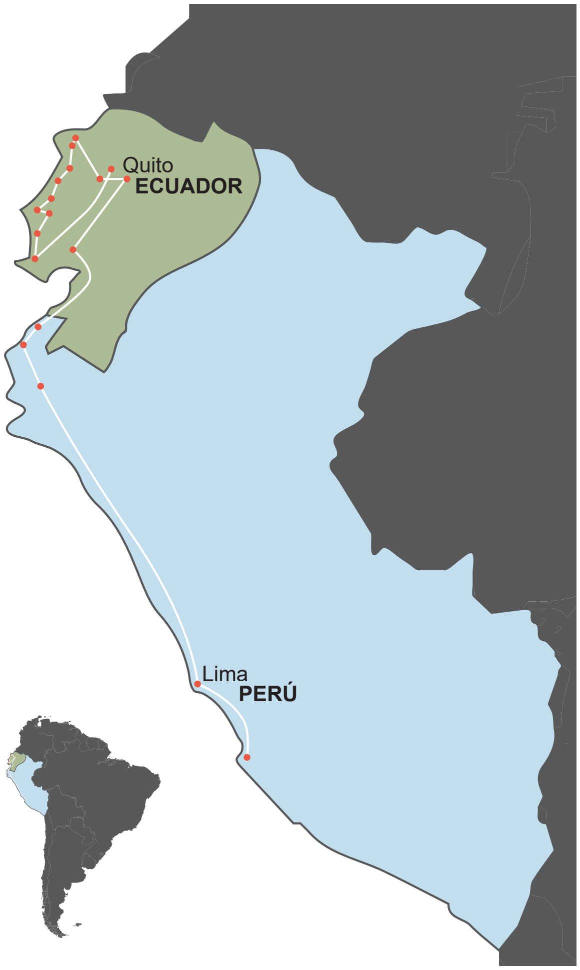


Fig 2.5 - Route of 10 week John Morse Travel Fellowship

GROWERS
CONTRACTORS
PROCESSORS
GOVERNMENT & NGO
ARCHITECTS
RESIDENTS
ACADEMIA

Fig 2.6 - Bamboo stakeholders interviewed during research travel

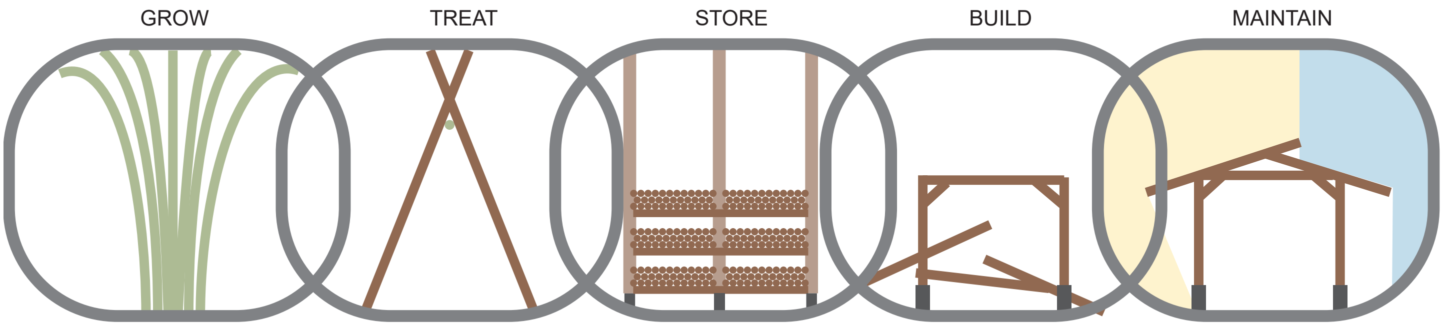


Fig 2.7 - Links of the bamboo value chain


Fig 2.8 - Dendrocalamus Plantation, Los Bancos, Ecuador


Fig 2.9 - Cane drying after treatment. Ayampe, Ecuador


Fig 2.10 - Bamboo warehouse. Santo Domingo, Ecuador

Interviews:

This anthropological ethnography of “bambuseros” (professionals who have dedicated their careers toward the advancement of bamboo) has resulted in insights that are based on lifetimes of observation that would not have been possible by literature research alone.

Most of the interviews occurred in Ecuador, as many of the reconstruction projects from the April 2016 earthquakes were recently completed (or are still in construction). This gave the author a unique opportunity to observe and participate in multi-sectoral initiatives of a country that has a rich history of use with bamboo. Each interview was filled with advice, and ended with recommendations of people or projects to visit.

The initial interview in Lima was with Yann Barnet and Faouzi Jabrane, two professors at San Martín de Porres University that were instrumental to the development of the Peruvian bamboo building code (Appendix A, #1). They both stressed that the governmental support and improvement to the bamboo value chain as one of the most exciting changes occurring across the region (fig 2.7). This influenced the author to develop the methodology of visiting experts at each link of the chain to hear how it has progressed following the initiatives enacted during post-earthquake reconstruction (fig 2.8 through fig 2.10)

Fig 2.11: Home owner interviews revealed insights into how disasters can alter opinions about heavy building materials

Interviews (continued)

For most of the reconstruction projects, the recipients did not purchase the materials for their new housing and often did not have a choice in the matter. It was important to capture the voice of homeowners, to get an unbiased opinion as to how the new homes were holding up structurally, and whether they were meeting all the needs of the family.

Residents were generally happy to have shelter again, especially a home that is seismic resistant as many had been traumatized by their previous homes collapsing (fig 2.11). One unique aspect of the house visits was the opportunity to witness how residents began to personalize their new homes as well as observe difficulties of self-expansion using the same techniques. (More on interviews, see Appendix C)

Photograph documentation of site visits:

One of the main objectives of the research trip was to visit “new” bamboo housing projects that were built in response to major earthquakes. These projects were built by a variety of actors ranging from International NGOs, solo architects, national ministry of housing, university partnerships to name a few. (fig 2.5, Appendix A, #5b and Appendix B, #15b). The appendices intend to tell a story of an evolving building technology. The synthesis and analysis of these photos helped the researcher discover trends, by filtering, grouping and classifying more than 10,000 photographs (fig 2.12)

Fig 2.12 - Sorting photographs as a means of analysis

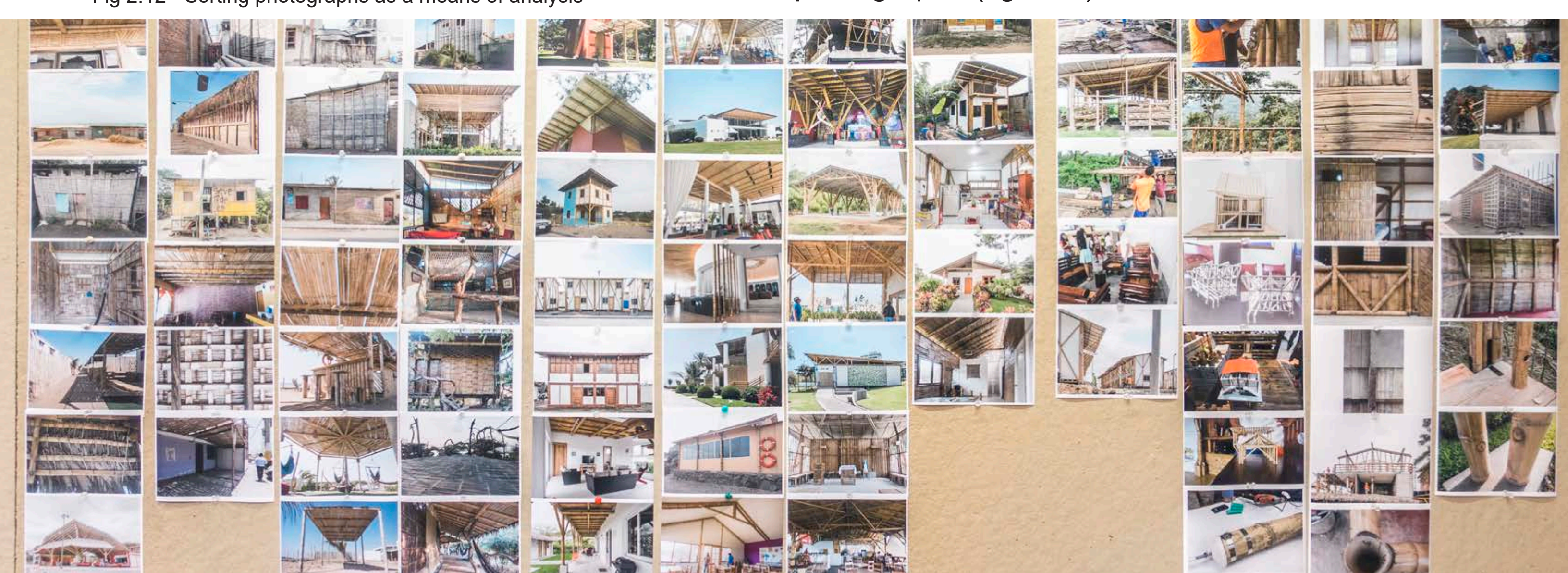


Fig 2.13 - Premio Sacha project submission


Fig 2.14 - Catholic University in Santo Domingo Ecuador


Fig 2.15 - Two day bamboo build workshop. Quito, Ecuador

Conferences:

Attending a 3 day conference exposed the author to a network of professionals working in Ecuador. The conference, titled “Premio Sacha” was an award program for sustainable agroforestry and buildings. It had six lecturers by experts from Peru and Ecuador, which gave the research trip a wealth of and up-to-date information.

Additionally, the Premio Sacha website displays dozens of projects submitted as award contestants. This database of recent Ecuadorian buildings built with bamboo was invaluable, as it was a map of potential site visits, with contact information of project architects as well as detailed photos and project information (fig 2.13).

Another conference in a nearby University trailed the Premio Sacha event, where a diverse audience of local artisans, farmers, architects and students asked pertinent question (fig 2.14). (Appendix A #1, Appendix B #6, 9, 17e)

Hands on building workshops:

The Premio Sacha conference had a build workshop component. Learning a new building technique is difficult, but with the correct tools and skilled teachers, a group of 20 attendees completed a partially prefabricated structure (fig 2.15). Physically working with the thick material allowed the author to understand the difficulties that contractors may have with the material. (see Appendix B, home construction #11b and 2-day workshop, #18b)

2.3 CONCLUSION

The research set out with a flexible structure of goals and strategies, allowing full immersion and networking to sweep the author off on an intense 70 day adventure.

The first step of the journey is an intimate understanding of the bamboo plant. Chapter 3 will describe bamboo’s strengths, weaknesses, and unique characteristics that give it such potential.

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CHAPTER 3: INTRODUCTION TO BAMBOO

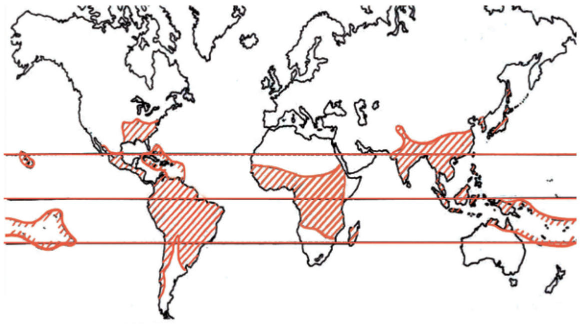


Fig 3.1- Global locations of native bamboo growth

Fig 3.2 - Varieties of bamboos

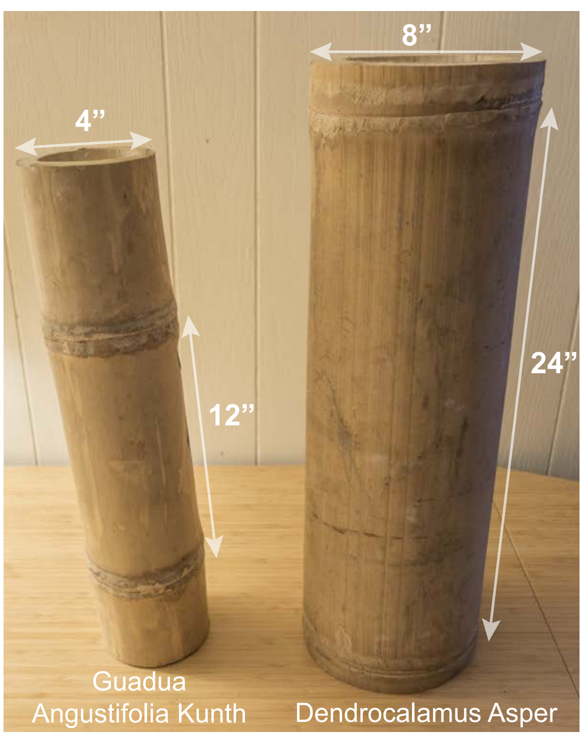


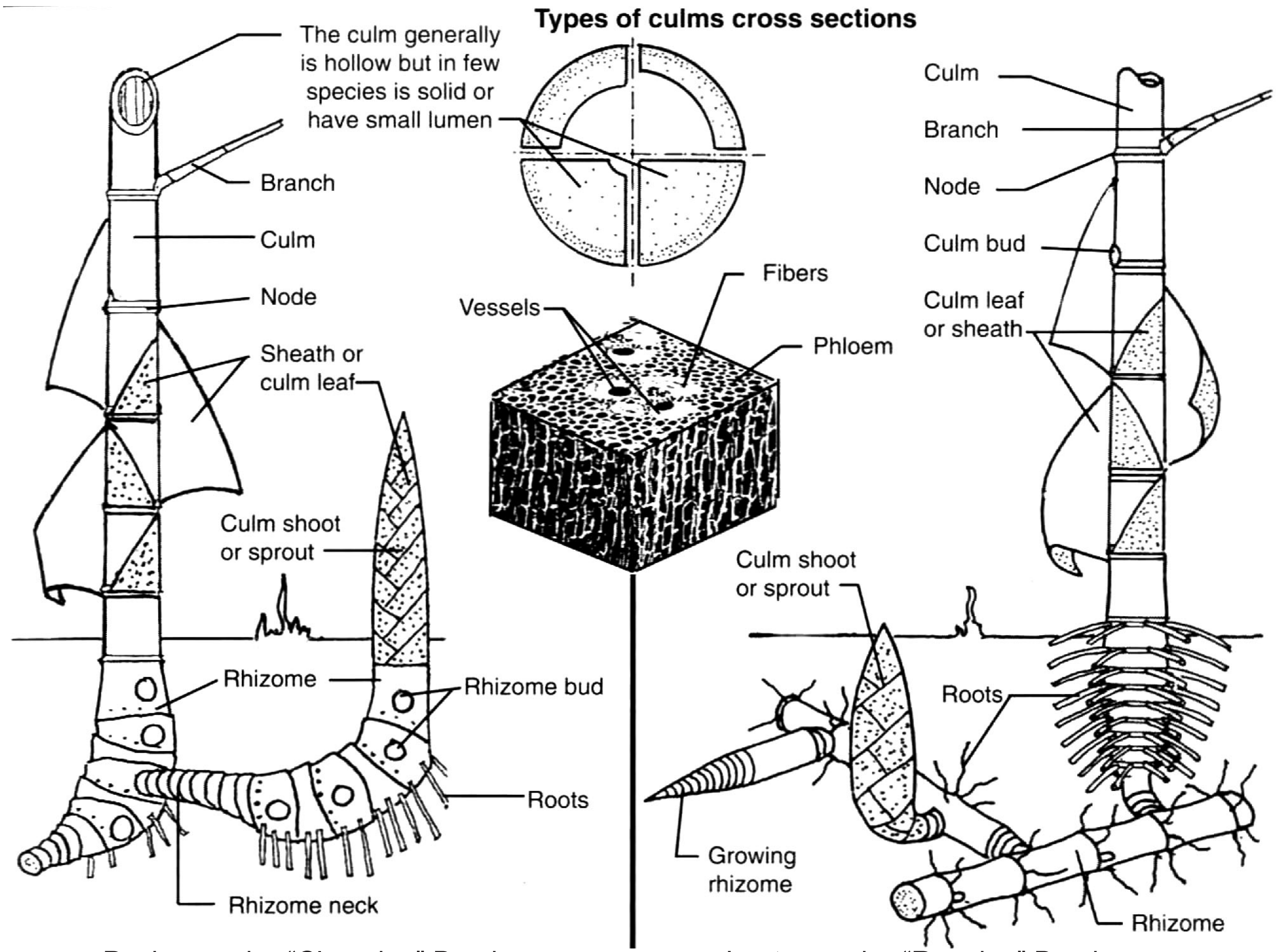
Fig 3.3 - Typical dimensions of structural bamboo culms

3.1 PLANT GROWTH, TYPES AND VOCABULARY

Bamboo is found globally, mainly within the tropics (fig 3.1). The plant evolved alongside other grasses and cereals during the Cretaceous period, over 100 million years ago.[1] The family has 121 genera and over 1,600 species, showing variety in color, diameter, strength and growing patterns (fig 3.2) [2]. The bamboo's global distribution is 30% in the Americas, 3% in Africa and the remaining 67% in Asia and Oceania (no bamboo is native to Europe).[3]

Bamboo can be divided into two types, based on growth patterns and geographical origins (fig 3.4). Both types look the same above ground, as their difference lies in their root structure. The pachymorph, or clumping bamboos, grow in dense groups. They cannot resist frost and therefore are only found in tropical zones. The leptomorph, or running bamboo, sends out long runners, spreading the bamboo plant far wider than pachymorph. This growth trait makes this type of bamboo useful in soil retention and is used commonly to prevent the collapse of riverbanks.[4] Leptomorph bamboo is frost resistant and therefore can be found in temperate climates or at high altitudes in the tropics.

The environmental needs of bamboo vary depending on species, but the most important factor to healthy growth is adequate rainwater. The requirement can be as low as 30 inches/year up to 200 inches/year.[5] Other factors that influence plant growth are climate conditions associated with latitude, topography, soils and seasonal swing of temperature.



Pachymorph - “Clumping” Bamboo

Leptomorph - “Running” Bamboo

Fig 3.4- Bamboo classification based on Rhizome (root) growth

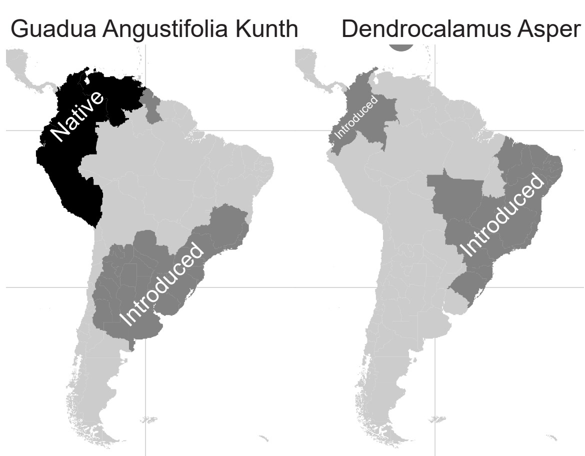


Fig 3.5 - Structural bamboo species commonly used in South America

Above the ground, bamboo sprouts vertical stems called culms, that can grow up to 4 feet in one day, making it the fastest growing woody plant in the world.[6] The culms are hollow and grow in segments that are separated by diaphragms, also known as nodes (fig 3.4). The distance between nodes varies by species, as does the thickness of the culm wall. Each year the plant sends up new culms quickly establishing a large amount of biomass. Due to this rapid growth cycle, a single plant will have culms at various stages of development.

3.2 STRUCTURAL PROPERTIES

It should be noted that not every species of bamboo has high structural capabilities. Many varieties grow slender culms and are used ornamentally. The varieties that have structural capacity are often strong enough to support multi-story buildings and, in some instances, are suited to match the strength of steel. Two structural varieties prevalent in the study area are Guadua Angostifolia Kunth and Dendrocalamus Asper (fig 3.3). Both are found in South America and while Guadua is a native variety, Dendrocalums has been imported from East Asia (fig 3.5). Guadua will be the variety of bamboo discussed in the remainder of the document.

The plant's structural development over its lifetime allows it to be employed for different uses (fig 3.6). For maximum structural capacity, the thickness of the culm wall needs to reach maturity, which takes between 4-6 years, depending on end use. Industrial products such as flooring or glue laminated products need additional time to grow as these products demand a higher structural capacity.

Guadua reaches its mature height rather quickly (80 to 100 days![7]), and the wall thickness increases in following years. Therefore, proper forestry management is crucial to ensure that the harvester knows the age of the culm they are harvesting, especially when the culm is being used for structural purposes. Bamboo changes in diameter and strength along the length of its culm. The diaphragm at the nodes are stronger in compression than the hollow internode areas (fig 3.7).

Bamboo has a high strength to weight ratio, especially in comparison to concrete, making it an attractive material for structures where overall weight is a factor (fig 3.8). The plant's stiffness outperforms other materials such as wood, which tends to buckle at a shorter unsupported length.

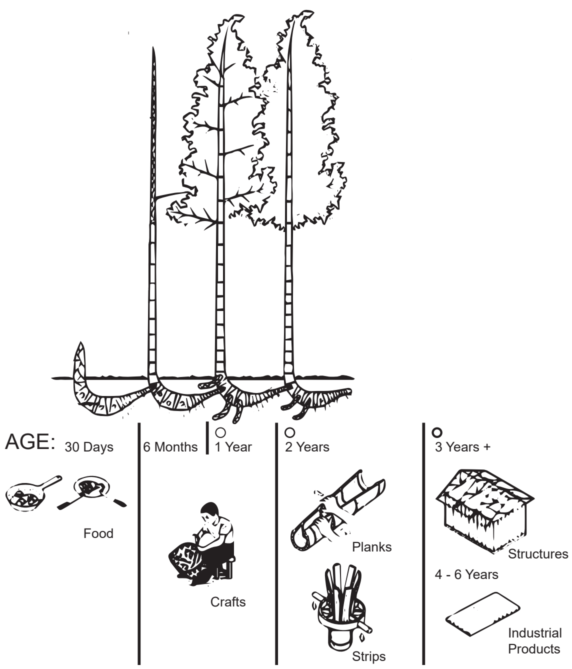


Fig 3.6 - Bamboo growth and use over time

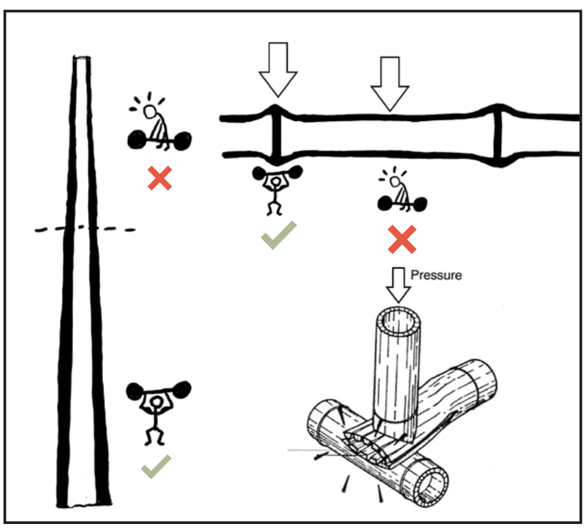


Fig 3.7 - Structural traits corresponding with axial loads

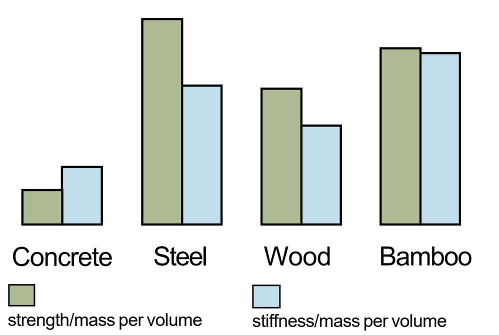


Fig 3.8 - Structural traits compared to industrial materials

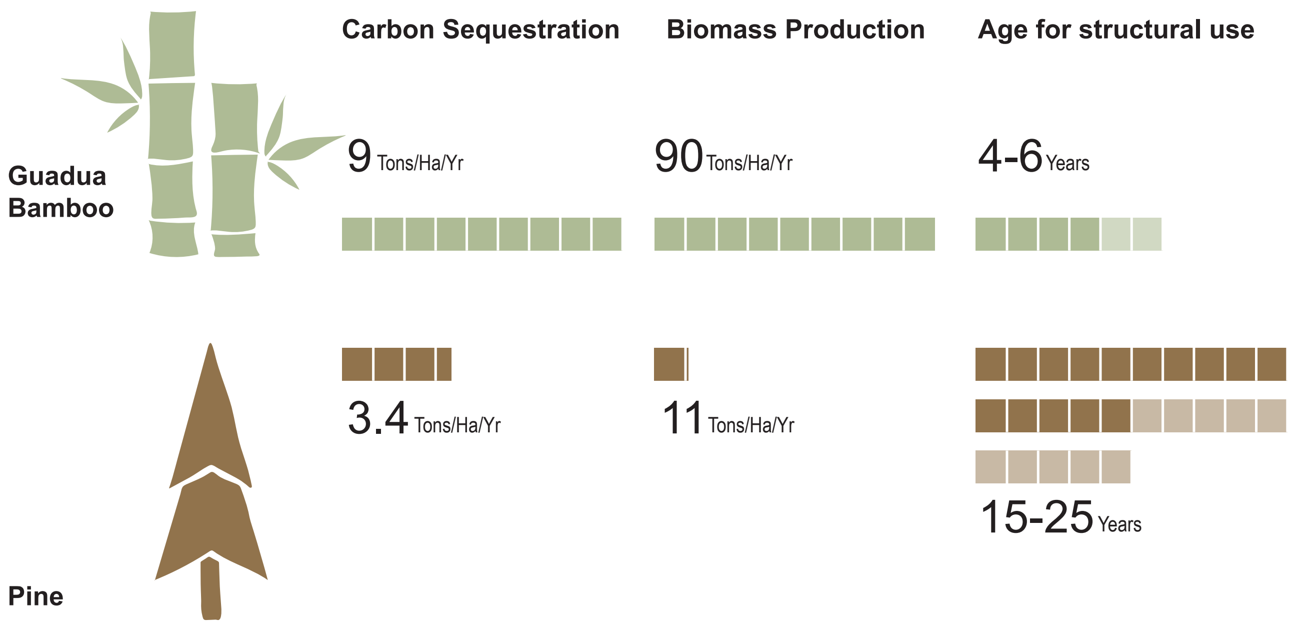


Fig 3.9 - Bamboo and Pine comparisons

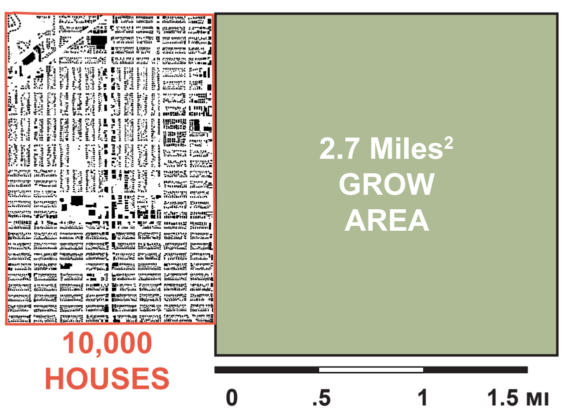


Fig 3.10 - Rapidly renewable and dense bamboo growth make it an ecological choice as a building material.

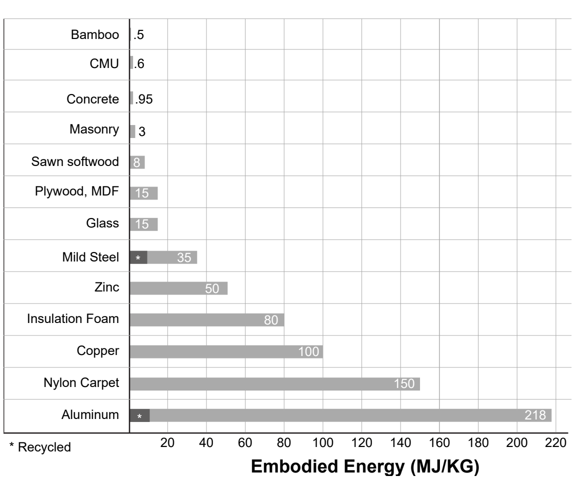


Fig 3.11 - Embodied energy compared to industrial materials

3.3 SUSTAINABLE TRAITS

Bamboo has some incredible statistics when it comes to sustainability. It is the fastest growing woody plant in the world with some varieties growing 36" to 48" in one day[8]. The National Bamboo Project of Costa Rica planted over 700 hectors of bamboo (2.7 mi^2), which produces enough material to build 10,000 rural houses annually (fig 3.10 for scale)[9]. Given the rapid regeneration and dense growth, bamboo sequesters high amounts of carbon per hector, generating large amounts of biomass in the process, making it an ideal selection for combating green house gases and global climate change (fig 3.9). Compared to pine, which takes 15-25 years to reach structural maturity as must be replanted with a 15-25 year growing period, bamboo is ready to harvest after just 4 years and can be continuously harvested year after year because new shoots sprout annually.

Additionally, bamboo also requires little processing after harvest, creating a construction product that has low embodied energy compared to other conventional materials, such as concrete and steel (fig 3.11).

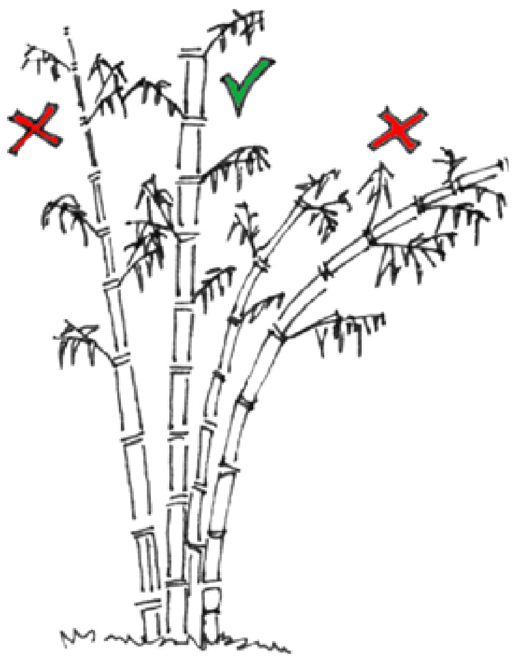


Fig 3.12 - Desirable characteristics, straight culms

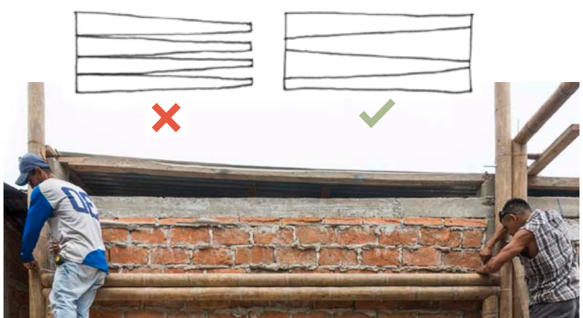


Fig 3.13 Building with cone nature of culms in beams

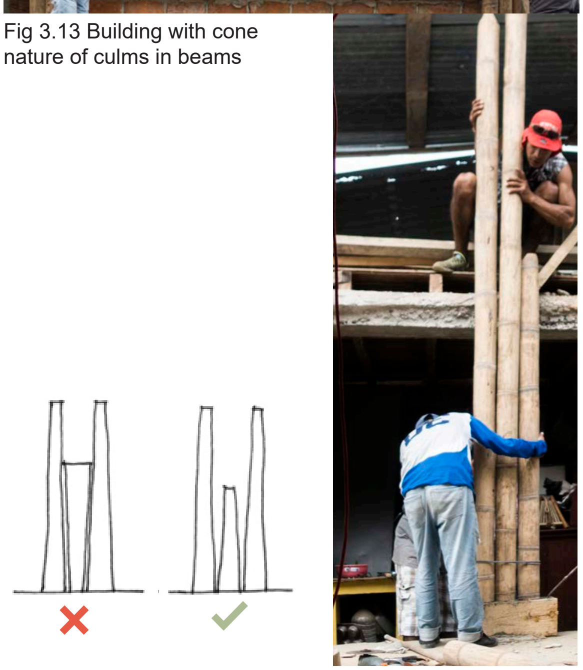


Fig 3.14 Building with cone nature of culms in columns

3.4 ORGANIC CHARACTERISTICS

Being an organic material, bamboo has irregularities that make it difficult to use when uniformity is necessary. For most uses, a straight culm is the most desirable (fig 3.12). Once bamboo has been harvested, the culms need to be sorted into usable and unusable categories based on how straight the stem is throughout its length. Culms that are too crooked for use can be processed in with other methods to minimize waste (fig 4.2 and 4.3).

As mentioned previously, bamboo does not have a consistent diameter from its base to its tip and difficulties arise when culms are combined to form structural elements with increased load capacity. Alternating orientation of culms can help combat the change in diameter (fig 3.13). When combining culms to create columns, it is best practice to match the orientation of growth, keeping the wide base at the bottom (fig 3.14).

Other organic vulnerabilities include susceptibility to insect attack and fungal damage if not treated (fig 3.15, 3.16). There are many ways to make the material unattractive to insects, such as smoking it, or soaking it in sea water. Modern techniques include inundating the material in a non-toxic borax salt solution followed by a drying period to ensure minimal expansion or cracking of the culms (fig 3.17- fig 3.20). Bamboo is also prone to rot when exposed to water. Lifting the material off the ground and shielding it from rain will prolong the lifespan (fig 3.21). The risk of cracking due to sun is another vulnerability, so exposed culms must be shaded or covered with concrete.

3.5 CONCLUSION

Now that the reader has a basic understanding of the material strengths and weaknesses of bamboo, the next chapter will explain how it has historically been used for housing in the study area.

Fig 3.15- Beetle damage

Fig 3.16 Termite damage

Fig 3.17 - Mix a 6% solution in water

Fig 3.18 - Pierce diaphragm

Fig 3.19 - Submerge for five days

Fig 3.20 - Drain and Dry, 6 weeks

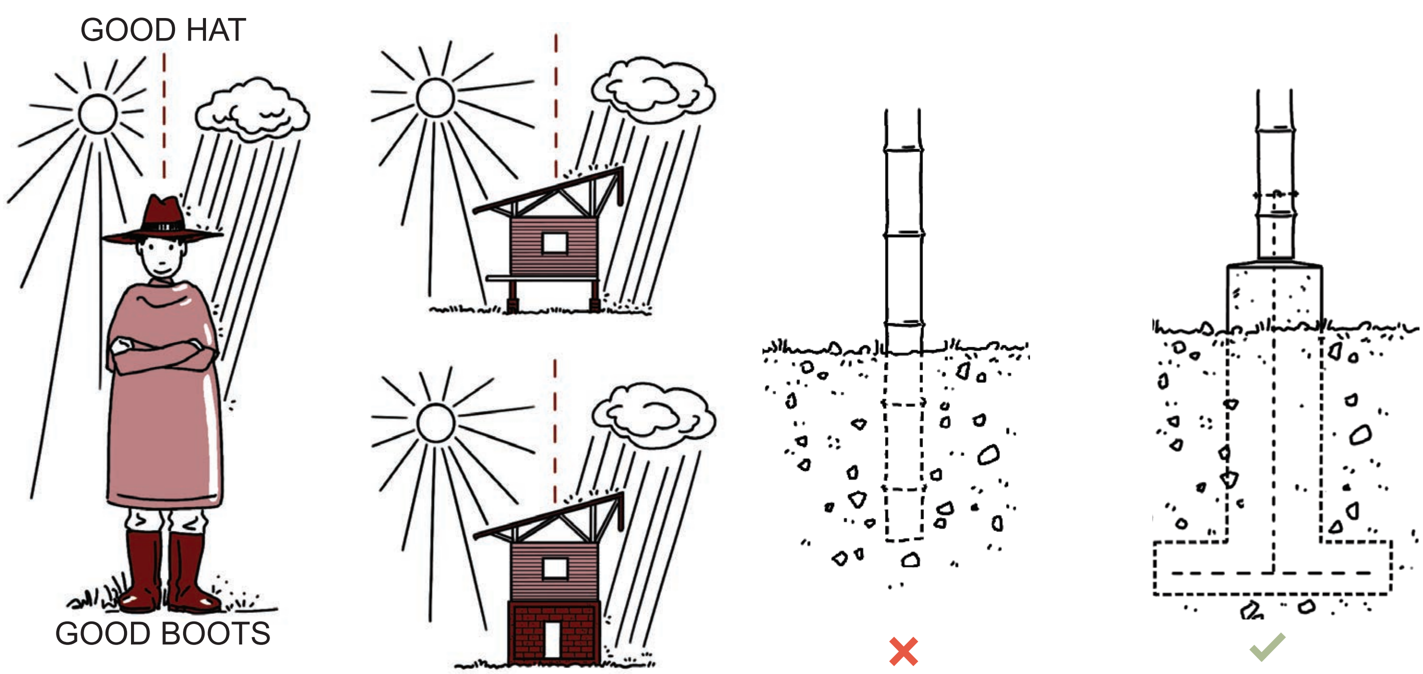


Fig 3.21 - Manuals promoting best practice

CHAPTER 4. BAMBOO HOUSING

Bamboo can be utilized in many ways in the construction of homes. For maximum structural capacity, entire culms can be bound together to create a ridged frame (fig 4.1). Culms which are not straight or have not grown to structural capacity are split into thin strips and woven into screens or used as purlins to support light elements (fig 4.2). Similarly, non-uniform culms can be split and flattened into bamboo boards, which are attached to bamboo studs or wooden frames creating walls, ceilings, or floors (fig 4.3). Industrialized processes, such as lamination, is discussed in further detail in Chapter 5.

Fig 4.1 - Building with culms

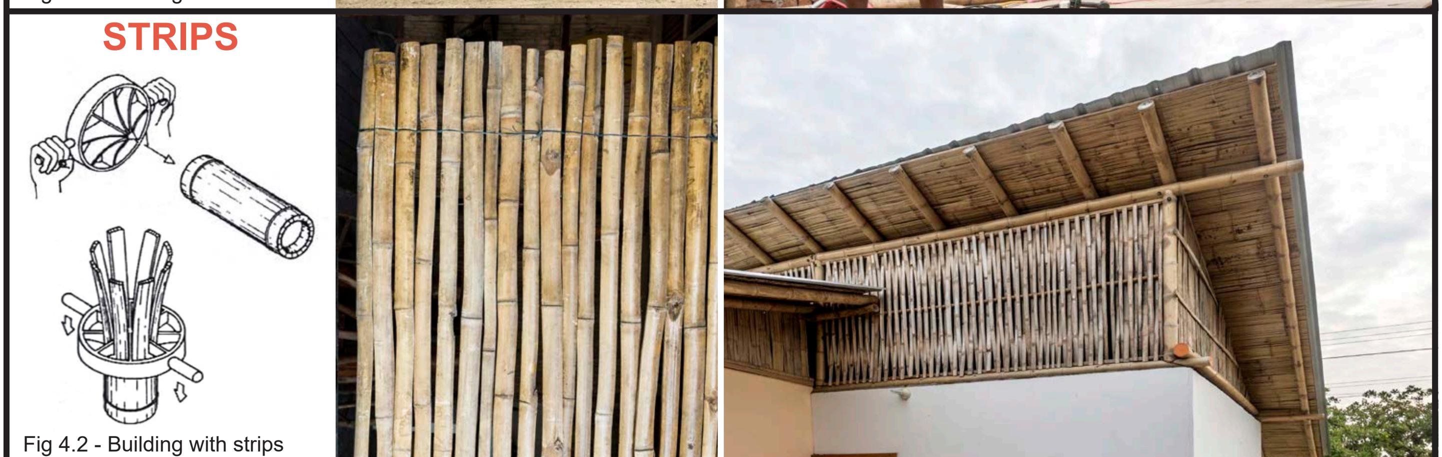


Fig 4.2 - Building with strips

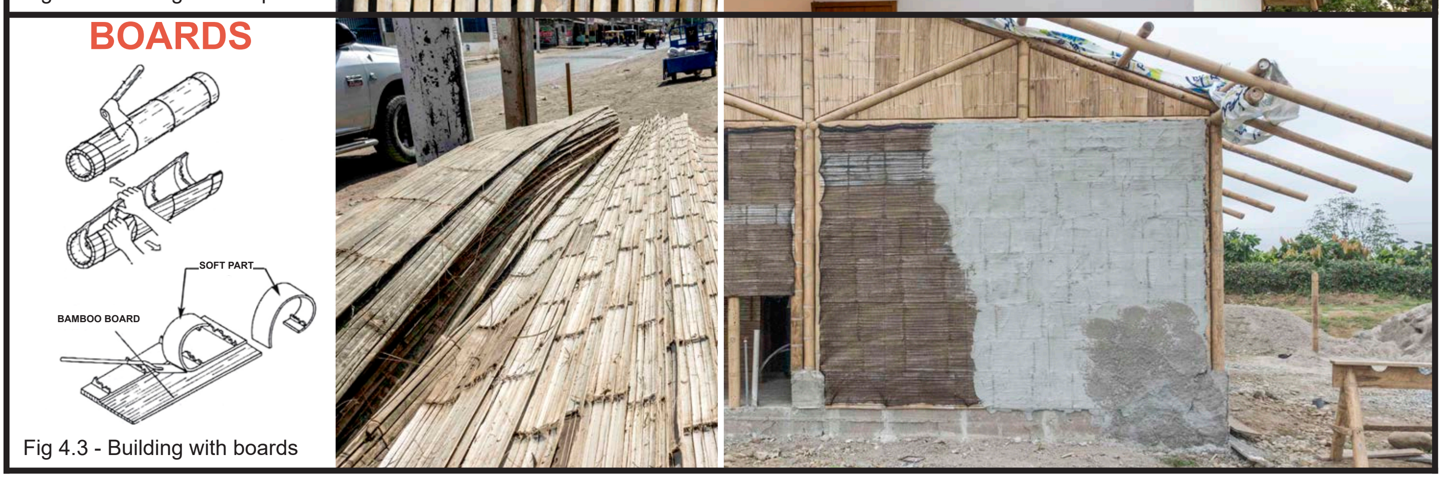


Fig 4.3 - Building with boards

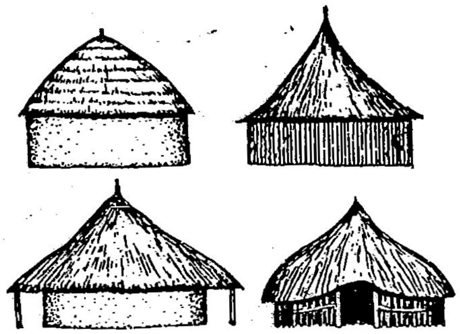


Fig 4.4 - Global examples of vernacular bamboo homes

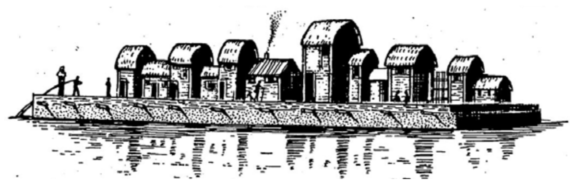


Fig 4.5 - Bamboo island villages, 17th c. China

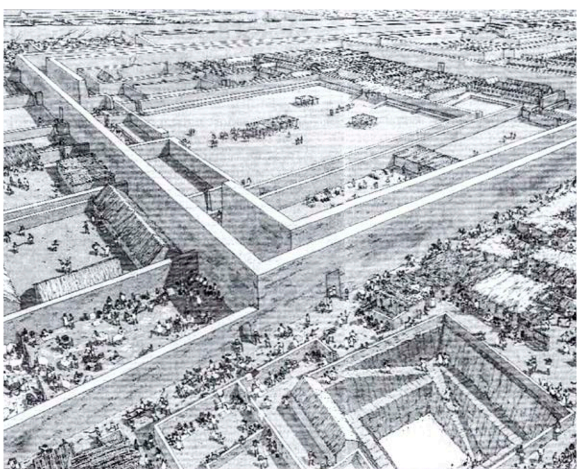


Fig 4.6 - Chan Chan, ancient Peruvian city housing 50,000

4.1 HISTORICAL VERNACULAR

The global distribution of bamboo has resulted in dozens of vernacular typologies that utilize the abundant plant (fig 4.4). East Asia in particular has a strong tradition of using bamboo for housing. European travelers in the 17th century were astounded by floating bamboo villages of over 200 families, showcasing an intimate understanding of the material[1] (fig 4.5).

A bamboo dwelling or funeral chamber found in Ecuador dating to 7.500 BC highlights the long historic use of the plant in the Americas.[2] Indeed, its use for housing can be found across the tropics of the Western Hemisphere, from Peru up to present day Guatemala. The structural bamboo Guadua was used by many cultures throughout history but not exclusively in regions where it grew. An archaeological discovery in Peru showcases that bamboo's seismic resistance has been utilized by the Chimu civilization dating back to 850 AD (fig 4.6 and 4.7) and it is believed that the cane was imported from present day Ecuador. Today, bamboo is still imported from Ecuador in large quantities, although the market in the northern departments of Piura and Lambayeque is growing with the help of local NGOs.

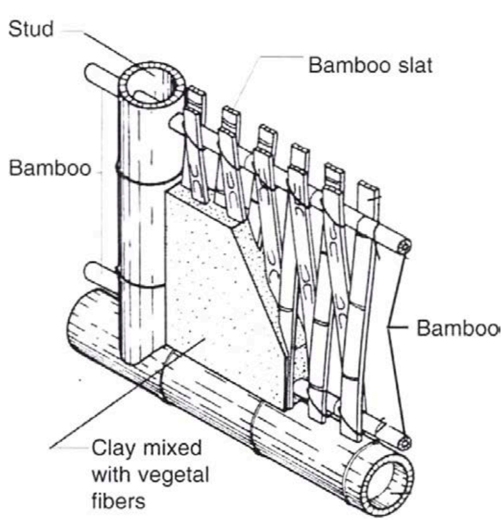


Fig 4.7 - Quincha construction technique

Fig 4.8 - Traditional building techniques seen through exposed quincha, Lima, Peru

In Peru, bamboo is often referred to as “caña de Guayaquil”, or cane from Guayaquil, Ecuador. The fierce sun along the Peruvian coastal desert is a hostile environment for exposed cane, and the vernacular construction of “quincha” protects the cane by covering it with mud (fig 4.7). These buildings have lasted hundreds of years and can still be found in modern day Lima (fig 4.8)

Ecuador’s vernacular typology responds to the environmental conditions of the Ecuadorian coast through elevated homes. The annual floods would pass beneath the homes, leaving the bamboo buildings intact (fig 4.9). The elevated houses in the Ecuadorian jungles, on the other hand, was a formal move in response to dangerous animals that prowled the jungle floors (fig 4.10). While the forms of contemporary housing have changed, the elevated home is a strategy that is still practiced today.

Colombian housing has a tradition similar to the Peruvian quincha technique, where culms are used as studs, attaching horizontal bamboo strips to form a cage. A mixture of clay and straw is stuffed in the wall cavity and is left to dry (for about a month), and is then coated with two layers of fine clay, sand and cement (fig 4.11).[3] Bahareque, a Colombian vernacular technique that is prevalent today, is constructed by attaching bamboo boards to bamboo studs or a wooden frame, often plastered with a cement mixture (fig 4.12).

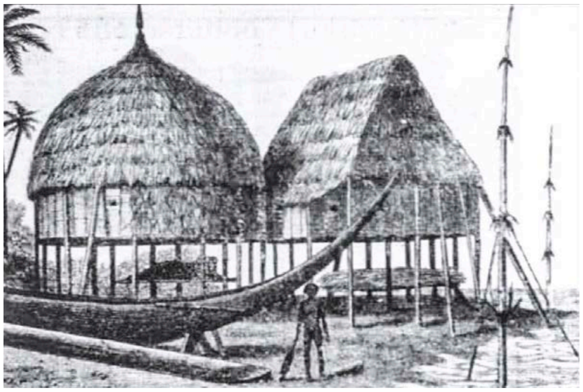


Fig 4.9 - Elevated coastal housing typology, Ecuador

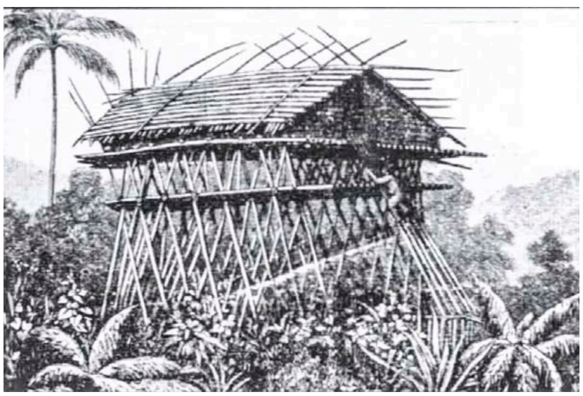


Fig 4.10 - Elevated jungle housing typology, Ecuador

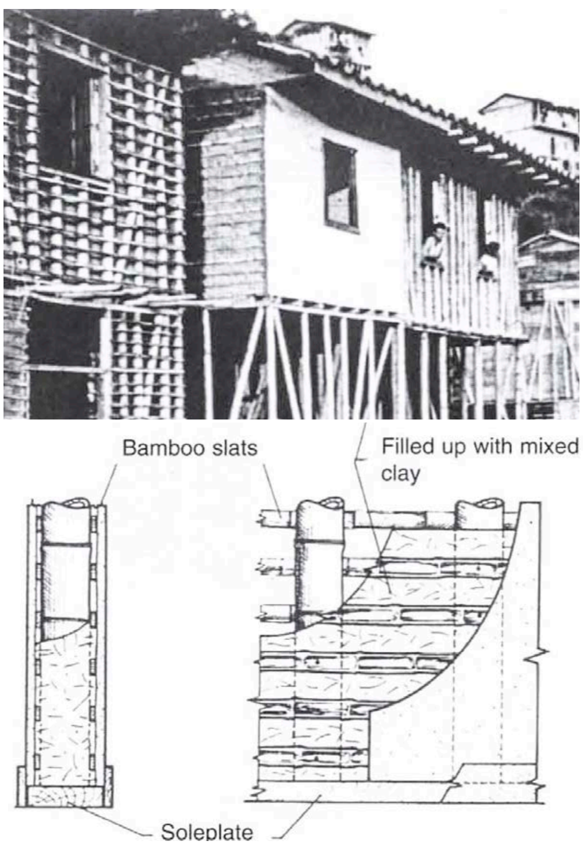


Fig 4.11 - Wattle and daub, clay filled slats, Colombia

Fig 4.12 - Bahareque in process, mesh improves adherence of concrete to board. Santo Domingo, Ecuador, 2017

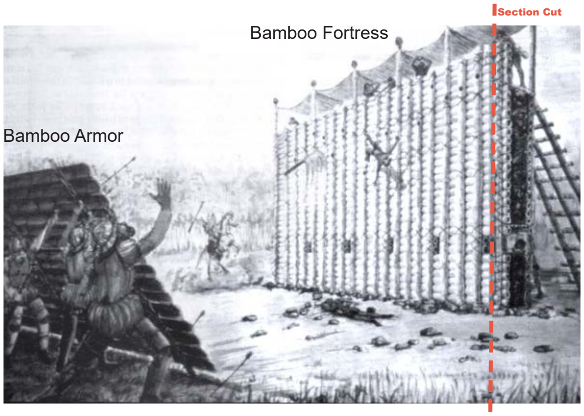


Fig 4.13 - Spanish attacking indigenous bamboo fortress

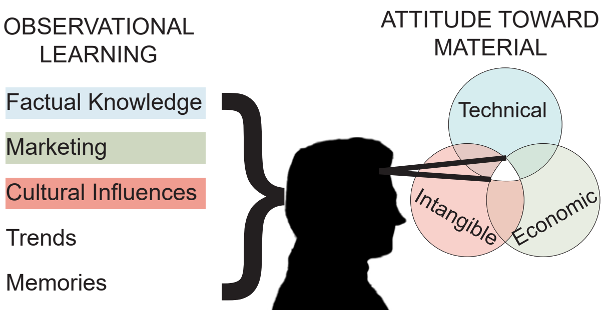


Fig 4.14 - Factors that influence our attitudes toward materials


Fig 4.15 - Bamboo facades styled to Spanish & French ideals Manizales, Colombia

4.2 SPANISH INFLUENCE

"Spaniards who have any self respect do not live in bamboo houses but in adobe houses" [4]

When the Spanish invaded South America, they brought with them their cultural values. During colonization, indigenous tribes were decimated and with the destruction of their bamboo villages, their vernacular building traditions were rendered obsolete (fig 4.13).

The Spanish viewed bamboo as a low quality material of the past and native people who wished to progress assimilated, adopting the elite's value system. A similar anthropological phenomena occurs today as rural farmers move to the city: they shed their traditional clothing, indigenous language and customs to fit in with the status quo.

During interviews in Ecuador and Peru, the author heard the same comment over and over: people have a stigma with the material. They think bamboo is a material used by the poor. To be modern means using "materiales nobles". Noble materials, meaning brick, concrete and steel have a higher status associated with them. People's attitudes toward materials are based on observational learning: mainly factual knowledge, marketing and cultural influences (fig 4.14).[5] The combination of these factors influence the way people think and it can be argued that the Spanish had a profound and lasting effect on the South American perception of bamboo as a building material.

While bamboo was still used to build in South America, new imported building techniques continually replaced or masked organic building materials. Clay roof tiles (and later corrugated metal) replaced thatch roofs and bamboo walls were covered in plaster or cement, rendering buildings to match the elite's material values (fig 4.15).

Year 2010
Provincial Houses According to Wall Materials

Province	Material of exterior walls		
	Bahareque or coated cane	Exposed cane	Total
El Oro	6,274	7,376	13,650
Esmeraldas	6,758	7,472	14,230
Guayas	52,939	82,148	135,087
Los Rios	13,902	26,467	40,369
Manabi	29,203	59,541	88,744
Santo Domingo	18,106	6,589	24,695
Santa Elena	5,991	8,812	14,803
Total	**133,173**	**198,405**	**331,578**

Fig 4.16 - Data on bamboo homes along coastal Ecuador

Fig 4.17 - Modular prefabricated bamboo home, Ecuador

Fig 4.18 - CMU infill below modular bamboo panels,
Rural context: Muisni, Ecuador

4.3 CONTEMPORARY APPLICATIONS

Low-Income Bamboo Housing: Current uses of bamboo in housing were observed by the author throughout the 10-week travel and has been augmented through supporting references. Due to its quick growth, light weight and low costs, bamboo still plays a role in the affordable housing market, both in rural and urban contexts. For example, in Ecuador in 2010, over 330,000 coastal homes were recorded to be made of bamboo, housing over 1.6 million people (fig 4.16).

Viviendas Hogar de Cristo (VHC), founded in 1973, provides financing services and housing options to low-income families around Guayaquil, Ecuador . Many of their models are affordable due to the modular prefabrication of bamboo wall panels, which can be shipped and easily assembled (fig 4.17).

Costs: VHC is providing extremely economical shelter, as their philosophy is "better to give a bamboo shelter today than a concrete house in five years".[6] An eight panel house (without plumbing/electricity) is 450 ft^2 and costs approximately $380.[7] In comparison, a 380 ft^2 concrete block house (with utilities) costs approximately $5,000.[8] The rudimentary shelter is an initial stage of the incremental improvements described in Chapter 1, which will eventually be replaced by concrete and block, adding plumbing and electricity as services become available (fig 4.18). The large low-income populations living in lightweight bamboo homes are safe from large earthquakes, but as they begin to improve their standard of living and build multi-story buildings, their homes become more vulnerable to natural disasters if built improperly.

See Appedix A, 5b for examples of self-built, low cost housing in Peru and Appendix B, 15b for additonal examples in Ecuador.

Fig 4.19 - Dinastia del Sol, Carmen de Apicala, Colombia. Architect: Carolina Zuluaga Zuleta

Fig 4.20- Architect: Carolina Zuluaga Zuleta

Fig 4.21 - Architect: Carolina Zuluaga Zuleta

High-Income Bamboo Housing

Colombia has had bamboo in the national building code the longest of the 3 countries in this study. Some developments have been built with bamboo as a main building material indicating that there is a market for bamboo housing among a high income group (fig 4.19 through fig 4.21). High-end bamboo housing requires a wealthy client that can afford to pay the services of design and engineering professionals, as well as a highly skilled construction crew that knows how to successfully build the proposed bamboo housing design (fig 4.22). Similar to sustainable design principles, it is possible that the progressive ideals of the elite class may one day filter down to middle and low income groups, making bamboo a prevalent building material in the housing sector to the same scale as industrialized “noble materials”.

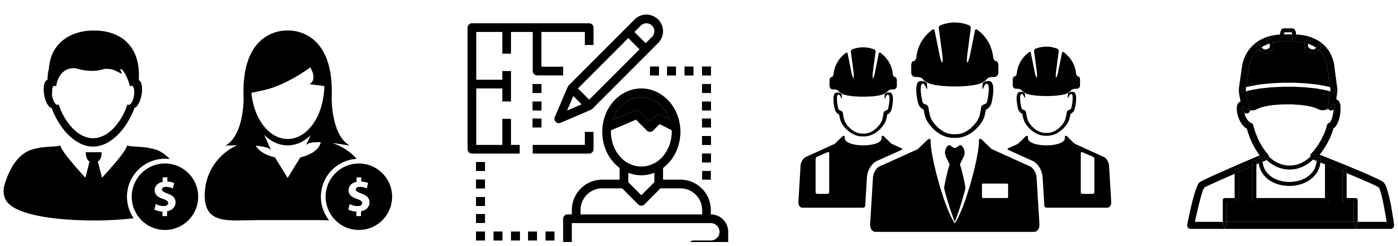


Fig 4.22 - Necessary stakeholders of complex bamboo projects: Wealthy Client, Architect, Engineers, Trained Construction Crew

Fig 4.23 - Beach bar, Paracas, Peru

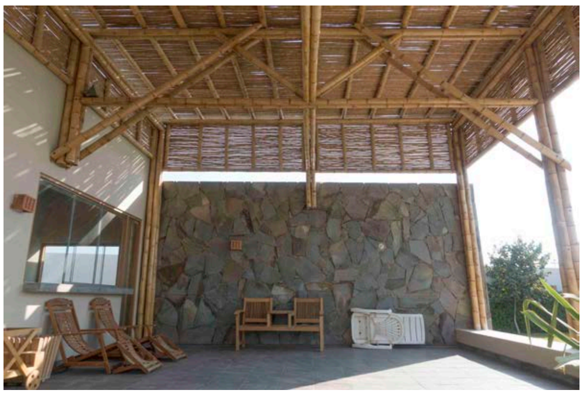


Fig 4.24 - Shaded patio, Paracas, Peru. Jairo Llamo Hoyos

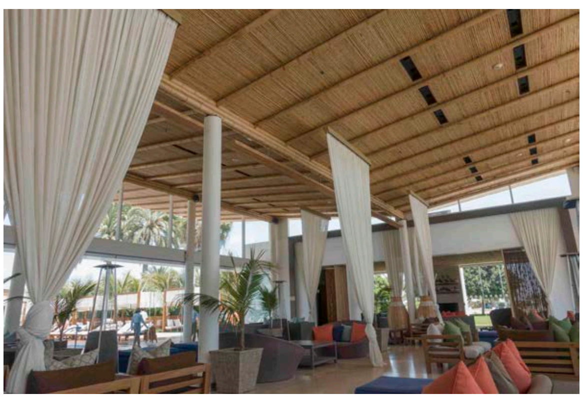


Fig 4.25 - High end resort, Paracas, Peru. Architect Mauricio Gonzalez

Fig 4.26 - Vineyard patio, Pisco, Peru. Contractor: Carlos Huauya Erribares

Niche Markets and Large Scale Projects

Current markets that utilize bamboo are those centered around tourism. Foreigners have a different attitude towards bamboo, as they associate the material with warm, tropical vacation destinations. This is a reasonable associate, because bamboo is a very affordable material to create shade on a hot beach or a pool patio (fig 4.23 and 4.26).

The new building code creates a potential to use bamboo for increased spans and complex structures, utilized to create impressive and beautiful hotels, country clubs and restaurants (fig 4.27 through fig 4.32).

4.4 CONCLUSION

This thesis focuses on bamboo housing, but it should be noted that these public works for the wealthy can raise awareness of bamboo's potential. The structural capacity, specifically through bamboo trusses and combined culms displays impressive capabilities. The more that wealthy clients see that bamboo is a material worth investing in, there will be an increase in demand for a high quality material, ultimately reinforcing the need for a strong value chain.

These projects also increase the demand for qualified contractors and large construction crews, exposing more people to the new building code. While the niche markets are not increasing the demand for low and middle income bamboo housing, they are advancing improved building techniques, which is a win.

Bamboo buildings have evolved drastically since the introduction of industrialized materials. The bamboo building code has resulted in a renewed investment in the industry. The next chapter explores how the 2016 earthquake in Ecuador has revitalized the market for bamboo housing and discusses challenges along the way.

Tourist Market - Beach Discoteca

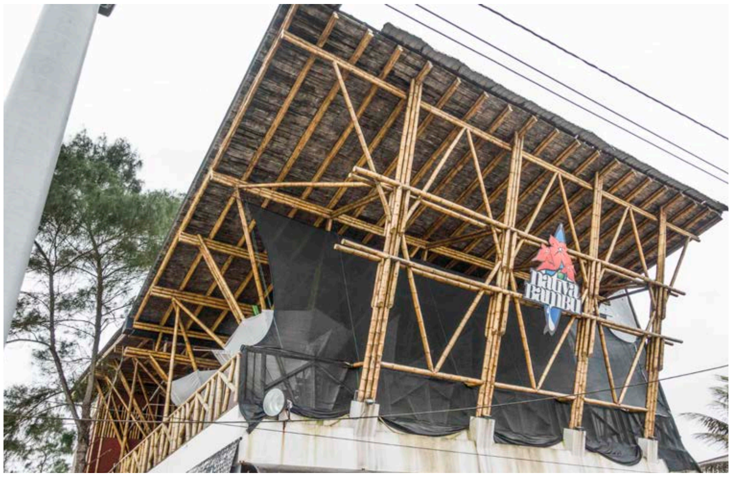


Fig 4.27 - Nighclub, Architect: Daniela Loaiza, Montañitas, Ecuador

Fig 4.28 - Nighclub, Architect: Daniela Loaiza, Montañitas, Ecuador

Resort Market - Modern Aesthetic

Fig 4.29 - Event space, San Rafael del Grupo Nobis, Guayas, Ecuador

Fig 4.30 - Event space, San Rafael del Grupo Nobis, Guayas, Ecuador

Restaurant Industry

Fig 4.31 - Restaurant, Lomas del Pino, Chancay, Peru
Architect Yann Barnet y Faouzi Jabrane

Fig 4.32 - Restaurant, Lomas del Pino, Chancay, Peru
Architect Yann Barnet y Faouzi Jabrane

CHAPTER 5. RECENT DEVELOPMENTS

Fig 5.1 - Location of earthquake and projects visited

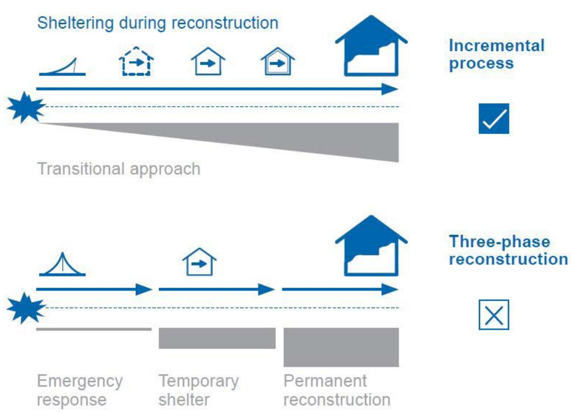


FIG 5.2 Two strategies of housing reconstruction

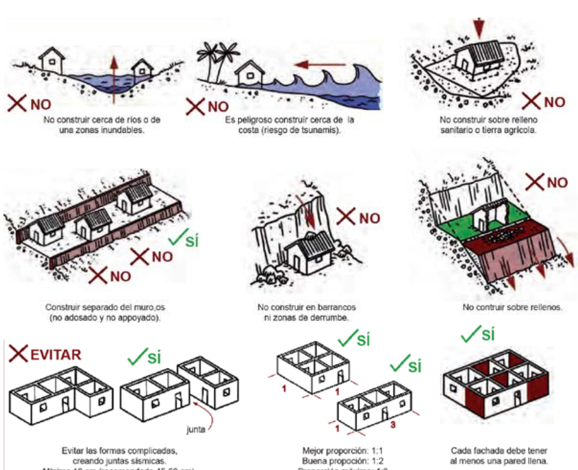


FIG 5.3 - Reconstruction pamphlets distributed by Shelter Sector to informal builders who would not wait delayed aid

5.1 EARTHQUAKE RECONSTRUCTION: A CATALYST

On April 16, 2016, a 7.8 magnitude earthquake struck off the northern coast of Ecuador, damaging over 45,000 homes (fig 5.1).[1] Ecuador is a middle income country and the national housing authority felt compelled to maintain control over the reconstruction response. However, the Shelter Sector of international humanitarian organizations assisted the ministry of housing (MIDUVI) in addressing the need for transitional housing responses in rural areas. Disaster reconstruction is difficult on many levels. According to the Shelter Sector:

Prior to the earthquake, there were a number of pre-existing vulnerabilities in the country. The hardest hit provinces of Manabí and Esmeraldas had levels of poverty about 30% and 40% respectively. Both provinces were over 40% rural. Almost half of the homes lacked access to public water networks and only a third had access to a sewerage system. The livelihoods of many people in the affected coastal areas depended on fisheries, aquaculture and tourism.

In urban areas, poor land use planning in many towns had resulted in an increase of inadequate and informal settlements. A high proportion of the population across rural and urban areas had no access to recognized land titles. Substandard and unsafe building practices and regulations were in evidence across a number of different building typologies, from lightweight to masonry construction.[2]

Additionally, under 30% of the victims owned the land they lived on. The scale of immediate need is usually addressed through providing emergency shelter in the form of tents, as they can be shipped in mass quantities very efficiently. The difficulties arise during reconstruction, especially when communities were living on land with soil that has low bearing capacity and is vulnerable to tsunamis. Families that began rebuilding illegally were given pamphlets explaining how to do so safer than before (fig 5.3). Additional information on earthquakes reconstruction issues and strategies can be found in Appendix D: Build Back Better.

Fig 5.4 - Services included, elevated off ground
Architect Silvia Flores. Jama, Ecuador

Fig 5.5 - Structural use, shear resistance
Architect Silvia Flores. Jama, Ecuador

Fig 5.6 - Bahareque with concrete for modern exterior look
Architect Silvia Flores. Jama, Ecuador

Re-Building Campaign

Regardless of reconstruction strategy, the goal is to reduce the vulnerability of the community, building back with better homes for the disaster victims. Bamboo played a crucial role in providing permanent and resilient housing.

Private, public, and non-governmental organization alike embraced bamboo as a viable solution to provide permanent housing to the disaster survivors. The earthquake reconstruction catalyzed a multi-sectoral revitalization of the bamboo building industry in Ecuador at a scale much larger than the Peru 2007 response. The passing of a bamboo building code 18 months after the earthquake shows promise that the increased interest will not fade with time.

Each case study embraces best-practices as a means of ensuring more than 50 years of life for the resilient buildings. The homes were raised off the ground on concrete footings (fig 5.4) to protect the culms from water damage. Treated, structural bamboo bracing was emphasized to provide a structural security in the earthquake prone coastal communities (fig 5.5).

Cultural sensitivity led to creating an aesthetic that matched the neighboring CMU houses, often covering the bamboo board siding with a cement mixture (fig 5.6). Additionally, as donations allowed, higher finishes such as ceramic, white washed walls and varnished cane gave the families a home that felt as contemporary as a block home (Appendix B, #11a). To avoid splitting of culms, long eaves are recommended (fig 5.6). Some projects left bamboo exposed, leaving homeowners to upgrade over time.

To combat issues with land tenure, panelized transitional houses without poured slabs or services served as an improvement from molding and degraded tents (fig 5.9). With time, families either moved their homes or gained tenure, upgrading these new homes through pouring slabs and expanding their usable space (fig 5.10).

Larger plots of land in rural or peri-urban greenfield sites allowed larger housing developments. Self-help and sweat equity is a model that cuts costs through having the future home owners participate in the construction of their own home (fig 5.11). MIDUVI, the Ecuadorian housing authority developed 160 duplex homes made of bamboo and plywood, although the water and electrical services will take 2 years to reach the site, revealing how bureaucratic inefficiencies fail to meet immediate need (fig 5.12).

Fig 5.7 - Proud resident posing in front of her new home. Bahia, Ecuador

Fig 5.8 - Rural Santa Elena, Heifer International funded

Fig 5.9 - Transitional bamboo housing, Manuel Palleres, Tonsupa, Ecuador

Fig 5.10 - CAEMBA housing expanded by homeowner, Tonsupa, Ecuador

Fig 5.11- Rural development of 50+ homes, funded by private citizen Nina Vaca. Villa de Alegria, Muisne, Ecuador

Fig 5.12 - MIDUVI funded development, 160+ duplex homes, La Chorrera, Pedernales, Ecuador. Architect: Luis Rivera

Fig 5.13 - Housing prototype, Porto Viejo, Ecuador

Fig 5.14 - 2 story prototype, Quito, Ecuador

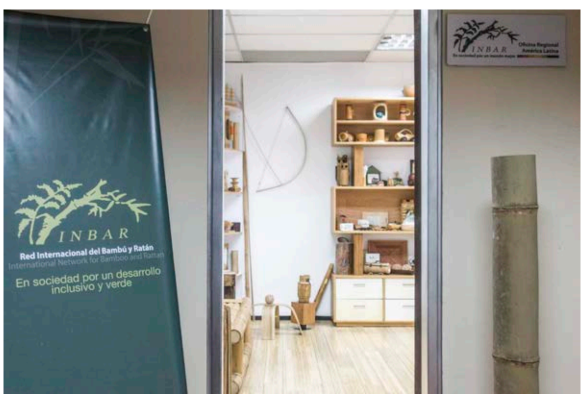


Fig 5.15 - INBAR Latin Amer. Headquarters, Quito, Ecuador

Fig 5.16 - Forestry management workshop, Piura, Peru

Bamboo Housing Prototypes

As the national housing authority updates its housing designs to include bamboo houses, prototype houses are often built in public parks to showcase the innovative designs (fig 5.13 and fig 5.14). The strategy to change public perception of people toward housing is following a similar model discussed previously: through showcasing high quality and aesthetically pleasing bamboo homes, the government is trying to sway people's attitude toward the material.

Returning to the diagram indicating what influences people's attitude toward a material (fig 4.17), these prototypes fall under the marketing category. When the buildings are open and an attendant is explaining the new building techniques, they are increasing the factual knowledge a person has as well. The next section describes additional efforts being made to make structural bamboo housing more economic, through improving the availability of quality building materials.

5.2 IMPROVEMENTS TO VALUE CHAIN

In the past 20 years, support for the bamboo industry has strengthened through multi-lateral channels. The International Network of Bamboo and Rattan (INBAR), a NGO based out of Beijing, China has been instrumental to the international development of the bamboo value chain across Latin America. Based in Quito, Ecuador, INBAR facilitates agroforestry trainings, conferences, and publishes documents promoting best practices (fig 5.15).

Grow: The seismic events discussed in Chapter 1 and investments by national governments has signaled a shift in political will. Governmental funding is now available to non-profits that teach bamboo plantations owners improved management as a means of improving rural livelihoods.

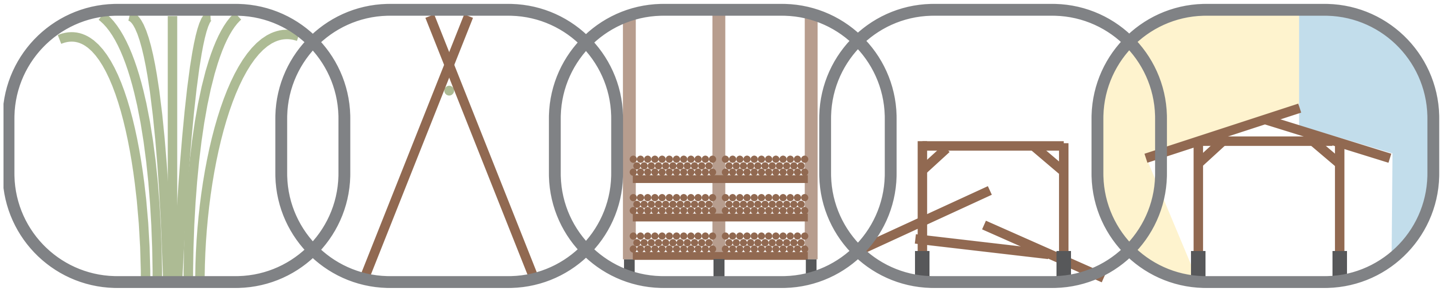


Fig 5.17 - Links of the bamboo value chain

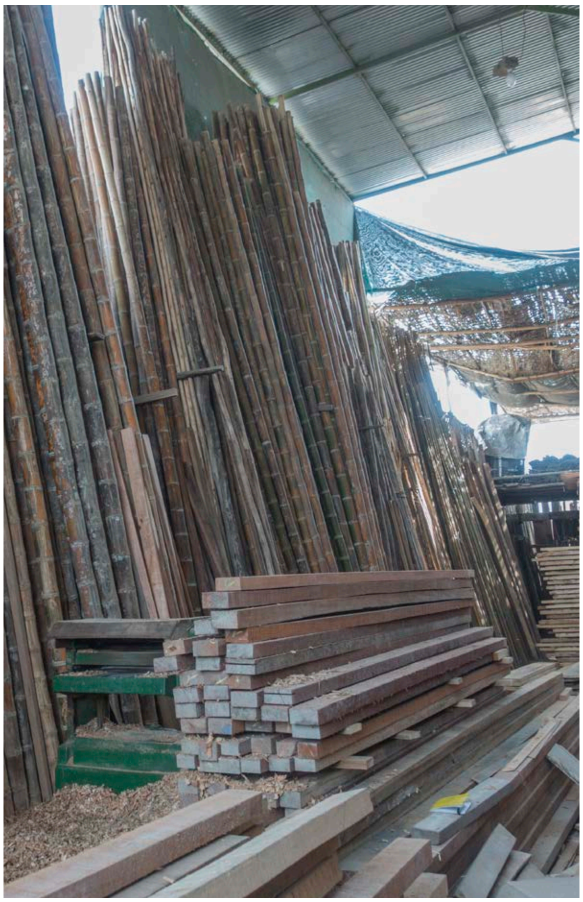


Fig 5.18 - Lumberyard owner didn't know age of culms, Peru

Fig 5.19 - Rural community treatment, Cilia, Peru 2013

Grow continued: Progreso, one such non-profit based in Piura, Peru is working with rural communities whose cash crops of coffee and cacao are failing due to effects of climate change. Bamboo is a resilient alternative crop that could prove to be a viable resource if the bamboo market improves.

Unfortunately, intermediary harvesters clear-cut cane that match a certain diameter, causing harm to the bamboo plantation. While bamboo may appear the same from year 1 onwards, the plant needs more than 3 years to gain its structural properties. This has resulted in a market flooded with cane that has low structural capabilities (fig 5.18). In addition, cane is sold untreated, leaving it susceptible to insect and fungal damage. To top it off, people use the material incorrectly, placing it directly on the ground, leaving it exposed to moisture and sun. The combination of these practices reinforcing a negative attitude towards bamboo as a material that is inferior to industrialized materials.

Progreso and other organizations are training plantation owners to manage their groves, marking the age of culms with paint and try to get owners to only harvest cane that has reached structural maturity (fig 5.15). They also train farmers how to treat the cane with borax. There is a dilemma in the current market, because no one sees value in buying more expensive cane and the farmer has no incentive to improve their management if it does not result in higher payment (fig 5.19).

Fig 5.20 - Large scale treatment plant, Santo Domingo, ECU

Fig 5.21 - High quantity production, Santo Domingo, Ecuador

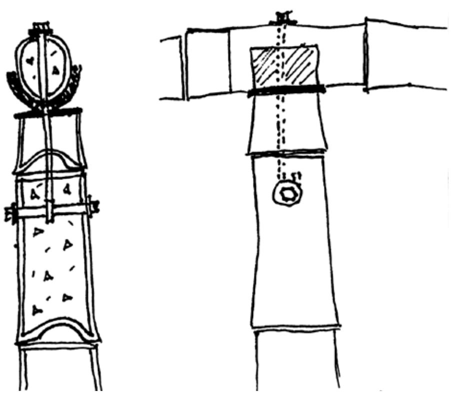


Fig 5.22 - Column to beam detail from Ecuadorian code

Fig 5.23 - Two-day build workshop, Quito, Ecuador 10-12-17

Treat: The regional government in Santo Domingo, Ecuador has invested in a large scale treatment facility to combat the difficulty associated with small scale farmers treating their own cane (fig 5.20). Farmers will sell their structurally mature culms to a the regional center at a fair market price. The center can obtain a better price by buying the treatment chemical at higher volumes and can be more efficient by recycling the chemical solution through more batches than a small scale farmer. Ultimately, the treatment center will produce structural, treated culm at a more affordable price.

Store: Treating large volumes during the dry season, when the plantations are easier to access is a better practice for farmers, but this could result in a lack of supply during the rainy season. To solve this issue, warehouses are being developed that store large quantities of treated cane should large projects occur during the rainy season (fig 5.21).

Build: The new building code reinforces best practices, such as avoiding contact with the ground, but also introduces modern building techniques, combining a traditional material with industrialized connections (fig 5.22). Stronger joints are created through fastening culms together with threaded rod and pouring concrete into the hollow inter-nodal sections. The dissemination of the building code is a crucial step, as it is useless if it is not practiced. Training workshops and illustrative manuals are the current strategies used to teach these techniques to contractors across the continent (fig 5.23 and 5.24).

Fig 5.24 - Construction manual highlighting new techniques and structural principles

Build continued: In addition to training contractors, much work is being done in the academic realm to teach future architects about the potential of the material. The author visited five Universities (one Peruvian, 4 Ecuadorian) that have champions promoting the benefits of working with bamboo. The work of these architects go back decades, demonstrating a disconnect between academic research and construction practice. Luckily, the public sector has utilized these amazing resources while developing the national building codes.

Academic research plays an important role in the research and development of innovative connection technology (fig 5.25 and 5.26). These connectors can ensure faster construction times and more secure connections, advancing the building technology to those who have a less skilled hand. University students are also developing engineered bamboo products that are easier to build with because they have standardized dimensions, and known structural capacity (fig 5.27).

Students are also learning about the opportunity that bamboo can play in addressing housing needs (Appendix A, #1, Appendix B, #9 and #17d). The University of San Martin de Porres annual enters competitions promoted by the national ministry of housing. These result in a bank of vetted designs that are available to anyone interested in using bamboo to build regionally appropriate houses.

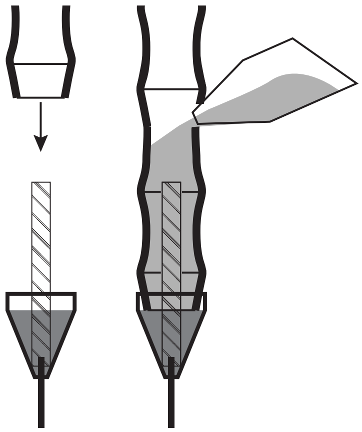


Fig 5.25 - Prefabricated metal caps to speed-up construction Catholic University, Bamboo Library, Guayaquil, Ecuador

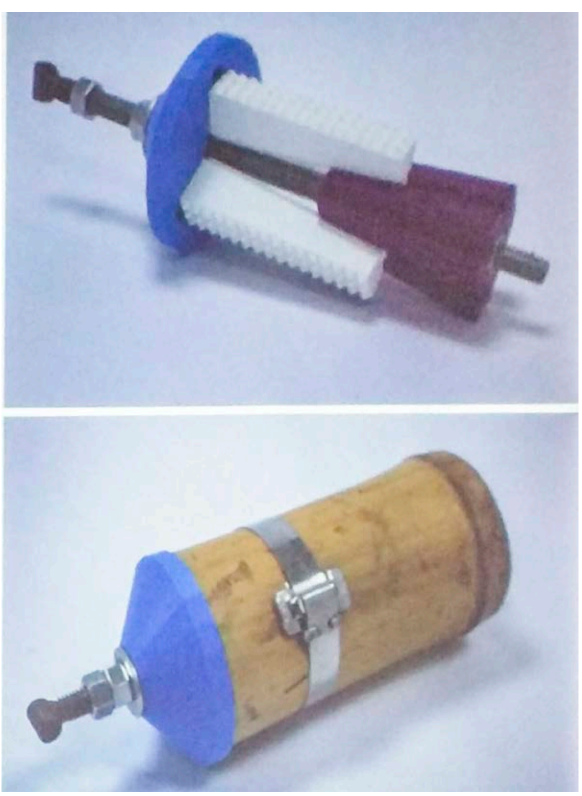


Fig 5.26 - 3D printed prototype connectors, University San Martin de Porres, Lima, Peru. Photo courtesy of Yann Barnet

Fig 5.27 - Plyboo engineered materials, developed at Catholic University of Guayaquil, under the direction of Jorge Moran Ubidia

Fig 5.28 - Bahia Beach Construction: Lucas Oshun has purchased property to grow the culms used by crew (See Appendix B, #11a)

Fig 5.29 - Jose Jairo Llamo Hoyos, Peruvian contractor and designers, Pisco, Peru (See Appendix A, #2b)

Fig 5.30 - Efrain Benitez: Contractor & bamboo-treatment owner, Santo Domingo (See Appendix B, #17c)

Fig 5.31 - Bamboo experts grow, treat and build with their own material, in ultimate control of the quality of their stock

Vertical Integration: Entrepreneurs seizing opportunity

Across Peru and Ecuador, entrepreneur designers and contractors are seeing the business potential of vertical integration defined as the combination in one company of two or more stages of production normally operated by separate companies.[3] By cutting out the middleman, they are able to maximize profits (fig 5.31).

These contractors or developers are promoting the use of bamboo, to increase their potential clientele. They take pride in the quality of their work and their innovative hybrid designs, mixing the contemporary aesthetic that people associate with high status with an affordable material that can allow them to produce housing more economically (fig 5.32). The contractors know the strengths and weaknesses so well, they often are correcting architects who are designing incorrectly (fig 5.29).

Fig 5.32 - Andres De Guzman Montero, Developer, Ayampe. His clean and modern housing design caters to beach tourists (See Appendix B, #8)

Fig 5.33 - Phone interview: Juan Caballero, Build Change

Fig 5.34 - Homes in disrepair. Bahia de Caraquez, Ecuador

Fig 5.35 - Dense slums are susceptible to fire, as seen in this 2017 blaze, leaving 15,000 homeless in Manila, Philippines

Fig 5.36 - The three little pigs highlight cultural concerns with security and building materials

5.3 BOTTLENECKS IN THE CHAIN

A phone interview with Juan Caballero, the Director of Programs and Partnerships works with Build Change in Latin America revealed a nuanced perspective of the informal building sector (fig 5.33). Build Change is an organization that aims to increase a community's resiliency to disaster through improving their built environment. This thesis' premise was explained to Mr. Caballero with the hopes to get his feedback on whether he thought bamboo could play any future role in the work he is doing. Bellow is his feedback based on 20 years of experience:

Mr. Caballero agrees that there is a cultural stigma; that noble materials signify status within a community in a similar way that a home-owner's car or fashion reflects status among his or her peers. This is something witnessed across all cultures and time, that will not change based on the sustainability of a material, unless society as a whole begins to equate status with how environmentally friendly a person is. We are far from this moment in our evolution as a society.

Mr. Caballero explained that to low-income communities, investment in one's home is also an investment in the future of one's children. The cost of building materials is not the issue, as people will pay for materials several times the cost of bamboo because it is a valid investment in their future and the future of their children. Bamboo is too risky of an investment, as it is prone to deterioration over time, is a potential fire hazard and is more vulnerable to theft or other criminal intent (fig 5.34 through 5.36).

The concerns of homeowners over the performance of bamboo are valid and need to be taken into consideration when proposing a bamboo housing solution. The informal housing sector utilizes the materials that it does because they satisfy most of the requirements listed above.

5.4 CONCLUSION

After introducing bamboo's material properties, historical use and recent development, let us return to the initial thesis question: Is bamboo a viable material to provide resilient housing, in Colombia, Peru & Ecuador? Bamboo building technology has progressed immensely. The case studies in chapter 4 and chapter 5 indicate that the technology is proliferating the housing sector as well but mainly through wealthy home owners, niche markets, or through top-down implementation in response to a large scale disaster. Unfortunately, this results in large segments of urban housing demand being met by the informal building sector, which continues to utilize conventional "noble" materials. This leads us to the second thesis question: What can increase the acceptance and use of bamboo for the informal sector?

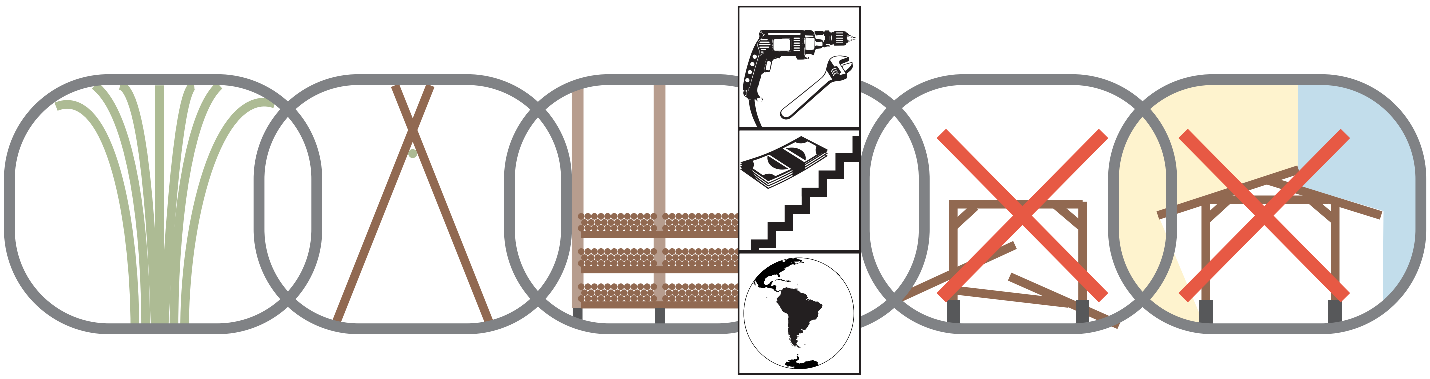


Fig 5.37 - Industrial materials perceived technical, economic and cultural superiority to bamboo blocks its use in the informal building sector

The main bottleneck blocking acceptance is people's attitude to the material (fig 5.37). This thesis argues that bamboo building designs must be proposed that address the negative technical, cultural and economic perceptions associated with the material (fig 5.38).

These "solutions" should build off of current practices in the informal sector, such as incremental building and hybridized structural systems. They must embrace bamboo's unique physical and economic strengths to outperform the competing industrial materials. Chapter 6 begins to unpack various strategies to move the resilient bamboo housing market forward.

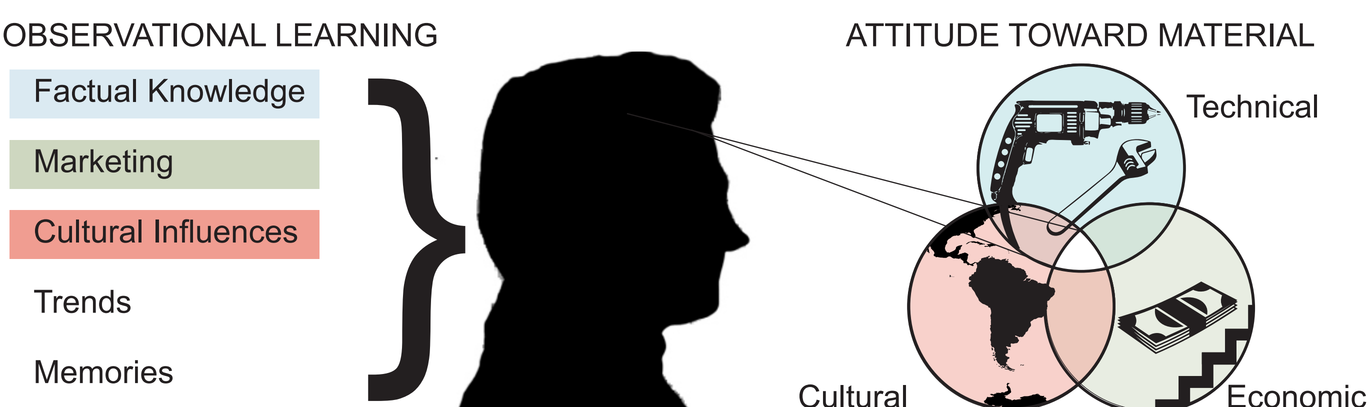


Fig 5.38 - Factors that influence our attitudes toward materials

CHAPTER 6. WAYS FORWARD

Fig 6.1 - Ana was grateful for the transitional homes in her community, Tonsupa, Esmeraldas, Ecuador

Fig 6.2 - CAEMBA home = Improved quality of life, mold free

Fig 6.3 - Family in Bahia, Ecuador imagining their new bamboo home addition as it is being built around them

6.1 A WINDOW OF OPPORTUNITY

"Around 68% of the families interviewed while living in refuges as a result of their homes being lost or made uninhabitable by the earthquake believe a timber or bamboo house to be the safest option for their future home."[1]

The argument that industrialized materials are the most sound investment breaks down in the aftermath of earthquakes. There are many ways which the destruction of one's concrete house can be avoided, but the average home owner must place their trust in the most informed builder that matches their construction budget. How is one to know how many floors the foundations and soil beneath one's house can support?

The author spoke to various residents who experienced traumatic loss of a lifetime of investment and often loved ones in the 2016 earthquake (fig 6.1). To them, safety was the most important factor in their future home. As new design solutions are being provided by the government and other aid agencies, there is a window of opportunity where treated bamboo cane and new building techniques can proliferate within the informal building sector. It is paramount that the houses being provided are built in the best way possible. If they are built poorly or use untreated cane, the negative stereo types will just be reinforced.

Bamboo's role in providing transitional housing on a large scale cannot be underestimated. In one community, people living in tents 18 months after the earthquake experienced infant mortalities due to exposure to mold (fig 6.2). Additionally, bamboo infill projects, built by groups of unemployed construction crews (see Appendix B, project 11a) also provide an opportunity to display and teach best practices to entire communities.

6.2 INCREMENTAL HYBRID: SAFE BASE, LIGHT ATTIC

Fig 6.4 - Residents find it difficult to expand using same techniques, due to lack of funds, desire, and/or understanding

Fig 6.5 - Living space built above a ground floor shop, Peru

Fig 6.6 - Incremental growth of neighboring homes, Peru

One major issue with the permanent housing projects being built is that it is difficult for homeowners to expand and improve their homes (fig 6.4). In order for bamboo to be incorporated into the informal building sector, it needs to adapt to typical construction practices.

One of the main strengths of CMU homes are their ability to grow incrementally (fig 1.5). During the research travel, it was observed that current building practices often incorporate bamboo in this process. While funds are being saved for further expansion with “noble materials”, bamboo is a cheap and fast material to add utility to the empty rooftop (fig 6.5 and 6.6).

This practice reinforces the mentality of bamboo as a non-durable element, but it provides an opportunity for further development. By introducing structural bamboo building technology into a process already in use, it is more likely to be adopted as a common practice. This strategy of construction that grows with the building also takes advantage of one of bamboo’s benefits: its lightweight nature (and therefore mobility, fig 6.7).

This design strategy should be improved, taking advantage of the amazing structural capabilities presented in bamboo “stud” construction techniques. Since specialized construction is expensive, how can this building technology become accessible to everyone?

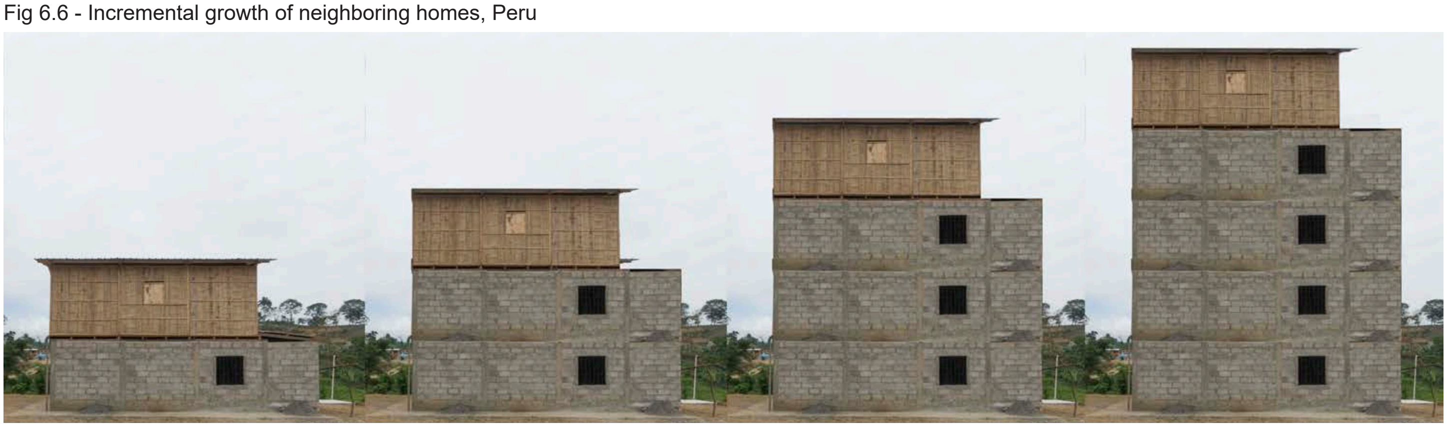


Fig 6.7 - Rendering of a current practice: Lightweight, portable level grows with home over time

6.3 “MEDIUM-TECH” PREFABRICATION

Affordability can be achieved through prefabrication on a large scale, as seen through VHC’s bamboo wall panels (fig 6.8), and this strategy should be improved upon with structural bamboo. High-tech prefab systems are being developed world-wide to produce high-end housing units (fig 6.9, and while the price point may not translate to low and middle income communities, there could be a middle ground between the two industries.

Specialized tools continue to be developed to create accurate connections between culms faster than traditional techniques, paving the way for rapid, structural prefab (fig 6.10).

By employing these “Medium-tech” prefabrication techniques, structural panels could be made in various standardized dimensions and flat-packed out to a job site where they are assembled with limited knowhow and simple tools (fig 6.11 and 6.12). This “IKEA meets structural bamboo” could provide a quality product to the masses at an affordable price.

To make these panels quick to disassemble, additional research and development needs to be done. Solutions are proposed in universities and through individual projects (figs 5.25, 5.25, 6.13) but to be affordable, standardization and mass production is necessary (similar to Simpson Smart-Ties for the lumbar industry, fig 6.14).

Fig 6.8 Low-tech prefab, non-structural panels

Fig 6.9 High-tech prefab, high-finish CNC technology


Fig 6.10 “Medium-tech” prefabrication tools (fast accuracy)

Fig 6.11 “Medium-tech” prefabrication of affordable, structural panels, Quito, Ecuador

Fig 6.12- Simple instructions, minimal tools

Fig 6.13 Unique plasma cut connectors, developed by Product Design Engineering student Daniel Palacio López

Fig 6.14 Simpson fasteners increase efficiency of construction time and strength of connections

Fig 6.15 Example of standardized, structural bamboo panel

Fig 6.16 Trusses are another potential prefabricated structural bamboo element. Pisco, Peru

6.4 FURTHER INDUSTRIAL DEVELOPMENT

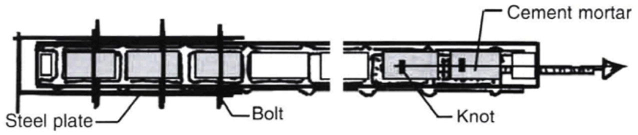
Cheap prefabrication is necessary for an affordable product and while economic accessibility is the end goal, industrialized bamboo products have the potential to serve middle and high income consumers as well.

As demand increases, new products could be incorporated into the medium-tech material pallet, increasing the range of design possibilities with amazing structural capacities (fig 6.16 through 6.19). Incredibly, materials are even being developed to address the flamable nature of bamboo (fig 6.17)

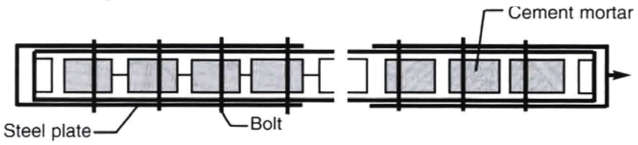
Industrialized materials can and should still play a role in the construction of housing. This thesis is not arguing for a return to vernacular building. The way forward is a hybrid response, mixing the best properties and techniques to optimize performance and sustainability.

There were many examples of hybrid construction discovered along the entire research trip (see Appendix A and B). Medium tech solutions would require the least amount of modification to the raw material, resulting in a sustainable and affordable structural bamboo product (fig 6.15). More expensive products are those that require machinery, glues, and energy intensive processing (6.19).

Fig 6.17 Flame-resistant bamboo products, developed at Catholic University of Guayaquil, under the direction of Jorge Moran Ubidia



A) **-Test T.45 - A long bolt or bar 3/4" in diameter with nuts and 2 internodes with cement mortar.- Number of tests 5**
Failure: *The cement mortar cylinders removed the internal nodes. There are cracks along 2 sides of the internodes.*



E) **- Tests PP90 - 3 internodes with mortar and bolts Ø1/2"**
Number of tests 6
Failure: *Same as (C).*

Rupture load (Kg)	Length section (m)	Exter. diamet. (cm)	Wall thickn. (cm)	Averag Interno (cm)
1) 4000	1.93	11	1.00	25
2) 4200	1.96	11.5	1.75	25
3) 4200	1.88	12.5	1.75	23
4) 4250	1.75	10.5	2.00	20
5) 4800	1.94	11.5	1.75	25
1)13500	2.52	11.5	1.75	29
2)11530	3.10	10	1.00	26
3)12800	2.54	12	2.00	28
4)11900	2.69	10	1.25	27
5) 9800	3.00	11	1.75	26
6)11730	2.94	10	1.25	28

Source: Jenny Garzon Caicedo (1996)

Fig 6.18 Structural capacity of "medium tech" design solution which relies on concrete and metal to increase the structural capacity of bamboo culms

4000 KG or about 1 Elephant
(Not to Scale)

12,000 KG or about 3 Elephants
(Not to Scale)

Fig 6.19 Plyboo engineered materials, developed at Catholic University of Guayaquil, under the direction of Jorge Moran Ubidia

Allowable Stresses (psi)

Species	Bending Fb	Tension Ft	Shear Fv	Compression parallel to grain Fc	Modulus of Elasticity E
Laminated Bamboo[1]	12,800	21,465 - 55,594	2,901	13,488	2,900,000
Laminated Bamboo[2]	16,104	13,764	1,307	8,659	
Laminated Southern Pine 30F-E2 used primarily in bending	2,400	1,350	300	1,750	2,100,000
Laminated Southern Pine 50SPN1D14 primarily in compression	2,300	1,550	260	2,300	1,900,000

sources: 1 Lamboo Inc. 2011
2 Correal 2010

Fig 6.20 Comparison of allowable stresses in lam. bamboo to lam. southern pine

6.5 HYBRID INCREMENTAL CONSTRUCTION REVISITED

Whether or not these products are low, medium or high-tech, they could seamlessly be applied to an incremental and hybrid construction technique, where block and bamboo products work in tandem to provide a contemporary home that is affordable and fashionable.

Combining the two strategies of incremental growth and structural prefabricated bamboo panels could begin to provide a solution that is appropriate in liquefaction zones, where the soils cannot support heavy structures. In these cases, if families knew that building higher with heavy materials would result in the destruction of their homes in the next earthquake, then an affordable bamboo product that matches their desired aesthetic would be the most logical option to add value to their home SAFELY (fig 6.21).

These hybrid structural solutions all need to address inherent problems in the informal building sector that lead to catastrophic building failure. One promising model in Pakistan is the Technical Training Resource Center (TTRC), which has trained almost 150 masons and neighborhood youth in surveying, foundation design, and strategies to build incrementally (see Appendix D).

Fig 6.21 Incremental Hybrid + Medium-tech prefab

Hypothetical: Sandy soil cannot support more than 3 stories of CMU

Government incentives allowing height with structural bamboo

Fig 6.22 Facilitating Community Participatory Design. Architect Jorge Alarcon, Lima, Peru

Fig 6.23 Participatory design workshop, Lima, Peru

Fig 6.24 Voting system to prioritize scope and location

6.6 THE ARCHITECT’S ROLE RE-IMAGINED

Architects could play a crucial role in finding solutions to the bottleneck in the bamboo housing industry. Thinking holistically while designing a housing project, balancing site conditions, budgets, with various other constraints is a unique trait of an architect. Various non-profit organizations or academic programs support public interest design professionals, funding non-traditional roles for architects.

Facilitating community design workshops allows architects the ability to slowly gain the trust of communities over time, as the author has witnessed in his work with the Informal Urban Communities Initiative in Lima, Peru.

“When starting Participatory Design Projects, you need to involve people from the beginning. They need to identify priorities which you can find out by asking 3 basic questions: What are their needs, meaning the basic things needed for living? What are their desires, what are their dreams and long term goals? Finally, what are their priorities? This helps ground the ideas in a budget and time to be achievable” - Jorge Alarcon[2]

This bottom-up method works well for communities that are organized and have strong social cohesion, especially when dealing with public space. But how do we address the issue of providing these services at scale, specifically with individual homes? How can these innovative hybrid design strategies become tailored to individual communities, each with a unique set of environmental conditions and contexts?


Fig 6.25 Community Architect Program, Havana, Cuba

6.6 THE ARCHITECT’S ROLE RE-IMAGINED continued:

In the early 1990’s the Cuban government realized that a top-down methodology for public housing was not addressing the socio cultural needs of the communities receiving public housing[3]. A bottom-up approach was developed, as most families knew what their individual needs were, and just needed access to design services. 1,000 architects were taught a participatory design methodology where families envisioned their ideal home. Architects designed phased housing approaches that matched neighborhood codes and met their clients budgets and overall visions.

While the communist government supports this program, capitalist societies must find other means to pay architects for services in the public interest.

6.7 CONCLUSION

The shift in political will that resulted in hundreds of bamboo housing projects coincided with a large group of earthquake survivors that needed safe housing. In order to maximize impact, resilient design solutions must allow families to expand their homes incrementally.

This chapter described various ways in which the bamboo building industry could adapt the material to fit with typical building practices to facilitate an acceptance of bamboo not based on preconceptions, but rather on economic and technological merits that are inherent to the material. Because bamboo is light weight and easily adaptable, it could enhance the incremental building system commonly practiced by providing strong and flexible homes.

Additionally, engineered bamboo products need to become standardized, accelerating bamboo’s proliferation in the high and middle income market. If bamboo is accepted and desired by high-income families, the cultural stigma associated with the material may slowly begin to shift.

Finally, bottom-up and public interest design should be supported as the preferred method of public housing, as it is a practice that gives the power of choice to those most affected by the projects. This will result in homes that reflect the needs and desires of those living in them, ultimately leading to personal ownership and investment in a resilient and sustainable home.

CHAPTER 7. CONCLUSIONS

Fig 7.1 - Meeting in 2013 began bamboo research

Fig 7.2 “Mesa Sectorial de Ecuador” Young bambuseros whose passion for bamboo building will propel the industry

Fig 7.3 - Leap of faith into the back of a stranger’s truck

Fig 7.4 Contractor showing measuring tools made to increase speed and accuracy on the job site

7.1 REFLECTING ON PROCESS

This research thesis began investigating bamboo’s potential to provide resilient housing because of its sustainable traits of being a rapidly renewable resource with low embodied energy. It has evolved into much more.

The John Morse travel fellowship propelled the research into the unknown. The author’s previous experience of living in Peru provided a foundation for the research to build on. Initial contacts with the professors of San Martin de Porres in Lima (fig 7.1) and the Piura based NGO Progreso allowed for the possibility to reach out to the network of bamboo experts (fig 7.2).

The openness of this ever expanding group to welcome the researcher into their world of bamboo led to a whirlwind travel itinerary. Over 80 hours on public buses, countless motorcycle rides with eager contractors and countless chance encounters led to a wealth of information that was never expected from the onset (fig 7.3 and 7.4). 10,000 photographs, dozens of hours worth of video and audio interviews left the author in a state of shock, like trying to drink from a fire-hose.

The thesis committee was supportive of the free-form travel and worked with the author to curate a digestible and salient body of research. While it was ever so tempting to plunge into an individual building design, the thesis has been much more than it set off to be by strictly unpacking the experience. Through a mainly visual exploration, the thesis became defined by sorting and filtering the content into categories and groups.

The biggest push forward occurred when the images allowed an understanding between the thesis committee and the researcher. The next steps are to take this body of work and disseminate it through a traveling expedition (in North and South America), in hopes to inspire others to continue searching for ways in which bamboo can re-enter society as a material that is embraced and used daily.

Fig 7.5 - Bamboo housing surrounded by brick counterparts

Fig 7.6 - Bamboo used to support concrete form-work

Fig 7.7 - A project stalled by the 2016 earthquake, weeds growing over the failed “noble” materials, Manta, Ecuador

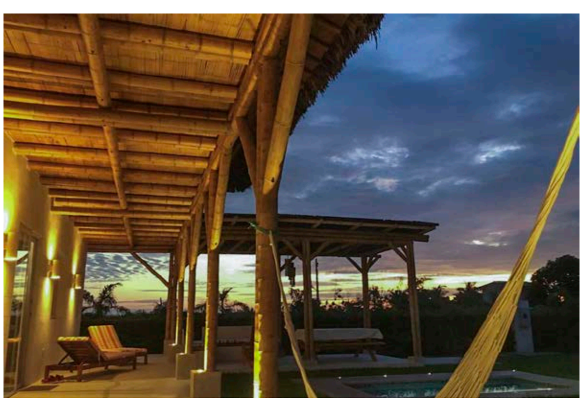


Fig 7.8 - Sunrise over a hybrid brick and bamboo beach house, Ayampe, Ecuador

7.2 REVISITING ARGUMENTS

The global demand for housing is an extremely complex problem that will not have a one size fit all solution. Each country, state, district and city has a unique conglomeration of factors and housing solutions that will need to be tailored accordingly.

Is bamboo housing a viable solution for cities in Andean South America? This thesis has argued that it is. Bamboo is a local, rapidly renewable resource with a long-standing building tradition. Bamboo housing is resilient to the frequent earthquakes and has had a resurgence of use and support by regional and national governments. There are many public and private institutions that have strengthened the bamboo value chain and the market shows promise.

What can increase the acceptance/use of bamboo for the informal building sector? There are many existing strategies designed to change people’s attitude toward bamboo. Training campaigns are disseminating new and improved building techniques. By standardizing structural connections, medium-tech prefabrication could improve the hybrid incremental building strategies being utilized by the informal building sector. Providing more resilient housing is the ultimate goal, reducing the loss of life and preserving livelihoods. Bamboo could play an instrumental role in this movement, but architects and other design professionals need to hybridize their role in society if they are to address the global housing need in a sustainable and equitable manor.

This research thesis has been built off of the work and contributions of hundreds of “bambuseros” of all walks of life: academics, professional architects, contractors, engineers and non-government organizations. Soon, bamboo will join concrete and brick as a common structural housing element, a truly hybrid solution to humanity’s greatest challenge.

ACKNOWLEDGMENTS

I would like to end by thanking the amazing people who have helped me in this research thesis. It could not have been done without your support!

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Thesis Committee: Brian McLaren & Elizabeth Golden
Reviewers: Louisa Iarocci & Jeffrey Ochsner

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Jose Jairo Llamo Hoyos
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Yann Barnett
Faouzi Jabrane
Raphael Paucar Cárdenas
Gerardo Gonzales Arevalo
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Esteban Torres Haro
Dr. Jorge Montoya
Efrain Benitez
Architects of Municipal plant
Manuel & Christine Palleres
Residents of Tonsupa
Residents of Via de la Alegria
Luis Rivera
Carlos Benavides
Residents of Jama CAEMBA Project
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The Sectoral Bamboo Technical Table & the countless others who helped along the way!

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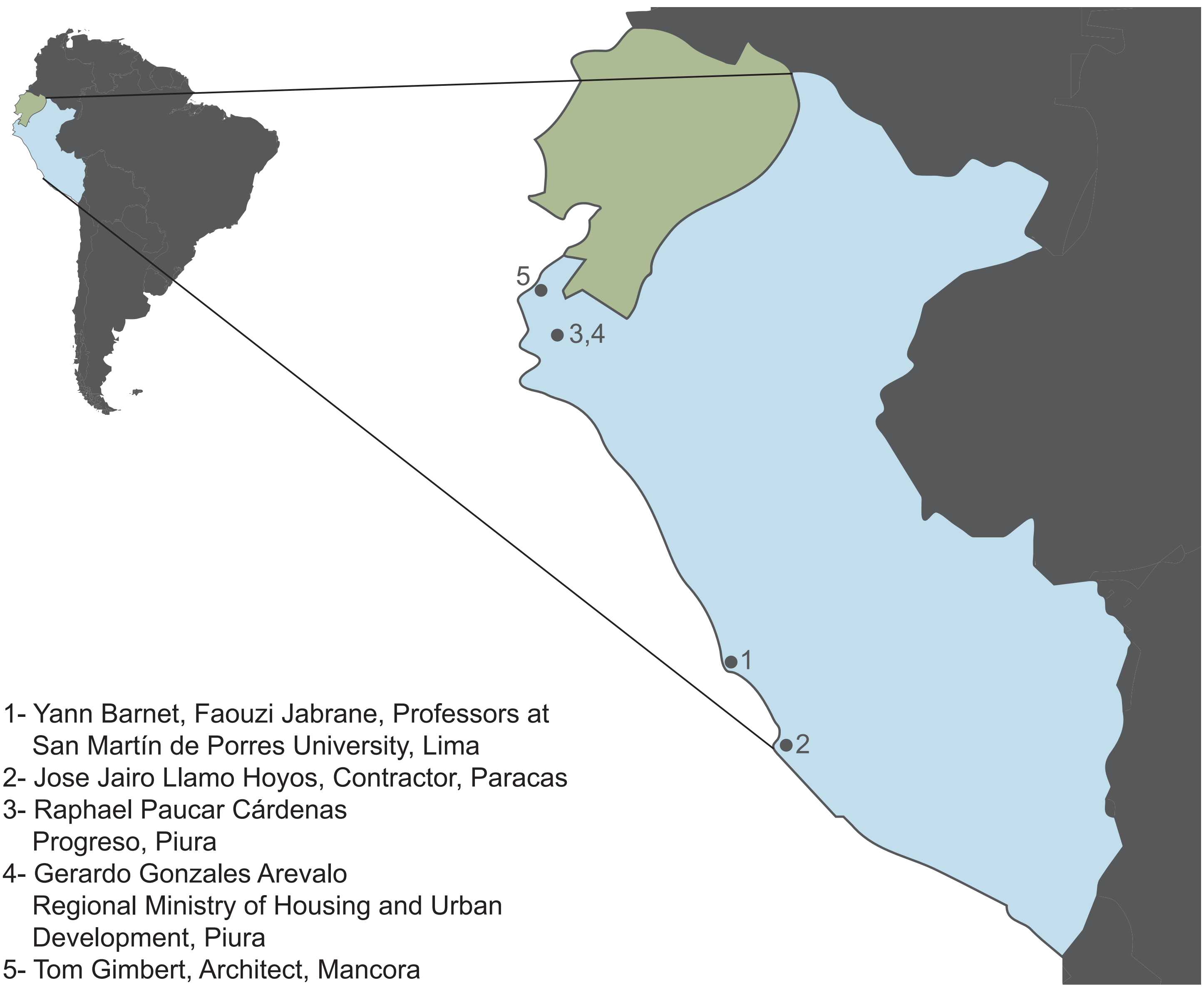
APPENDIX A: PERU SITE VISIT LOCATIONS

The research travel began in Lima, Peru, at San Martin de Porres University, where the project architect's behind the 2007 earthquake recovery are teaching. They me with a contractor in Pisco and a key contact at INBAR in Quito, Ecuador. The majority of the site visits in Peru were coordinated with previous contacts I had during my Peace Corps Service, and through the Centro de Bambu, an online platform that showcases bamboo projects and experts (http://www.usmp.edu.pe/centro_bambu_peru).

The coastal homes in Peru are exposed to a harsh desert climate. Therefore bambu is often a cheap material used to create shade on the beach or porch area of homes. I also witnessed long stretches of land with fences made out of bamboo boards and culms, an affordable barrior.



1- Yann Barnet, Faouzi Jabrane, Professors at San Martín de Porres University, Lima
2- Jose Jairo Llamo Hoyos, Contractor, Paracas
3- Raphael Paucar Cárdenas Progreso, Piura
4- Gerardo Gonzales Arevalo Regional Ministry of Housing and Urban Development, Piura
5- Tom Gimbert, Architect, Mancora

Fig A.1 Research Travel Partners and Destinations - Peru

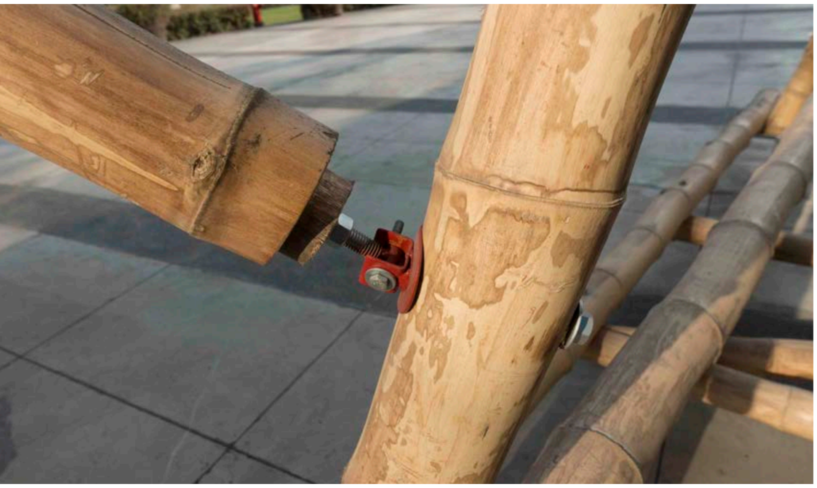


Fig A.2 - Bamboo Joint Detail, San Martin de Porres University, Lima, Perú
Architects: Yann Barnet and Faouzi Jabrane

Fig A.3 - Structurally testing joint, San Martin de Porres University, Lima, Perú
Architects: Yann Barnet and Faouzi Jabrane

1- Yann Barnet, Faouzi Jabrane, Professors at San Martín de Porres University, Lima

These French professors have catalyzed the Peruvian bamboo building code through their work in Pisco, Peru after the 2007 earthquake that left 58,000 homeless. Their work on the Pisco bamboo church influenced public officials to begin writing the national bamboo code E-100.

In addition to teaching workshops, they are developing stronger, user friendly connections that will make bamboo construction more accessible to those who rarely use bamboo in a structural way (patent pending).

Fig A.4 - 3D Printed joint, patent pending, San Martin de Porres University, Lima, Perú
Architects: Yann Barnet and Faouzi Jabrane

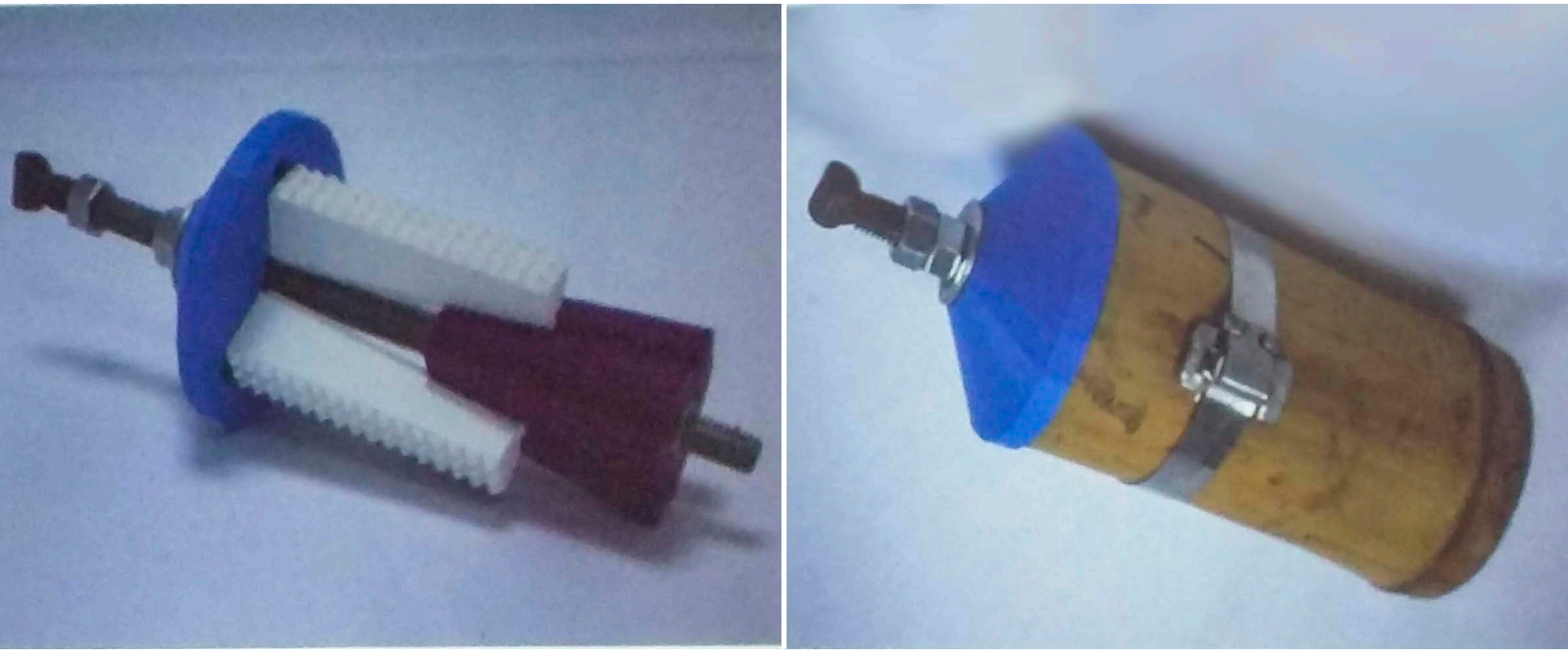


Fig A.5 - Restaurant: Lomas del Pino, Chancay, Peru
Architects: Yann Barnet and Faouzi Jabrane

Fig A.6 - Restaurant: Lomas del Pino, Chancay, Peru
Architects: Yann Barnet and Faouzi Jabrane

1- Yann Barnet, Faouzi Jabrane, Professors at San Martín de Porres University, Lima

Yann and Faz continue to strengthen international networks through maintaining the “Centro de bambú” webpage, linking designers with contractors, and showcasing impressive bamboo buildings across the country. They continue to build public works to change public perception of bamboo. The work ranges from park pavilions, to restaurants and housing prototypes. Their students enter national ecological housing competitions, indicating that the research and academic teaching is making an impact.

Fig A.7 - 2 Story bamboo home prototype, El Ejido Park, Quito, Ecuador
Designers: Mesa Sectorial Bambú ECU, contributors: Mr. Barnet, Mr. Jabrane

Fig A.8 - 2 Story bamboo home prototype, El Ejido Park, Quito, Ecuador
Designers: Mesa Sectorial Bambú ECU, contributors: Mr. Barnet, Mr. Jabrane

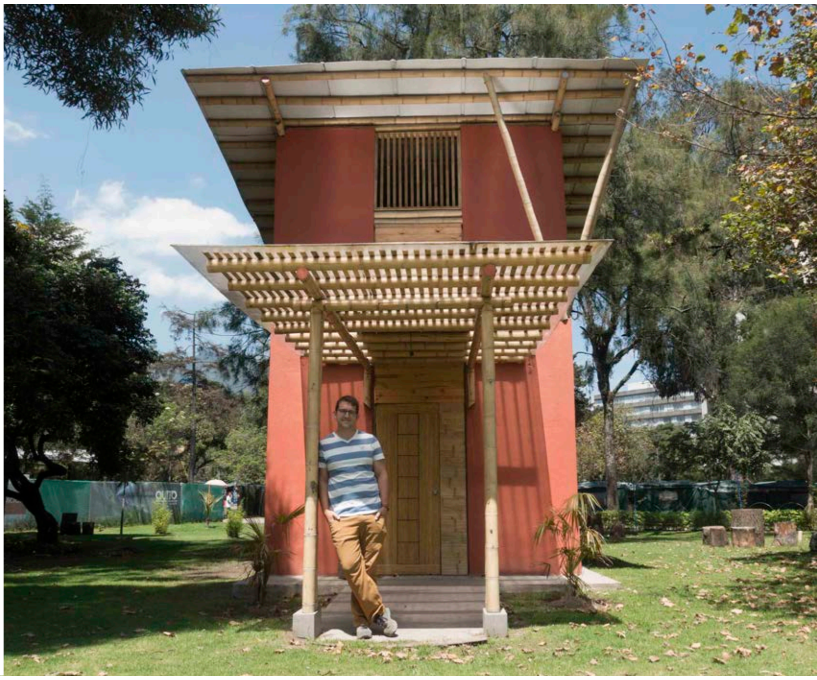


Fig A.9 - HOTEL PARACAS, Paracas, Peru
Architect: Mauricio Gonzalez

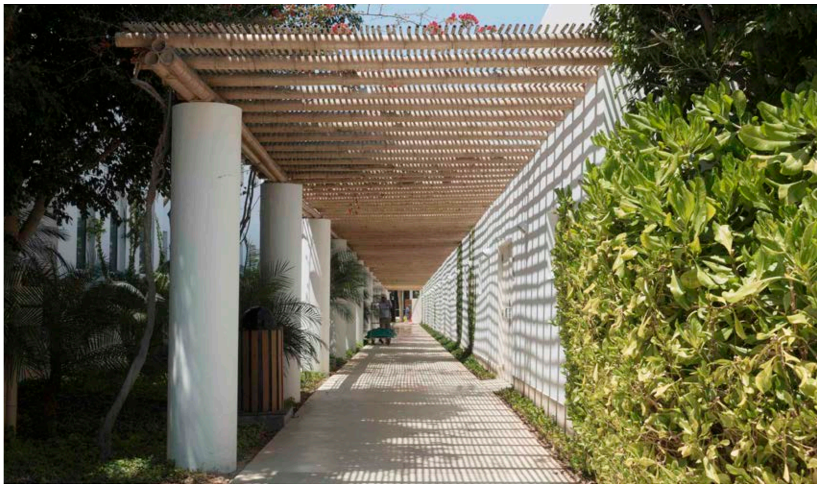


Fig A.10 - HOTEL PARACAS, Paracas, Peru
Architect: Mauricio Gonzalez

2a- Paracas, Peru

Paracas is a coastal city in southern Peru, known as a tourist destination, as there is a nationally protected ecological reserve just south of the city.

Hotel Paracas is a prime example of bamboo's use in vacation resorts. This high end luxury hotel mainly uses bamboo as beams or shading surfaces (as opposed to columns).

Fig A.11 - HOTEL PARACAS, Paracas, Peru
Architect: Mauricio Gonzalez

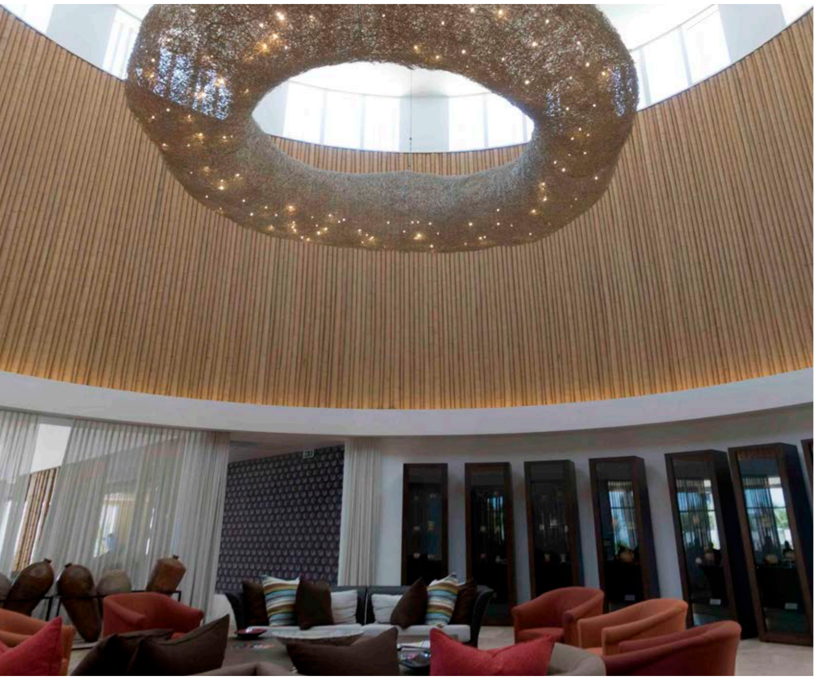


Fig A.12 - HOTEL PARACAS, Paracas, Peru
Architect: Mauricio Gonzalez

Fig A.13 - Hotel Restaurant Patio, Pisco Peru
Designer: Jairo Llamo Hoyos

Fig A.14 - Bamboo Church, Pisco Peru
Architects: Yann Barnet and Faouzi Jabrane

2b- Jose Jairo Llamo Hoyos, Contractor, Paracas

Jairo is a contractor that first learned to build with bamboo from earthquake reconstruction workshops led after the 2009 earthquake in Pisco, Peru (led by Yann Barnet and Faouzi Jabrane). He also was a part of the construction crew that built the bamboo church (above), a much needed public space after the earthquake. He continues to build with all materials, but has found a niche market of beach tourism to continue his bamboo work. He often teaches unexperienced architects best practices as well.

Fig A.15 - Private Residence patio, Paracas, Peru
Designer: Jairo Llamo Hoyos

Fig A.16 - Vineyard Patio, Pisco Peru
Designer: Carlos Huauya Erribares

Fig A.17 - Raphael painting culms as a means of forestry management (2012)
Photo courtesy of Progreso

Fig A.18 - Raphael interview at Progreso, Piura, Peru (2017)

3- Raphael Paucar Cárdenas
PROGRESO, Piura

I have known Raphael (Rafa) since working with Progreso during my Peace Corps Service in 2013. This agricultural non-profit is based out of Piura, Peru, and works with rural communities to improve their livelihood's by improving the quality of product through improved management of their crops (cacao, coffee, panela, etc). They work closely with INBAR to improve forestry management of bamboo to produce a high quality product. These organizations are instrumental to improving this link in the bamboo value chain.

Fig A.19 - INBAR forestry management training
Photo courtesy of Progreso

Fig A.20 - INBAR forestry management training
Photo courtesy of Progreso

Fig A.21 - Regional Government of Housing and Sanitation, Piura, Peru
Architect: Gerardo Gonzales Arevalo

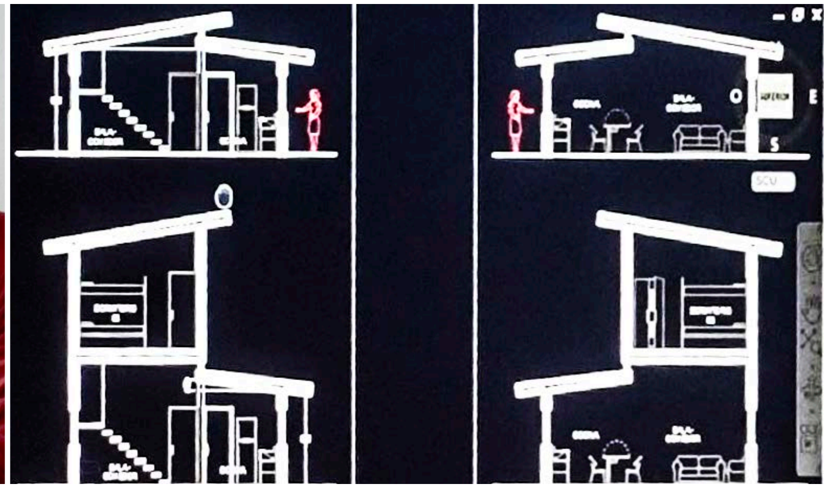


Fig A.22 - Two story prototype bamboo/block/wood
phased hybrid housing design for disaster victims

4- Gerardo Gonzales Arevalo
Regional Ministry of Housing and Urban Development, Piura

5a- Tom Gimbert, Architect, Mancora

In 2017, there was a large flood displacing many rural families. Gerardo works with the regional bamboo technical table and is promoting a design that can grow from a single story to a two floor home, designed to match typical housing design in the region.

Tom Gimbert is a French architect designing and building social impact projects funded by French students who come and assist in the build (similar to the model used in project 11a, Appendix B).

Fig A.23 - Architect Tom Gimbert
Mancora, Peru

Fig A.24 - Architect Tom Gimbert
“Tree House” Mancora, Peru

Fig A.25 - Photographed while in public transit from Mancora to Zorritos, Peru

Fig A.26 - Photographed while in public transit from Mancora to Zorritos, Peru

5b- Vernacular bamboo homes

Northern beach communities in Peru are exposed to intense sunlight and bamboo is often bleached white due to exposure, eventurally cracking.

Many coastal cities are tourist destinations, such as Mancora, Zorritos and Ernest Hemingway's Cabo Blanco. Bamboo is a common building material due to the foreign clientel and the proximity to Ecuador.

Fig A.27 - Photographed while in public transit from Mancora to Zorritos, Peru

Fig A.28 - Photographed while in public transit from Mancora to Zorritos, Peru

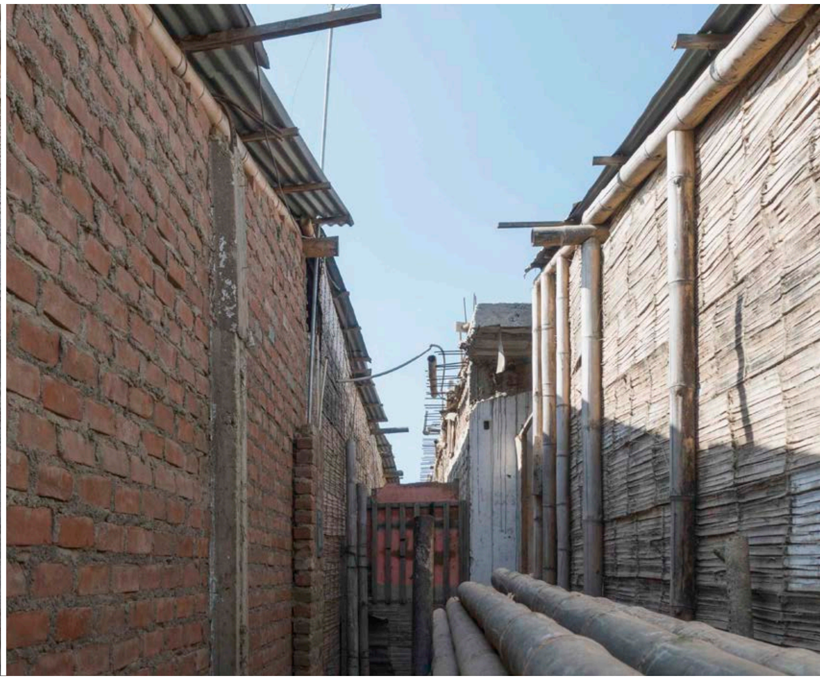


Fig A.29 - Photographed while in public transit from Mancora to Zorritos, Peru

Fig A.30 - Photographed while in public transit from Mancora to Zorritos, Peru

5b- Vernacular bamboo homes

The quality of craft runs a wide spectrum, from simple beach cabanas to intricate bamboo screens.

The bamboo home is much more comfortable and easier to ventilate compared to the block alternative, making the material ideal for hot beach towns.

Fig A.31 - Photographed while in public transit from Mancora to Zorritos, Peru

Fig A.32 - Photographed while in public transit from Mancora to Zorritos, Peru

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APPENDIX B: ECUADOR SITE VISIT LOCATIONS

The travel in Ecuador was completely unknown to me. I started in Quito at the regional office of the International Network of Bamboo and Rattan (visit 18A), and hoped that they would be able to connect me to the network of bamboo experts in Ecuador. I was not let down! As chance would have it the day after my interview with Pablo Jácome kicked off a 3 day conference (with a bamboo building workshop). I was instantly connected to 20 regional experts, and my network of connections exploded from there.

I could have traveled in Ecuador for another 10 weeks and not been able to visit all of the projects recommended to me. The friendly nature of everyone I met allowed me to visit the breadth of projects shown below. It was a wonderful experience and I am still in contact with many of them today.

6- Robinson Vega, Architect, Guayaquil
7- Riccardo Mondello, Architect, Santa Elena
8- Andres De Guzman Montero,
Developer, Ayampe
9- Jacob Mero, Architects, Manta
10- Site visit, Porto Viejo
11a- Residents, Bahia de Caraquez
11b- Lucas Oshun, Bamboo Design/Build
12A- Carlos Benavides, Contractor,
12B- CAEMBA Resident, Jama
13- Site visit, La Chorrera
14- Residents, Villa de la Alegria
15- Residents, Tonsupa
16- German Villareal, Plantation &
Processing Plant owner, Los Bancos
Santo Domingo
17A- Fernando Loayza, Architects
17B- Jorge Montoya, Colombian Professor
17C- Efrain Benitez, Contractor
17D- Architects of Municipal treatment-plant
17E- Bamboo Conference
Quito
18A- Pablo Jácome, INBAR Latin America
18B-Nicolás Van Drunen, Student Architect,
Designer of Bamboo Workshop structure
18C- Manuell & Christine Palleres, Architects
CAEMBA housing design along coast

Fig B.1 Research Travel Partners and Destinations - Ecuador

Fig B.2 - The Bamboo Library has material samples of various engineered bamboo products on display. Catholic University of Guayaquil, Ecuador

Fig B.3 - Innovative glue-lam bamboo floor joists
Bamboo Library, Catholic University of Guayaquil, Ecuador

6- Robinson Vega, Architect, Guayaquil

Jorge Moran, a pioneer in bamboo building, who has worked over 40 years developing bamboo building materials. He taught at the Catholic University of Guayaquil, where there is a bamboo library highlighting advancements in sustainable materials. Robinson Vega, once a student of Jorge currently leads bamboo building workshops with Lucas Oshun (11b), teaching good building practices to the carpenters working to rebuild Bahia de Caraquez, a coastal city hard hit by the earthquake.

Fig B.4 - Examples of bamboo acoustic and thermal insulation, placed beneath corrugated metal roofing Bamboo Library, Catholic University of Guayaquil, Ecuador

Fig B.5 - The Bamboo Library has material samples of various engineered bamboo products on display. Catholic University of Guayaquil, Ecuador

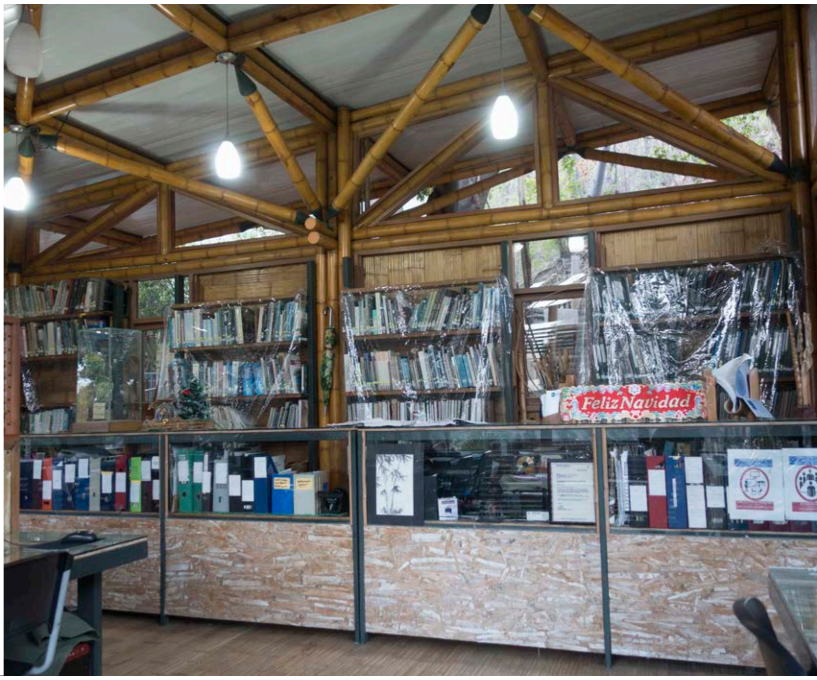


Fig B.6 - Culms being cut by table saw,

Fig B.7 - Cut and planed strips drying in heated room

7- Riccardo Mondello, Architect, Santa Elena

A common industrialized process that has developed to combat the irregular sizes is to slice bamboo into thin strips, plane, glue, and pressure treat into dimensional sections.

Once the material is standardized, the potential for use matches that of wood products. Like any processed material, the embodied energy and cost of the end product rises. But the end product also has a higher-end finish, entering luxury markets otherwise unobtainable. Furniture produced with laminated bamboo is a growing market that shows great potential.

Fig B.8 - Bamboo furniture built with glue-lam bamboo products

Fig B.9 - Italian Architect Riccardo Mondello showing the high quality products that can be achieved with the municipally funded processing plant

Fig B.10 - Andres showing his robust fences, which are prefabricated in panels and attached to bamboo with tar applied to the base for moisture protection

Fig B.11- Treated cane draining borax solution

8- Andres De Guzman Montero, Developer, Ayampe

Mr. Guzman is an example of an entrepreneur who is able to look past cultural stereotypes associated with bamboo. He sees the beauty that can be achieved and has developed various hybrid construction vacation homes in the Ayampe region.

Andres also practices vertical integration. By processing his own cane, he is able to control the quality of his stock and can store a large supply. He was very welcoming to the author, sharing details of an 18 unit development in progress.

Fig B.12 - Example vacation home Developed by Mr. Guzman

Fig B.13 - Example vacation home Developed by Mr. Guzman

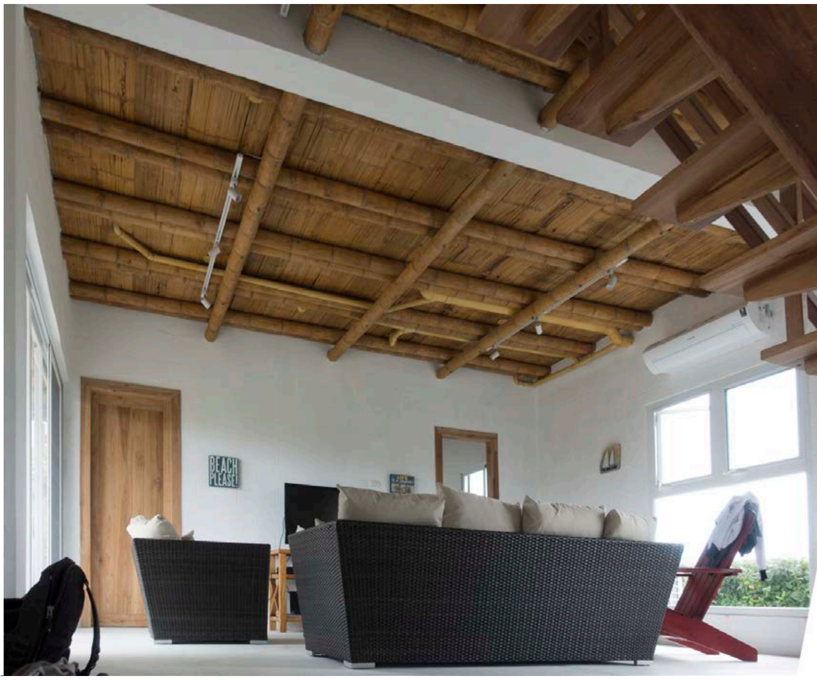


Fig B.14 - Quincha wall mock ups alongside other innovative designs, recycling plastic containers

Fig B.15 - Restaurant dining area, Manta

9- Jacob Mero, Architects, Manta

Miguel Camino, the dean of a coastal Ecuadorian university (ULEAM), has also been a long time advocate of bamboo construction. Their students are developing innovative wall sections and thesis addressing sustainable construction. Architect Camino worked in the municipal urban planning office, which resulted in various public works, such as a large market, restaurants, and a fire-station structure.

Fig B.16 - Bamboo structure over fire station, Manta

Fig B.17 - Market restaurants promoted by Mr. Camino during his time on the regional urban planning board.

Fig B.18 - One story bamboo house prototype
El Parque Forestal, Porto Viejo

Fig B.19 - One story bamboo house prototype
El Parque Forestal, Porto Viejo

10- Site visit, Porto Viejo

This housing prototype is on display in El Parque Forestal, Porto Viejo. The regional government planned to build 2,000 homes of this model, but when the author inquired about these plans, it was no longer being pursued.

Fig B.20 - One story bamboo house prototype
El Parque Forestal, Porto Viejo

Fig B.20 - One story bamboo house prototype
El Parque Forestal, Porto Viejo

Fig B.21 - One story bamboo house prototype
El Parque Forestal, Porto Viejo

Fig B.22 - One story bamboo house prototype
El Parque Forestal, Porto Viejo

10- Site visit, Porto Viejo

The interior finishes of the home are both exposed (varnished) bamboo boards, as well as ceramic floor and bathroom. The clerestory lighting and natural ventilation is a feature that would make it appropriate to hot coastal environments.

Fig B.23 - One story bamboo house prototype
El Parque Forestal, Porto Viejo

Fig B.24 - One story bamboo house prototype
El Parque Forestal, Porto Viejo

Fig B.25 - Disaster relief housing
Designed and built by Bahia Beach Construction

Fig B.26 - Disaster relief housing
Designed and built by Bahia Beach Construction

11a- Residents, Bahia de Caraquez

Lucas Oschun, an American working in Bahia for 6 years, felt called to help in the reconstruction, similar to Manuel and Cristina (project 18c). Unlike CAEMBA, his strategy is to solely focus on the community he now calls home. To address the unemployment crisis, he created Bahia Beach Construction, employing carpenters to use the seismic-resistant building techniques being promoted by local universities. As of 2017, Bahia Beach Construction has built 19 homes, 27 shelters and 5 renovations.

Fig B.27 - Disaster relief housing
Designed and built by Bahia Beach Construction

Fig B.28 - Disaster relief housing
Designed and built by Bahia Beach Construction

Fig B.29 - Disaster relief housing
Designed and built by Bahia Beach Construction

Fig B.30 - Disaster relief housing
Designed and built by Bahia Beach Construction

Lucas currently funds the reconstruction efforts through donations and by leading volunteer build trips with university students from the United States, partnering with Catholic University professor Robinson Vega from Guayaquil (Appendix B #6). The goal is to eventually hand off the construction company to a local contractor as a self sustaining business. Lucas purchased land to grow bamboo, with the intent to develop the company to source and treat the material, maximizing profits for the contractors.

11a- Residents, Bahia de Caraquez

Fig B.31 - Disaster relief housing
Designed and built by Bahia Beach Construction

Fig B.32 - Disaster relief housing
Designed and built by Bahia Beach Construction

Fig B.33 - Disaster relief housing
Designed and built by Bahia Beach Construction

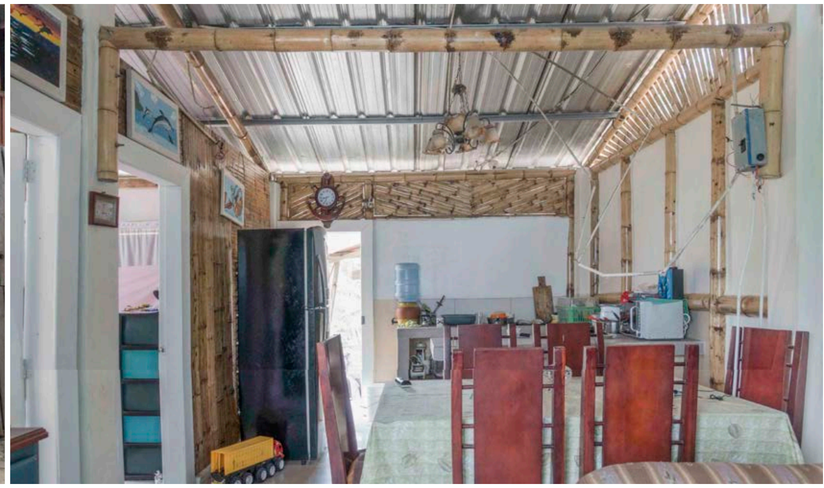


Fig B.34 - Disaster relief housing
Designed and built by Bahia Beach Construction

11a- Residents, Bahia de Caraquez

This project highlights that well designed bamboo homes can be beautiful, durable, and safe, changing the negative mindset when it comes to building with “poor mans timber”. The Bahia Beach Construction Company is an example of a developing market that can create a livelihood for those struggling to find work after a natural disaster, in this case, an earthquake.

Fig B.35 - Disaster relief housing
Designed and built by Bahia Beach Construction

Fig B.36 - Disaster relief infill housing
Designed by author with contributions by local contractors

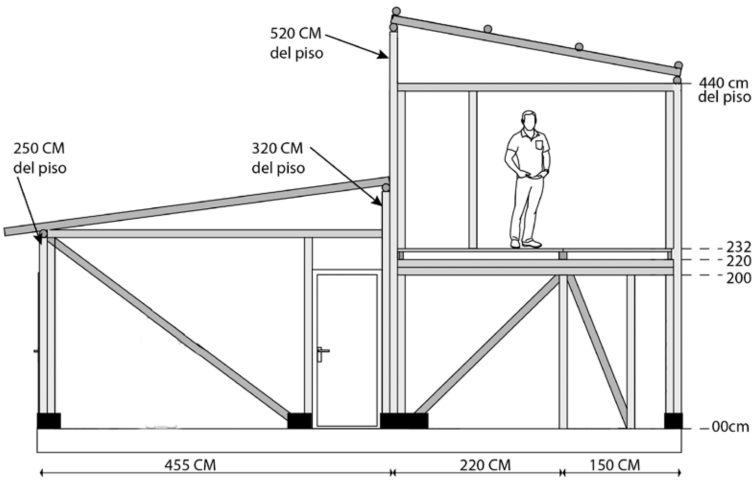


Fig B.37 - Disaster relief infill housing
Designed by author with contributions by local contractors

11b- Lucas Oshun, Bamboo Design/Build

I offered to help Lucas design a tricky infill project, where a portion of a home collapsed. The basic model he had been building is a lot larger, and has been mainly on a tabla rasa site.

In the matter of two days, the slab was being poured, the contractor mainly discussing design options as it was being constructed. I made a basic plan with dimensions for column placements, and worked out the details with the construction crew on site.

Fig B.38 - Disaster relief infill housing
Designed by author with contributions by local contractors

Fig B.39 - Disaster relief infill housing
Designed by author with contributions by local contractors

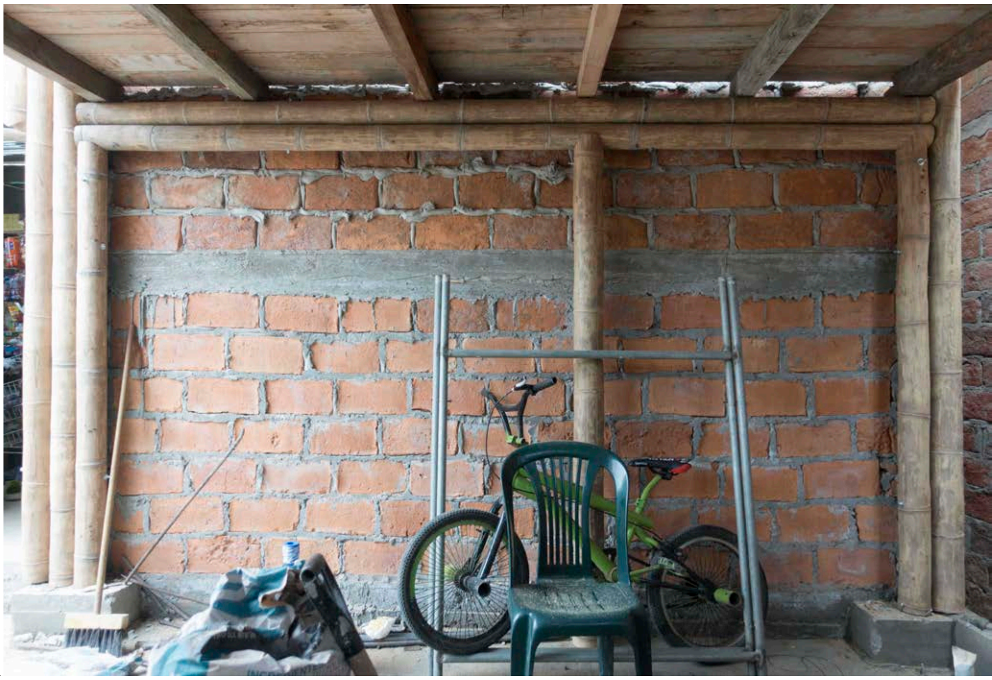


Fig B.40 - Disaster relief infill housing
Designed by author with contributions by local contractors

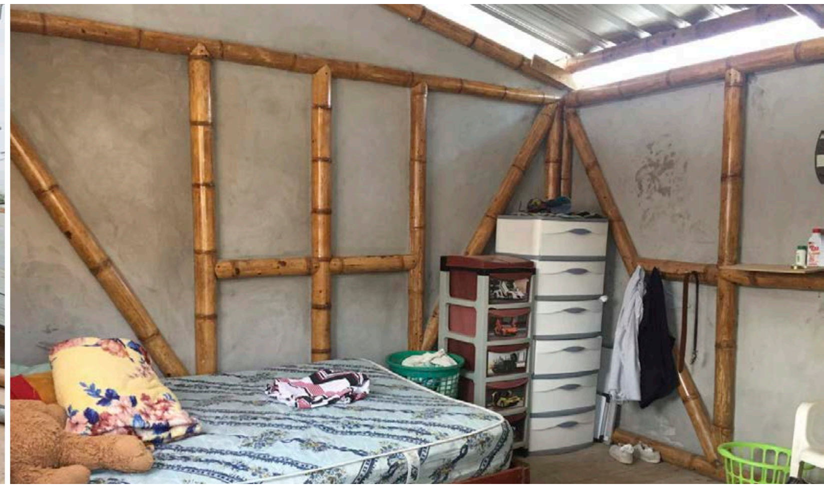


Fig B.41 - Disaster relief infill housing
Designed by author with contributions by local contractors

11b- Lucas Oshun, Bamboo Design/Build

This project utilized salvaged wood floorboards and beams for the second floor bedroom. The unresolved design components were completed by the master-craftsman who built many similar models with Lucas before this project.
Through being part of a 7 day design/build, I learned a lot about how I would stage the job site in future projects, pairing trained contractors with the volunteers. Specific tools, such as chop saws, or the clamped hole press jig would increase speed and accuracy in future builds.

Fig B.42 - Disaster relief infill housing
Designed by author with contributions by local contractors

Fig B.43 - Disaster relief infill housing
Designed by author with contributions by local contractors

Fig B.44 - Single story bamboo housing reconstruction
Jama, Ecuador. Architect: Silvia Flores

Fig B.45 - Single story bamboo housing reconstruction
Jama, Ecuador. Architect: Silvia Flores

12a- Carlos Benavides, Contractor, Jama
Architect Silvia Flores

The design of these single story homes incorporated many shear walls, and employed the modernized cement bahareque technique to protect the bamboo from sun and moisture. The eaves are extened to add additional protection.

Fig B.46 - Single story bamboo housing reconstruction
Jama, Ecuador. Architect: Silvia Flores

Fig B.47 - Single story bamboo housing reconstruction
Jama, Ecuador. Architect: Silvia Flores

Fig B.48 - Single story bamboo housing reconstruction
Jama, Ecuador. Architect: Silvia Flores

Fig B.49 - Single story bamboo housing reconstruction
Jama, Ecuador. Architect: Silvia Flores

Carlos Benavides, Contractor, Jama
Architect Silvia Flores

This model was being built in four locations and I was able to see various stages of the construction process. The unevenness that can sometimes result from different diameter floor joists was solved by simply pouring a thin topping slab on top of the bamboo culms.

Fig B.50 - Single story bamboo housing reconstruction
Jama, Ecuador. Architect: Silvia Flores

Fig B.51 - Single story bamboo housing reconstruction
Jama, Ecuador. Architect: Silvia Flores

Fig B.52 - CAEMBA home, slowly being upgraded by residents outside of Jama, Ecuador

Fig B.53 - CAEMBA home, slowly being upgraded by residents outside of Jama, Ecuador

12b- CAEMBA Resident, Jama
Designer: Manuel Palleres

This small community of homes was created through a group effort of citizens that wanted action faster than the national government could provide. A landowner divided a large area of his property into 30 lots and CAEMBA provided the transitional housing.

Residents were in various phases of home improvement, but those interviewed were happy with their home. One gentleman explained that by personally upgrading the home, he felt a sense of pride over his improved living situation.

Fig B.54 - CAEMBA home, slowly being upgraded by residents outside of Jama, Ecuador

Fig B.55 - CAEMBA home, slowly being upgraded by residents outside of Jama, Ecuador

Fig B.56 - Duplex units with full services provided
La Chorrera, Pedernales, Ecuador

Fig B.57 - Duplex units with full services provided
La Chorrera, Pedernales, Ecuador

13- Site visit, La Chorrera
Architect Luis Rivera

MIDUVI, the national housing ministry is building a dense housing development using bamboo as a structural building element. This large scale government housing project is the first of its kind in the area, thanks to the recent development of the Ecuadorian building code, released in 2017.

The development is 165 houses, each costing $10,000 and taking a mere 15 days to build, due to the replicated design, and the ability to build in series. (see Appendix D.5)

Fig B.58 - Duplex units with full services provided
La Chorrera, Pedernales, Ecuador

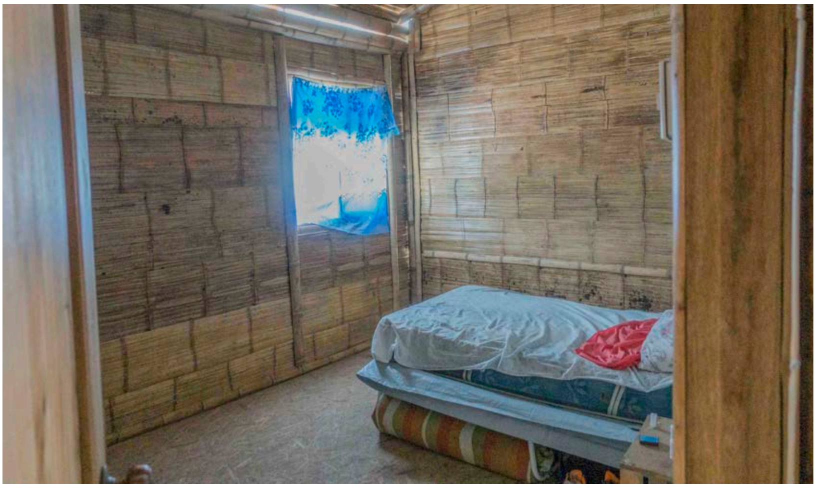


Fig B.59 - Duplex units with full services provided
La Chorrera, Pedernales, Ecuador

Fig B.60 - Duplex units with full services provided
La Chorrera, Pedernales, Ecuador

13- Site visit, La Chorrera
Architect Luis Rivera

A few issues with the project are that it relocates the fishing community away from the coast (livelihood), and will take two years to complete, leaving many in emergency tent shelters without a temporary home.

The new development layout provides little privacy, and no clear property lines. There is no room for expansion and very little open space around the home, which is quite different from the housing types from which the community is moving from.

Fig B.61 - Duplex units with full services provided
La Chorrera, Pedernales, Ecuador

Fig B.62 - Hybrid housing development, rural greenfield site, Muisne, Ecuador

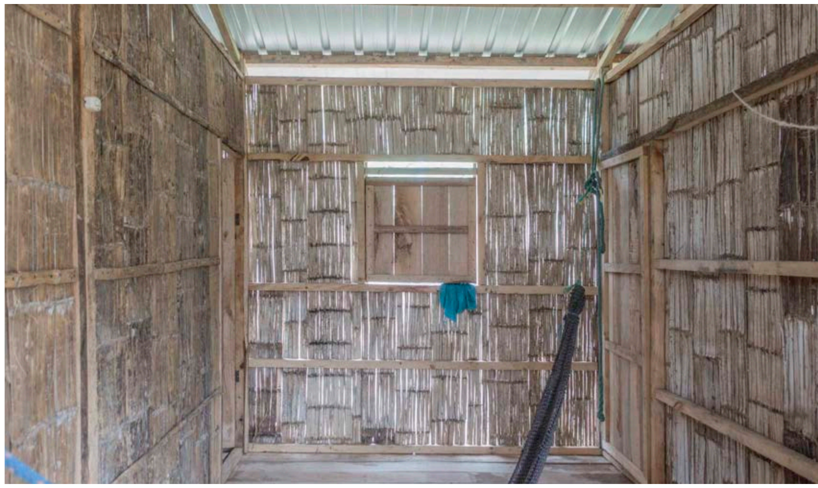


Fig B.63 - Hybrid housing development, rural greenfield site, Muisne, Ecuador

14- Residents, Villa de la Alegria
Muisne, Ecuador

I spotted this development while driving to my next destination and was able to hire a taxi to take me out to talk to some community members. These housing designs are similar to Hogar de Cristo (they may have been provided by them, uncertain to the author).

The families were required to invest "sweat equity" by helping with the construction of the home. Some complaints of the design were that the stairs were exposed to the rain, and the cold night air blew directly into their home.

Fig B.64 - Hybrid housing development, rural greenfield site, Muisne, Ecuador

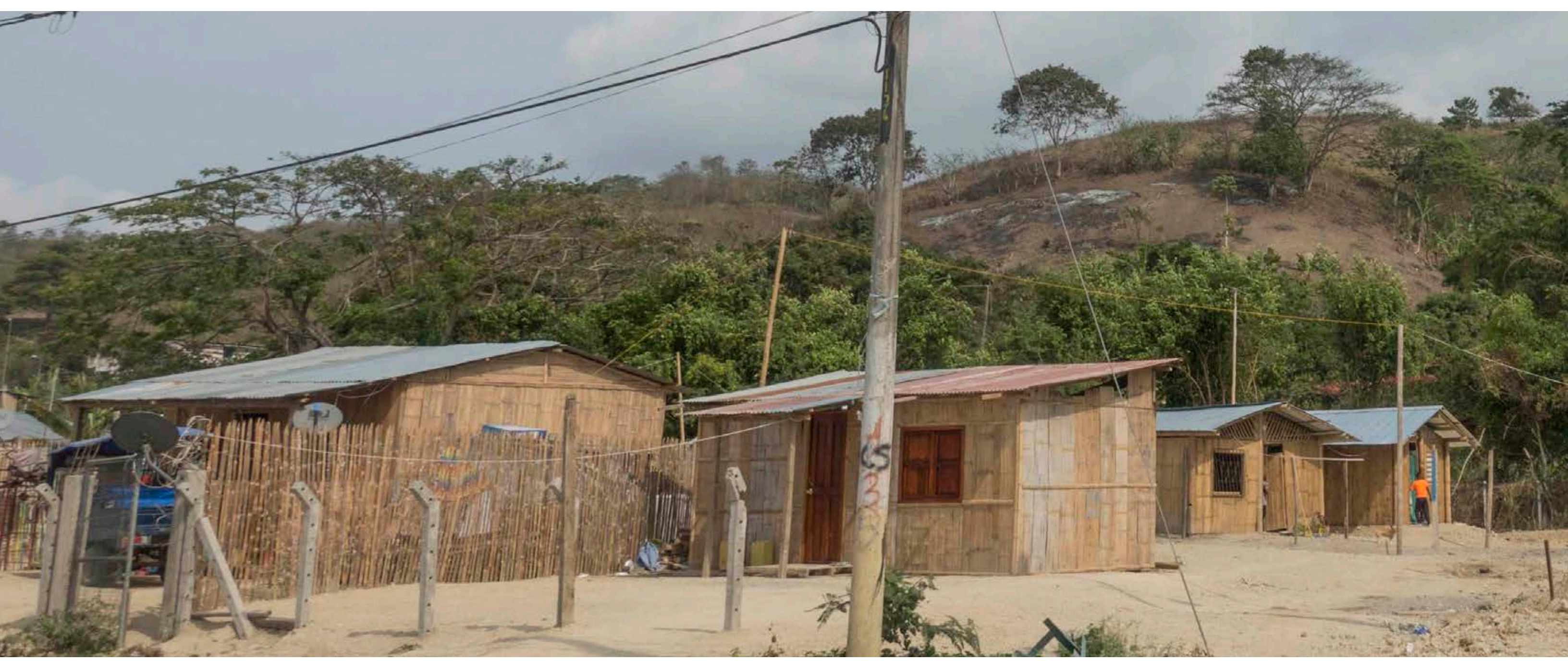
Fig B.65 - CAEMBA home, slowly being upgraded by residents outside of Esmeraldas, Ecuador

Fig B.66 - CAEMBA home, slowly being upgraded by residents outside of Esmeraldas, Ecuador

15a- Residents, Tonsupa, Esmeraldas, Ecuador
Designer: Manuel Palleres

Tonsupa was the first community I visited. I was apprehensive of approaching strangers, but Ana was very friendly and showed me around the entire area. Unlike other panelized housing systems on the market, CAEMBA homes use treated cane, which will prolong the life of the material. But exposure to rain and sun is still an issue and families are aware of the need to add concrete.

Fig B.67 - CAEMBA home, slowly being upgraded by residents outside of Esmeraldas, Ecuador



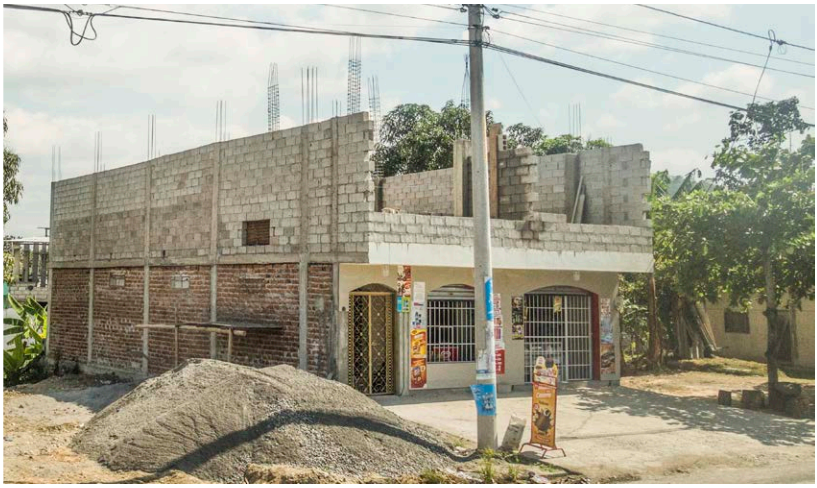


Fig B.68 - Photographed while in public transit
Santo Domingo to Esmeraldas, Ecuador

Fig B.69 - Photographed while in public transit
Santo Domingo to Esmeraldas, Ecuador

15b- Vernacular housing

During the hours of idle time on buses, I often kept my camera at the ready. This roadside documentation was by no means exhaustive, but recurring themes helped me understand common modes of self-construction.

Fig B.70 - Photographed while in public transit
Santo Domingo to Esmeraldas, Ecuador

Fig B.71 - Photographed while in public transit
Santo Domingo to Esmeraldas, Ecuador

Fig B.72 - Processed, cut and ready to ship
Bamboo treatment plant, Los Bancos, Ecuador

Fig B.73 - German supplies treated bamboo to a nearby factory
that produces glue-lam products, Los Bancos, Ecuador

16- German Villareal, Plantation & Processing Plant owner, Los Bancos

One of the presenters from the Premio Sacha workshop was German Villareal, a bamboo plantation processing plant owner. I arranged a visit to his treatment plant and plantation, learning about his exporting operation, which has shipped bamboo to Los Angeles, Chicago, and the Netherlands. German is another example of a vertical integration entrepreneur: growing, treating, selling and building. In this fashion, he controls the quality of the material and cuts out the middle men, ensuring a better profit margin.

Fig B.74 - German grows Dendrocalamus Asper, the gigantic
variety of structural bamboo, Los Bancos, Ecuador

Fig B.75 - Processed, cut and ready to ship
Bamboo treatment plant, Los Bancos, Ecuador

Fig B.76 - Two story prototype showing weathering issues only a few years after built, Santo Domingo, Ecuador

Fig B.77 - One story prototype, Santo Domingo, Ecuador

17a- Fernando Loayza, Architect, Santo Domingo

At a conference in Santo Domingo (#17d), I met many members of the Ecuadorian technical table for bamboo, a multi-sectoral group of professionals that share advancements in the industry. Fernando showed me two government prototypes that had technical detailing issues, illustrating that the government still did not intimately understand the material if it is promoting a prototype that is not designed properly.

Fig B.78 - Two story prototype showing weathering issues only a few years after built, Santo Domingo, Ecuador

Fig B.79 - Two story prototype showing weathering issues only a few years after built, Santo Domingo, Ecuador

Fig B.80 - Two homes designed and built by Efrain,
Near Santo Domingo, Ecuador

17c- Efrain Benitez
Contractor & bamboo-treatment owner, Santo Domingo

I met this contractor during the tour of the municipal treatment plant in Santo Domingo (17E). Another vertical integration entrepreneur, Efrain has designed many bamboo homes, hoping to provide a style that middle-income families are attracted too. He believes strongly that the market will eventually develop.

Fig B.81- Efrain supports local artisans by giving them his scrap bamboo from construction (which can be up to 30%)

Fig B.82 Efrain drove me around Santo Domingo for half of a day and was very helpful connecting me with other bamboo experts

Fig B.83. Bamboo project in process
Efrain Benitez, Santo Domingo, Ecuador

Fig B.84 - Innobambu is the design arm of
Efrain's business venture

17c- Efrain Benitez
Contractor & bamboo-treatment owner, Santo Domingo

Efrain has worked with the regional government on various projects. They often hire Colombian experts to train the contractors in best practices, and Efrain has learned how to build accurate and well executed bamboo buildings.

Fig B.85 -Efrain has learned many new techniques and styles
from Colombian contractors

Fig B.86 -Efrain has learned many new techniques and styles
from Colombian contractors

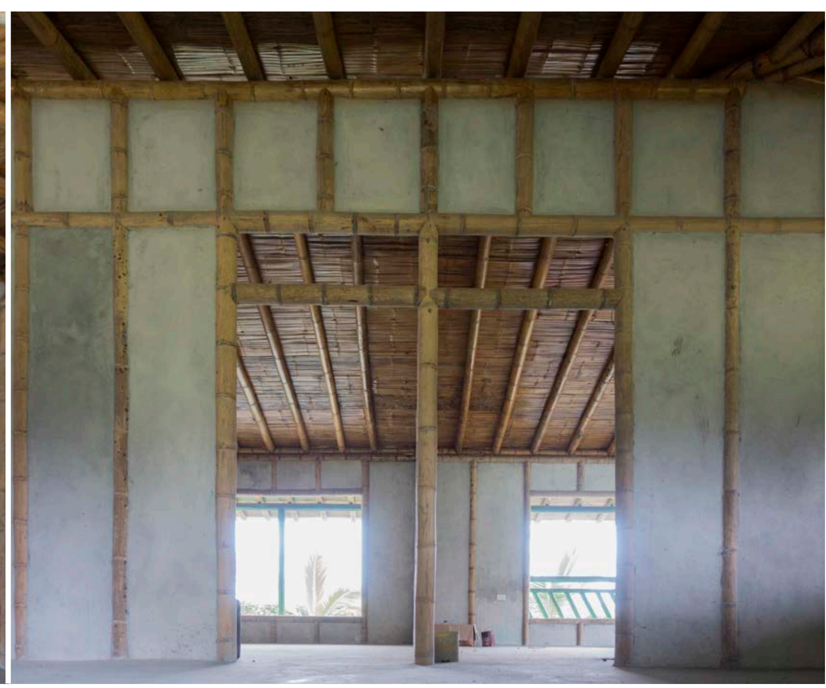


Fig B.87 - Dr. Jorge Montoya explains every aspect one could hope to learn about bamboo growing and treatment

Fig B.88 - Dr. Jorge Montoya explains that the number one aspect holding bamboo back is fear of ones home burning down

17d- Bamboo Conference, Santo Domingo

To better understand the issues with the value chain, I attended a 2 day conference at the Catholic University in Santo Domingo Ecuador Colombian professors, Ecuadorian architects as well as other agricultural experts described common issues with bamboo plantations, the numerous ways to treat bamboo, and common design mistakes that compromise the material in bamboo buildings. Many of the projects I visited resulted from interviews or informal conversations I had with people at the conference.

Fig B.89 - Fernando Loayza presents on how architects need to understand pitfalls of their bamboo designs

Fig B.90 - A local artisan asks “who here buys bamboo products?” pointing out the disconnect between academic promotion and reality

Fig B.91 - This regional treatment plant could not find a local engineer to do structural calculations and had to pay a Colombian specialist

Fig B.92 - The architect shows a tool they built to make rapid and accurate cuts at specific angles

17e- Municipal treatment-center, Santo Domingo

At the end of the second day, we visited a newly constructed processing plant (FIG 8), an investment from the local municipality. The large scale plant shows positive signs for access to more affordable treated cane. The tour of the treatment center by the project architect was especially informative, as we were able to see the architectural drawing set, details, and demonstrations of new tools and techniques developed for the large bamboo structures.

Fig B.93 - A foreman explains a tool they use to measure diameter of culms.

Fig B.94 - Efrain talks to a group of young students and contractors about the economic opportunity bamboo presents

Fig B.95 - Pablo Jácome was instrumental to connecting me with the national network of bamboo experts

Fig B.96 - INBAR is an organization that has helped the bamboo industry develop in Latin America since 1992

18a- Pablo Jácome, INBAR Coordinator for Latin America, Quito

I began my time in Ecuador by interviewing the Regional Coordinator of the International Network of Bamboo and Rattan (INBAR), who connected me to the network of bamboo professionals across the country. As luck would have it, that week had various events as part of Premio Sacha, an award program for sustainable agroforestry and buildings. I signed up for a two-day bamboo-building workshop, which had six lecturers from Peru and Ecuador, culminating in a hands on construction project (18b).

Fig B.97 - The INBAR office in Quito displays various bamboo housing models, promoting the material

Fig B.98 - The INBAR office in Quito displays various bamboo housing models, promoting the material

Fig B.99 - Precut and partially assembled components allowed our group to complete the project in one day

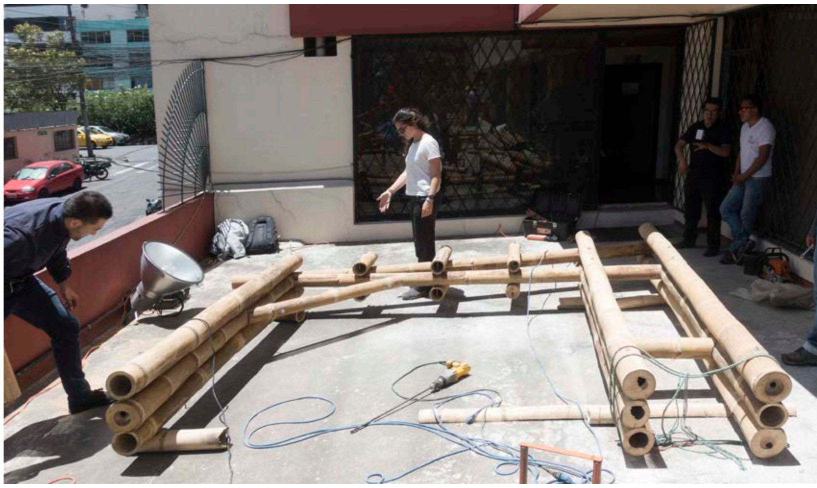


Fig B.100 - Precut and partially assembled components allowed our group to complete the project in one day

18b-Nicolás Van Drunen, Student Architect, Designer of Bamboo Workshop, Quito

This two-day workshop had prefabricated components, allowing our large group to divide into smaller teams. We all had a chance to work with the material, learning about the difficulties and learning tricks of the trade and were able to complete the small structure in the short time we were allotted. The structure was designed for disassembly, so that our efforts would benefit a non-profit. This project highlights one of the benefits of bamboo: the light weight allows large components to be fabricated and relocated with relative ease.

Fig B.101- Precut and partially assembled components allowed our group to complete the project in one day

Fig B.102 - The project installed in its final destination Photo courtesy of Nicolas Van Drunen

Fig B.103 - Model CAEMBA home built in their own backyard, an example that bamboo homes can be contemporary

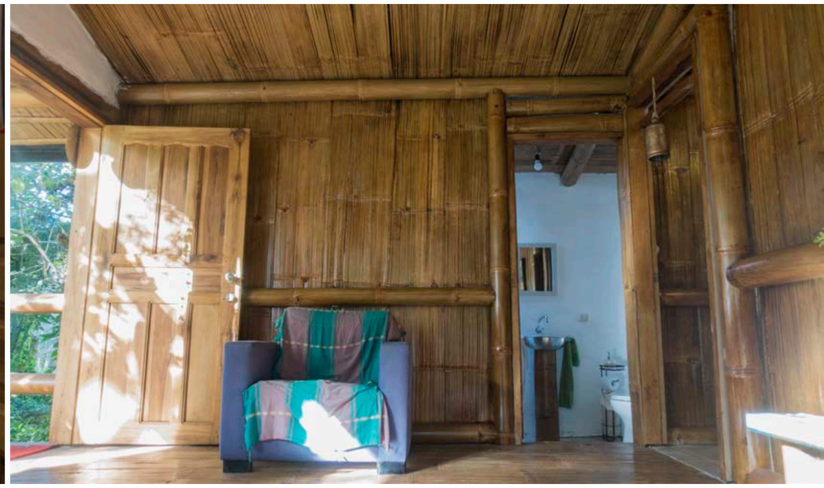


Fig B.104 - Model CAEMBA home built in their own backyard, an example that bamboo homes can be contemporary

18c- Manuel & Christine Palleres, CAEMBA housing, Quito

After the earthquake struck, Manuel Pallares and his partner Cristina Latorre felt called to help out their fellow Ecuadorians in a time of need. They developed a bamboo shelter-system to provide much needed emergency shelters, schools, and safe areas for children to play. As time went on, the emergency shelters were infilled with bamboo wall panels, evolving into permanent housing. The low cost, light weight, and easy to build nature of bamboo made CAEMBA's transitional housing model possible (see Appendix D3)

Fig B.105 - Model CAEMBA home built in their own backyard, an example that bamboo homes can be contemporary

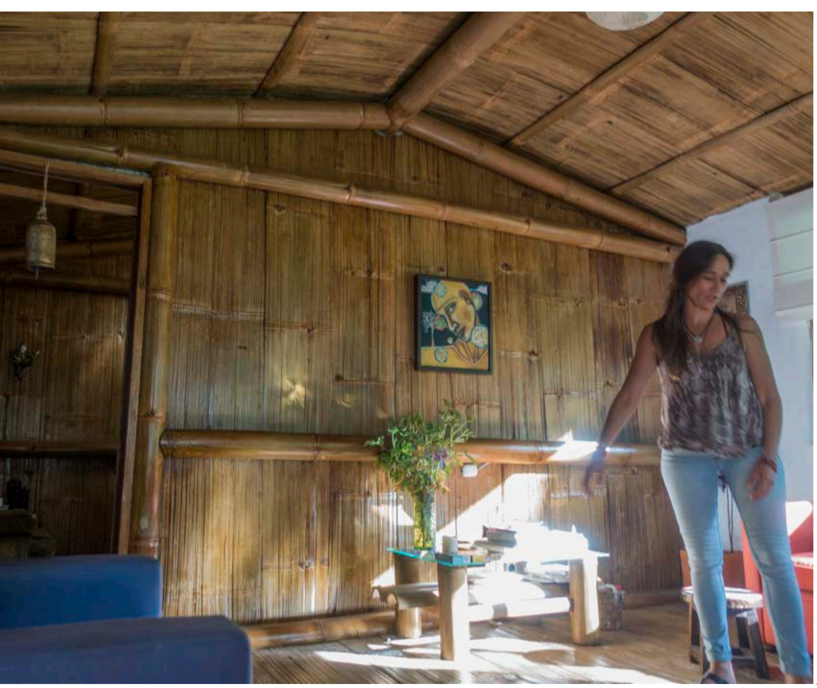


Fig B.106 - These work of these two inspired citizens resulted in: 366 homes, 27 classrooms, 12 youth/community centers, directly benefiting over 3,600 people.

Fig B.107 - These work of CAEMBA resulted in: 366 homes, 27 classrooms, 12 youth/community centers, directly benefiting over 3,600 people.

Fig B.108 - These work of CAEMBA resulted in: 366 homes, 27 classrooms, 12 youth/community centers, directly benefiting over 3,600 people.

18c- Manuell & Christine Palleres, Architects
CAEMBA housing, Quito

To reach the greatest number of families in need, Manuel and Cristina developed a structure that matched the dimensions of standardized sheets of plastic, and prefabricated bamboo panels tailored to fit the width of the delivery trucks. The lightweight nature and durability of bamboo allows everyone to help during construction. The structure was able to be disassembled and moved, or slowly upgraded as the family received more resources. Many families upgrade the finishes of their shelters, and are transitioning into permanent homes (12b, 15a)

Fig B.109 - These work of CAEMBA resulted in: 366 homes, 27 classrooms, 12 youth/community centers, directly benefiting over 3,600 people.

Fig B.110 - These work of CAEMBA resulted in: 366 homes, 27 classrooms, 12 youth/community centers, directly benefiting over 3,600 people.

APPENDIX C: INTERVIEW MATERIALS

The interviews, both formal and informal, was one of the most informative aspect of the travel research. The author is in the process of combing through the hours and hours of recordings for salient quotes, but those will be saved for the next publication. What can be said is that each person brough a new opinion to the table. The interviews were also curated by people passionate about bamboo, so the opinions are weighted.

Spanish is the author's second language, but the questions below are the original questions posed to the interviewee. Interviews lasted between 30 minutes to one hour.

- How long have you worked with bamboo?
- What are the benefits of working with bamboo?
- What are the challenges of working with bamboo?
- What is missing for a future where you can buy treated bamboo at your local Home Depot?
- People prefer to buy green, untreated cane, because it is cheaper and they do not see the value in paying up to 6 times the price. What will change this?
- What do you think about a certification system to ensure people are buying quality cane?
- To maintain cost effectiveness, some think bamboo building needs to become industrialized and prefabrication will play a big role. Do you agree with this train of thought?
- In the past 10 years, there have been many advances in the field of bamboo buildings: codes, prototype homes etc. But people still want a confined masonry home because they think that is what a durable, modern home of the 21st century looks like. Do you think there is a future where treated bamboo will be a material used in the market of low-income housing? What is its biggest obstacle?
- What are the most exciting changes that are happening that show promise for improving the bamboo market?

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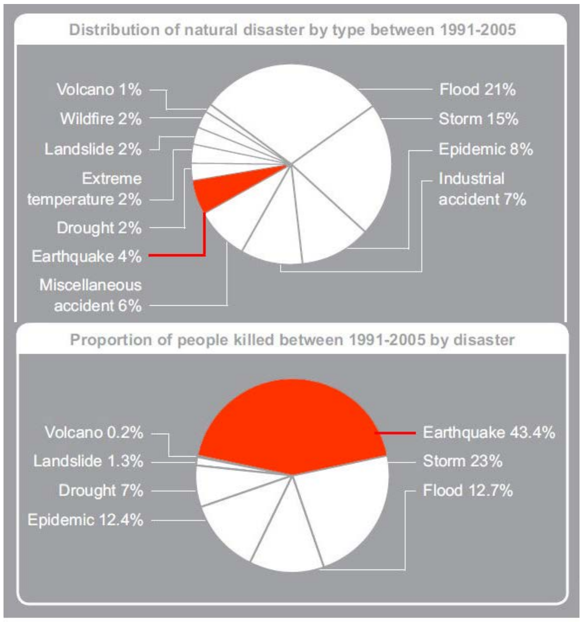
APPENDIX D: BUILD BACK BETTER



Source: EM-DAT: The OFDA/CRED International Disaster Database

Fig D.1 Statistics on fatality of natural disasters by category

Fig D.2 - Vulnerable informal settlements in Lima, Peru, a country with over 10,000 squatter communities.

D.1 CLIMATE CHANGE, URBANIZATION, AND VULNERABILITY

Earthquakes are the most deadly of natural disasters, accounting for over 40% of worldwide disaster fatalities between 1991 and 2001, but only representing 4% of the total disasters in the same time period (fig D.1). Reconstruction following earthquakes is an opportunity to "build back better", creating more resilient communities, decreasing loss of life in the next large quake. On April 16, 2016, Ecuador suffered a 7.8 magnitude earthquake, resulting in damages to over 35,000 homes leaving 140,000 people without adequate housing.[1]

This Appendix highlights the development of modernized bamboo housing in Colombia, Peru, and Ecuador after large-scale earthquakes and discusses the opportunities that the fast-growing, locally sourced building material could provide for vulnerable communities in earthquake prone areas of South America. The material was gathered over a 10-week period, where the author traveled through Peru and Ecuador to various case studies, interviewing architects, builders, bamboo growers, NGOs, professors, residents and public officials.

The failure of the Low and Middle Income Country's (LMIC) governments to regulate massive urban migration is one of the reasons why earthquakes result in higher fatalities. In fact "an estimated 97% of natural disaster related deaths each year occur in developing countries."[2]

One form of urban migration occurs through municipal land squatting, where a group of people plan a coordinated "invasion", creating a settlement overnight. Often, these families are living in poverty and cannot afford qualified builders, resulting in communities living in high risk situations: unsafe structures on unstable soil, in dense, hard to access neighborhoods (fig D.2).[3]

D.1 CLIMATE CHANGE, URBANIZATION, AND VULNERABILITY continued:

To make matters worse, climate change is causing an increase in intensity and frequency of natural disasters, increasing the vulnerability of those living in disaster-prone areas.[4]

The solution is not always as simple as relocating communities to safer areas. In large cities, safe vacant land is typically on the outskirts, removed from the livelihood and services that the community migrated for in the first place. Relocating impoverished communities away from their cultivated social support networks and employment opportunities, often exacerbates economic disparities.[5] While bulldozing slums has been condemned by human rights groups, it is estimated that 5 million people are forced to relocate every year because of this practice.[6]

Ignoring or moving urban slums have disastrous results, so the strategy of slum upgrading has been the next logical solution to decreasing the vulnerability of communities that migrated to cities in search for a better life.

D.2 DISASTER RECONSTRUCTION

It is a recognition that exposure of settlements to hazards (such as tremors, hurricanes, floods, disease vectors and conflicts) has a major influence on the type of shelter solutions that can be supported. Similarly, whether settlements are rural or urban, formal or informal, temporary or permanent will influence how shelters are conceived, built and maintained.
- European Civil Protection and Humanitarian Aid Operations [7]

Recovering from a natural disaster, requires aid of various forms, depending on the emergency and phase of recovery. During the acute emergency phase following an earthquake, there is immediate need for triage care to those wounded in building collapse, and emergency shelter for those who have lost their homes.

As mentioned earlier, displacement can have a negative effect on a community, so emergency shelters are intended to be a short term solutions employed while reconstruction is being coordinated. Victims who lost housing in an informal settlement are often unable to receive further government assistance beyond emergency shelters because they do not own the land their housing was located on.

In this situation, the state should address the quagmire of urban slums, as there is political pressure from the international community to show improved infrastructure and resilient housing as a disaster mitigation strategy, preventing further loss of life in any future events. Additionally, international aid agencies are often available to provide resources and expertise to develop a multi-faceted solution to the rebuild a resilient community.

Successful slum upgrading programs have three components: providing access to urban services (utilities, education, healthcare, employment), securing land tenure, and increased access to credit.8 These processes can take months or even years to occur, so temporary or transitional shelters are provided in the interim period.

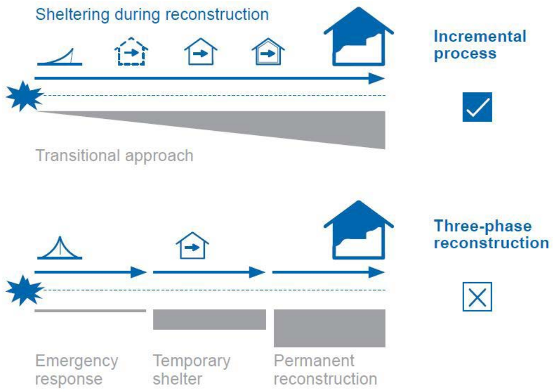


Fig D.3 - Two strategies of housing reconstruction

Fig D.4- Sized to flat-pack into trucks, maximizing panels/trip

Fig D.5- Rudimentary emergency shelter

Fig D.6 - Emergency shelter with plastic privacy screen

D.2 DISASTER RECONSTRUCTION continued:

Transitional and temporary shelters fall under two different approaches to reconstruction (fig D.3). An incremental process allows a transitional shelter to continually gain value as resources become available, and a three-phased approach, builds a different shelter during each phase.

The primary characteristics of a transitional shelter is that it is: relocatable, resaleable, recyclable, reusable, and upgradable.[9] Temporary shelters on the other hand only house families while their permanent home is being built.

The flexibility of the transitional shelter to be upgraded to permanent housing, or disassembled and used to build a home on other land make it a much more useful housing typology for displaced families. It should be noted access to water, electricity and sanitation are not integrated into the shelter, and must be provided as additional utilities.

Regardless of reconstruction strategy, the goal is to reduce the vulnerability of the community, building back with better homes for the disaster victims.

D.3 CAEMBA TRANSITIONAL HOUSING - ECUADOR

After the earthquake struck, Manuel Pallares and his partner Cristina Latorre felt called to help out their fellow Ecuadorians in a time of need. They developed a bamboo shelter-system to provide much needed emergency shelters, schools, and safe areas for children to play. As time went on, the emergency shelters were infilled with bamboo wall panels, evolving into permanent housing (fig D.5 and D.6)

Fig D.7 Initial shelter, tents from UNHCR

Fig D.8 Interview on current living situation, CAEMBA model

Fig D.9 Incremental home improvements

Fig D.10 A family's transition towards a secure shelter, Salima, Ecuador

D.3 CAEMBA TRANSITIONAL HOUSING - ECUADOR continued:

"We developed a do-tank, not a think-tank...Many architects that worked with bamboo, they went into a duality of whats good and whats bad...they didn't act in the moment. We just said, lets do it, you know, lets go...We realized what people really needed...At the moment of the emergency, you don't need to spend that much money. You just go ahead and put the families together because the most tremendous thing is to see all these children in the streets and the mother desperate to take care of their children and the father also angry because he was vulnerable in the situation. The only way to go through this mourn(ing) is to be in your family system. It's the only way to get active again and to be able to process the emotions and what you lost... People can't do that in these huge refugee camps, it's impossible...

- Cristina Latorre, on CAEMBA's reaction to the earthquake

To reach the greatest number of families in need, Manuel and Cristina developed a structure that matched the dimensions of standardized sheets of plastic, and prefabricated bamboo panels tailored to fit the width of the delivery trucks (fig D.4). The lightweight nature and durability of bamboo allows everyone to help during construction. The structure was able to be disassembled and moved, or slowly upgraded as the family received more resources.

The couple created a foundation CAEMBA (CAsas EMergente de BAmboo - Emergency Bamboo Homes) in order to receive grants for the community built projects. In the end, they built 366 homes, 27 classrooms, 12 youth/ community centers, directly benefiting over 3,600 people.

The low cost, light weight, and easy to build nature of bamboo made CAEMBA's transitional housing model possible, providing shelter to those in need. Many families upgrade the finishes of their shelters, and are transitioning into permanent homes (fig D.7 through D.10)

Fig D.11 - The Bamboo Training Center of San Clemente

Fig D.12 - Church of Society of Jesus, located in Pisco, Peru

Fig D.13 - Housing model built out of pre-fabricated bamboo components

Fig D.14 Two contractors who build with bamboo, often teaching novice architects how to improve their designs

D.4 TRAINING BAMBOO BUILDERS - PERU

In 2007, a magnitude 8.0 earthquake struck southern Peru, destroying over 58,000 homes.[10] Similar to Ecuador and Colombia, bamboo was selected as an appropriate material for reconstruction, due to its traditional use in Peru. The sandy soil proved to have a low-bearing capacity for heavy structures, making any brick or concrete building a costly investment.[11]

The local organization leading the reconstruction opted to build permanent housing, so the design team had to tackle three logistical problems in order to rebuild with bamboo:

- *the lack of cured bamboo, needed for durable construction*
- *the lack of skilled labor in the modernized bamboo building techniques required for the housing design*
- *the general insecurity of the area in which the project would be built*

To address these problems, the project architects Yann Barnet and Faouzi Jabrane decided to build a “Bamboo Training Center” so that they could effectively cure and dry the bamboo, train a local work force, and prefabricate housing elements to mitigate any theft of construction supplies at the build site (fig D.11).[12]

Following the disaster, the city had no large public gathering space because the large churches had collapsed during the earthquake, tragically killing 148 of people inside.[13] The team decided to rebuild a church out of bamboo (Fig D.12), providing a large, multi-functional space out of a material that was relatively light and earthquake resistant. This project had two goals: to hone the newly trained builder’s skills with a complex project and to demonstrate to the population at large that bamboo is a durable and safe alternative building material.

D.4 TRAINING BAMBOO BUILDERS - PERU

The project built 54 bamboo houses (fig D.13), and trained 15 local builders. 10 years later, two of those builders continue to cure and build using the skills they learned in the reconstruction projects (FIG 19), indicating that bamboo construction can provide a livelihood and that workshops can successfully increase the number of skilled tradesmen in an industry that lacks qualified builders. The publicity of the bamboo church started the dialog that led to the building code being developed in 2012.

D.5 BAMBOO HOUSING DEVELOPMENT - ECUADOR

. While speaking with Pablo Jacome, the Regional Coordinator for INBAR Latin America, he noted that the most exciting development after the earthquake is the investment that the public sector has begun to make in the building industry.

For example, in Santo Domingo, Ecuador, the regional government has built a large scale bamboo curing center, which will increase the availability of treated bamboo (fig D.15). The impressive structure allowed Colombian contractors to teach Ecuadorian builders new techniques, and Ecuadorian architects the opportunity to lead a large, complex project.

Additionally, MIDUVI, the national housing ministry is building a massive housing development using bamboo as a structural building element (fig D.16). This large scale government housing project is the first of its kind, thanks to the recent development of the Ecuadorian building code, released in 2017.

Fig D.15 - Bamboo treatment center of Santo Domingo, Ecu.

Fig D.16 - La Chorrera housing project near Pedernales, Ecu

Fig D.17 - Living in emergency shelter, 18 months later

Fig D.18 - Living in emergency shelter, 18 months later

D.5 BAMBOO HOUSING DEVELOPMENT - ECUADOR continued:

The development is 165 houses, each costing $10,000 and taking a mere 15 days to build, due to the replicated design, and the ability to build in series. One big issue with the project is that it relocates the fishing community away from the coast (livelihood), and will take two years to complete, leaving many in emergency tent shelters without a temporary home (fig D.17 and D.18).

D.6 CONCLUSIONS

"While building houses is relatively easy, developing meaningful, livable settlements that redress social injustices is a complex endeavor" - The Invisible houses: re-thinking and designing low-cost housing in developing countries [14]

The Chorrera development layout provides little privacy, and no clear property lines. There is no room for expansion and very little open space around the home, which is quite different from the housing types from which the community is moving from. This example shows that regardless of the material being used, the urban design and use of public/private spaces plays an important role when building a new urban development.

It is evident that earthquakes have catalyzed the public sector into taking actions to improve the legality of building with bamboo. The case studies highlight how a diverse set of actors (designers, government ministries, academics and foreign nationals) have turned a disaster into an opportunity to build back better.

Furthermore, families that were traumatized by falling brick FEEL safer as well. Architect Silvia Flores described a case in Jama, Ecuador where a family was provided a new concrete home, but still spent the nights in the better ventilated, light-weight bamboo shelters.

From transitional shelters, to permanent housing, bamboo's inherent properties of rapid growth, high weight to strength ratio, and ease of transport have been able to provide more houses per dollar spent. The seismic-resistant homes will ensure that in the next earthquake, fewer buildings will fall, and lives will be saved.

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APPENDIX D

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ENDNOTES

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