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Lessons from Vernacular Bamboo Architecture for Sustainable Design in Hot Humid Areas of Coastal Manabi

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Abstract

It is now understood that vernacular architecture essentially embodies the tangible and intangible values of a community that comes to identify itself with what it builds as a result of its engagement and cultural legacy. In the coastal province of Manabí, Ecuador, the vernacular architectural heritage is mestizo, stemming from the intermingling of Spaniard techniques and indigenous craftsmanship that made extensive use of bamboo as the main building material. For centuries, vernacular bamboo houses have adapted to social changes and harsh coastal climatic conditions, displaying the effectiveness of their bioclimatic design with highly sustainable construction methods. However, over the past decades there has been a loss of passive climate control principles, mainly due to the substitution of bamboo in favour of culturally and environmentally foreign processed materials. Scientific literature has further explored the properties that distinguish Guadua angustifolia kunth from other bamboo species, placing it as one of the most sustainable and cost- effective materials for human use.

This paper proposes, based on historical analysis, to reveal the bioclimatic strategies bound to the material which could be implemented in a sustainable and comfortable housing design proposal. The aim is twofold: to highlight the bioclimatic nature of traditional architecture when associated with other local materials, such as cade and quinche, and to demonstrate the versatile performance of bamboo for sustainable constructions. Design Builder software is used to model the proposal, which is then evaluated under ASHRAE 55 adaptive comfort parameters. The results show a sustainable and energy efficient annual performance, with more than 98% comfortable annual hours using only bamboo, quinche and cade architectural and construction strategies. The study also highlights that a high thermal mass of the building, in conjunction with cross ventilation, is a very efficient strategy in hot humid climates, capable of ensuring indoor comfort without resorting to mechanical air-conditioning.

Keywords: Vernacular Architecture, Coastal Ecuadorian Houses, Bioclimatic Design, Bamboo-Building Techniques, Project Simulation

Introduction

The use of materials with low environmental impact is a much sought-after objective today, promoted by sustainable building initiatives; in addition to the latest technological advances or applications aimed at reusing primary materials from dominant construction components, like steel or concrete, natural materials such as wood are also attracting interest at an engineering level, with improvements in laminating or gluing, while maintaining the ecology of these technologies [1]. Within the field of natural materials, bamboo has shown a line of development in constant growth and possibilities [2]. The structural virtues of this material have offered versatile solutions to constructive components in ancient architecture as well as in contemporary projects seeking sustainable features. In addition to properties such as lightness and tensile strength, its relatively short production period and availability have brought it closer to remote areas where conventional materials are not available, making it a very attractive option in remote settlements that require to be self-sufficient in building materials [3]. It is hardly surprising, then, that bamboo is now considered one of the most interesting sustainable materials, and the study of its historical engagement in construction lets us understand how architecture can be fashioned through a material, adopting these very same principles in contemporary projects [4]. Vernacular architecture in many cultures in the warm humid climates of the tropics has harnessed the qualities of bamboo, and its technological development has proved its versatility in construction techniques such as bamboo culm lattices, split bamboo or woven bamboo [5]. However, the growth of cities and the globalization of building techniques tend to displace locally based construction methods, and in this transition from vernacular to modern building systems we often lose design principles of sophisticated adaptation to the environment. The architecture focused on environmentally friendly solutions is also giving way to an architecture that relies on artificial systems for climate control. In this context, the study presents a typology of vernacular coastal architecture in Ecuador and delves into its relationship with bamboo- based construction techniques, to provide an example of how the qualities of this technique can be used in a contemporary architectural project.

Architectural Heritage in Manabi

For the purposes of this study, the city of Puerto López, Manabí, is chosen as the location for a house proposal. Documental research is carried out on the available census data spanning the last three decades to develop a better understanding of the social dynamics of its population. Likewise, literature research on the city's origins and growth is key to grasp the historical evolution of vernacular housing under its sustainable dimension. A customized interpolated Energy Plus Weather file (EPW) is then created using Meteonorm software in the absence of existing weather data. The year-round hourly information is used in two climate assessment tools (Climate Consultant and Mahoney sheets) and their subsequent passive- design recommendations are linked with those found in vernacular bamboo architecture. Adaptive Comfort Model from ASHRAE Standard 55-2010 is chosen as the framework to determine indoor wellbeing criteria. The model proposes two acceptable operative temperature ranges. The first is designed for typical applications where 80% of people would be satisfied (within ±3.5°C of average comfort temperatures). The second range assumes a narrower and less tolerant thermal comfort range, where 90% of people are satisfied (within ±2.5 ºC of average temperatures). These parameters are evaluated when using Design Builder software to model the proposal.

Manabí and its Enriched Architecture

Manabí is the oldest, largest coastal province in Ecuador and the third most populated in the country. It spreads along the Pacific Ocean for 350 km covering an area of 18 940 km2, with lush vegetation ranging from tropical dry shrubs to tropical rainforest on a varied landscape of low altitude rarely exceeding 500m. Due to its mega biodiversity, it's home to the Machalilla National Park as well as other protected areas, making it a source of tourist attraction especially during the humpback whale breeding season. Throughout the year temperatures keep high, reaching up to 35ºC in the wet season and diminishing to a minimum of 17 ºC during the dry season; on average, there is 82.4% relative humidity while annual precipitation levels stay close to 400 ml.

Manabí also holds a deep ethnic and architectural background, having been occupied from as early as 3500 BC by the Valdivia culture and then by a myriad of Pre-Columbian civilizations until the Integration Period [6]. Archaeological studies on the central coastal province suggest the use of organic materials, such as local timber, lianas, palm leaves and bamboo poles, in domestic buildings as well as ceremonial constructions. Throughout the province, numerous sites have revealed the stone foundations of settlements, lined with holes from which wooden posts would have stood to support thatched roofs. Bamboo would have been split and tied to these poles to fashion simple partitions or interwoven with branches and mud to create bahareque walls. Furthermore, what has survived of pottery models portraying house-like buildings suggests the widespread use of bamboo beams for the roof structure [7].

The conquest led by the Spaniards in early 1530s forcibly disrupted the way of life of the last of the native cultures in Manabí: the Manteño people known worldwide for their balsa and bamboo boat houses and their "U" shaped stone seats. A large part of their settlements disappeared under viceroyalty rules and were replaced by villages occupied mostly by Europeans and mestizos. Spaniards designed and planned the buildings, but the construction was taken out almost exclusively by indigenous craftsmen using local materials. Hence, a hybrid architecture appeared, neither fully Spanish nor native, but stemming from the merging of ideas between both races.

One of the most remarkable outcomes of this mestizo architecture was the use given to local materials. Instead of following the Crown's orders and building exclusively with stone and mortar, every new town was built with wood, bamboo, and palm leaves with astonishing results. The town of Portoviejo, capital of modern Manabí, was amongst the first founded by the Spaniards and was visited a few years later by the explorer Girolamo Benzoni. He described it as a city inhabited by Spaniards, with about twenty-two houses of bamboo covered with thatch [8]. By the beginning of the seventeenth century, in 1605, the use of bamboo remained constant, and the dwellings had changed little. They were humble and made of bamboo and mud, sometimes with wood, all under thatch roofs. However, as the Spaniards took on a more permanent position and as wood construction became more elaborate due to the naval industry expanding in the southern coastal regions, urban buildings began to lean away from bamboo cladding and thatched roofs. Houses were now built solely on timber frames with elaborate wooden facades and tiled roofs, evoking Iberian architecture with internal patios, ample balconies and porches spanning sidewalks [9]. Outside these cities, however, a more autochthone way of life remained in the wilderness. Native people fleeing from social oppression raised bamboo houses on stilts and protected themselves under thatched roofs in camouflage of natural colours and textures. Benzoni mentioned it in his chronicles, and a more in-depth description of rural stilt houses along the coast was written up by Juan and Ulloa in 1748.

Centuries later, bamboo stilt houses continue to populate the Manabí countryside and are now called eponymously after the province. Even though they are deeply rooted in coastal people's heritage, traditional bamboo bouses have suffered decades from political and social neglect and are currently threatened by the onslaught of processed and imported materials.

Sustainability in Vernacular Bamboo Houses Through Time

In addition to their heritage value, vernacular dwellings also illustrate the highest form of sustainable construction. In fact, many principles of sustainable architectural design can be found in vernacular buildings, which is why they constitute a true reference point for contemporary constructions aiming towards a greener future. In this respect, traditional bamboo houses of coastal Manabí have much to teach us.

First of all, they represent an inexpensive form of housing given its traditional construction and socio- environmental features. Materials are obtained locally from the natural environment and do not require specialized tools for their gathering and shaping, beyond those that the montuvio (coastal farmer) occupies for his work. Use of native guadua bamboo (Guadua Angustifolia Kunth) for construction is widespread throughout the country but it is especially true for Manabí, where it is most abundant. Likewise, cade (Phytelephas aequatorialis) and bijao (Calathea lutea), which are used for thatching, are also native species that thrive close to bamboo and share with it a historical background stretching to pre-Columbian times. Moreover, the construction of traditional bamboo houses is undertaken by its future owners and other community members who share in the local empirical knowledge conveyed through generations. Thus, the construction of the house becomes a social event infused with important connotations: interpersonal relations are reinforced, past and present are confirmed, and the identity of a people is reaffirmed to outsiders.

a) b) c)

Figure 1: Various examples of bamboo stilt houses found in the province: a) A stilt house in its simplest form; b) Open floor plan design; c) Additions and adaptations due to growth and urban influences.

These dwellings are known for their deep and adequate understanding of the tropical environment typical to Manabí. Traditional bamboo houses throughout the province seek shelter from the heat by setting themselves amidst nature, close to water bodies, under dense trees or near areas rich in vegetation. Because of their location, they can easily gather fresh materials to construct new additions when the number of family members increases or the need for extra space arises. The houses stand on high stilts mainly to avoid floodings, landslides and deter wildlife from penetrating indoors, but also to provide a cool and shaded open ground level where an important part of their social life is held. Its raised and orthogonal floor plan makes extending the house easier and assures superior performance against earthquakes. Besides, the danger due to collapse from recurring seismic activity is significantly lessened because of the lightweight materials used for structure, roofing, and cladding.

Steep and wide eaves divert the rainwater away from the walls and structure, thus ensure there is a quick drainage from the thatched roof. The pronounced eaves also protect the stairs and corridor that lead up to the house and so provide an ideal shaded area for receiving people. Internally, zoning is clearly marked with simple bamboo partitions that never reach the roof and allow for cross ventilation throughout the house. Eating and living are held in the main room, and from there the kitchen and bedrooms are accessed. Special consideration is given to the kitchen in many ways due to it being the only indoor source of heat and humidity (toilets are placed outdoors). It is bigger than other rooms since it also serves as a storing space and washing area; it has its own back door that leads to the garden and, most importantly, is located upwind from prominent air currents. Cooking is done in the traditional oven, so a bamboo lattice is set up in the upper part of the adjacent walls through which most of the smoke and warm air is readily evacuated. This strategy, together with the correct orientation of the house, prevents the smoke from spreading inside and causing discomfort or even fires.

Additionally, the use of organic materials improves internal comfort, ensures cross ventilation, and makes the most of natural illumination in a highly humid and hot environment. Guadua bamboo used in traditional housing has a lower density than other building materials, such as steel, brick, or concrete, as well as a relatively low thermal conductivity, effusivity and diffusivity. It is inherently a poor conductor of energy, and its high specific heat capacity means it keeps the house cooler than the outside environment. Moreover, bamboo's light colour and natural tendency to go white with age enhances its reflectivity and diminishes its heat absorption. Though windows and doors remain open, the main source of ventilation and lighting comes through the walls. Since bamboo is slit open to make flat panels, air naturally filters through its interstices and light breezes enter the house, buffering strong winds. Similarly, the slits in the walls create a pleasant display of shadows and light throughout the house, letting in adequate brightness while providing relief from the outside glare.

a) b) c) d) e)

Figure 2: Organic and local materials used in vernacular dwellings: a) bamboo panel or "caña picada"; b) quinche; c) coating of quinche on the inside of the bamboo panel; d) coated and uncoated walls; e) cade roofing

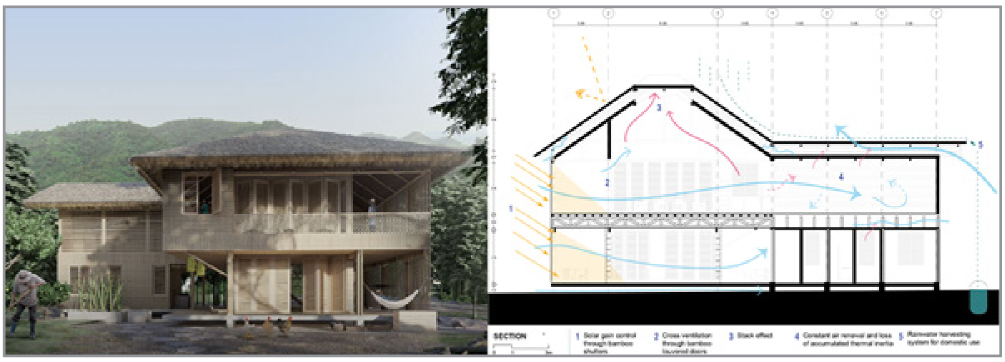
It is also quite common however, to find walls coated with quinche, an old traditional mixture of adobe, straw, clay, and donkey manure, adhered to the rough inside of the panels and set either facing outwards or inwards. Generally, bamboo panels are placed vertically to allow raindrops to fall against the smooth side and descend parallel to the fibres, hence preventing moisture and drizzle penetrating from the outside. When laid horizontally though, the coating of quinche adheres more easily to the inner side and absorbs in some degree the room's humidity. This ingenious strategy not only mitigates the effects of fire, but also forms a thermo-acoustic barrier, protects bamboo against insects, and provides solidity to the walls.

The bioclimatic design features described above are the general principles designed to promote indoor comfort in traditional coastal bamboo houses throughout Manabí. This holds true for Puerto López, a growing beach city located on the southwest end of the province and built over the land once occupied by some of the earliest pre-Columbian settlements of the region.

Designing a Bioclimatic Bamboo House in the Town of Puerto López

The personalised EPW file was imported into the Climate Consultant software, which placed annual hours on a psychrometric chart and displayed a set of general design guidelines aimed at making all hours comfortable (Fig.3). Adaptive ventilation and dehumidification stood out as the strategies with the greatest bearings. Likewise, the Mahoney bioclimatic analysis revealed that air movement is essential (H1) every month of the year to achieve optimal comfort levels in the highly thermal stressed days and nights. Since both tools also suggested numerous in-detail passive recommendations that resembled those found in bamboo houses, a list was done which included every recurrent and appropriate strategy for designing in such an environment: a north-south orientation, high form factor, modulation based on available bamboo sizes, design flexibility, semi open ground level, zoning of hot-humid spaces, correct positioning and size of openings, enhanced crossed ventilation and dehumidification with a raised ground floor, solar radiation control, natural illumination, thermal gain reduction and household waste recycling. Double roofing with a ventilated chamber was chosen as a bioclimatic strategy that combines the traditional cade thatching (external roof) with quinche (internal roof), on a bamboo structure.

The conclusions derived from the census statistics led to the architectural programme being oriented towards a single-family dwelling composed of four members and projected to grow in number. The layout, both on the ground floor and on the first floor, was established according to the lifestyle, needs and possibilities observed in the local population (Figure 3).



a) b)

Figure 3: House design proposal: a) view of the house in the local surroundings; b) bioclimatic features achieved with bamboo-based techniques.

The evaluation of the proposal began with the insertion of the climate file and the designation of the passive mode into the Design Builder software. The modelling of the house was carried out in accordance with the strategies proposed and included the construction specification of the materials (Table 1). Repeated hourly comfort simulations were run during the extreme summer (19-25 February) and winter week (31 July-6 September) to test the validity of the design in the worst-case scenarios and then make appropriate modifications. The hourly data from the annual comfort simulations was exported to an Excel spreadsheet where it was translated into a diagram for quick understanding. Other simulations were also run, such as daylighting rates under cloudy skies and specific graphical analysis (temperature of external and internal surfaces, air renewal and dynamic fluid calculations).

Table 1: Thermal Transmittance

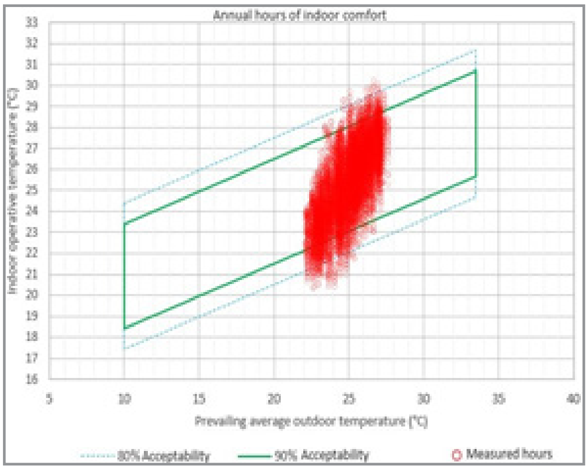
Component	Thickness (cm)	U value W/m2K
Cade external Roof	15	0.59
Roof substructure Bamboo beam Quinche		
Bamboo strip inner lining	10	2.56
	15	
	1.5	
Envelope		
Bamboo strip inner lining	1.5	
Quinche External bamboo panel Bamboo strip on stave	12	2.1
	1.5	
	1.5	
Second level flooring Bamboo Elite flooring finish Bamboo panel		
	1.5	4.55
	1.5	
First level flooring Bamboo Elite flooring finish Adhesive mortar		
	1.5	2.32
	2	
Concrete slab	18.5	

Assessing Results

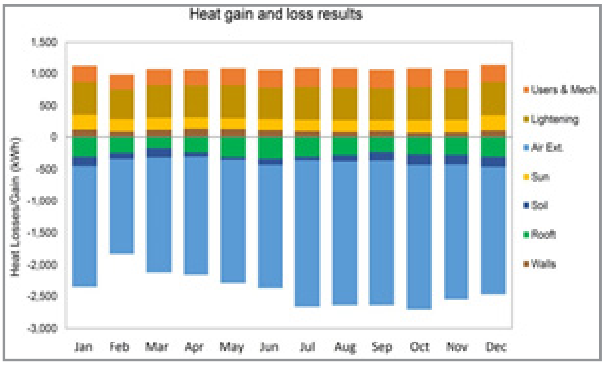
The bamboo construction technique revealed efficient applications for structure, envelope and cladding, which contributed to the overall performance of the house. Bamboo's potential to be associated with cade and quinche was highlighted and confirmed its ancestral construction tradition.

The proposed design for a single-family house in the city of Puerto Lopez showed very encouraging results that corroborated the validity of passive strategies derived from vernacular bamboo houses and bioclimatic analysis tools. Of the 8760 hours measured over the annual period, 89.4% were in the 90% range of acceptability and 98.4% within the 80% range of acceptability, according to the adaptive comfort model (Figure 4a). In other words, the house would be perceived as comfortable for most of the year, without resorting to mechanical air-conditioning and with few hours outside the acceptable range, which translates into significant energy saving and financial relief. The hours outside the comfort ranges occurred essentially during the winter period, with few hours in the summer. This is commendatory as the main challenge in a hot-humid climate is to lower the operative temperature sufficiently to reach a state of comfort. Moreover, during the extreme summer and winter periods the operative temperatures fluctuated within a comfortable range of 5°C, where variations are more easily assimilated by the users.

The cade roofing along with layered bamboo and quinche walls revealed a high specific heat capacity and increased the thermal mass of the building, which resulted in higher heat losses and lower radiant temperatures. There is evident heat dissipation through the internal roof, which amounts to -3272.8 kWh per year. This fact backs up the advantages of introducing a double roofing. Under normal conditions, the roof of a house stores heat and increases its radiant temperature by its daily exposure to solar radiation. In this case, the external cade roof, held by a bamboo substructure, generates a ventilated void of 0.5 m above the internal roof, casting a permanent shadow that reduces the temperature of the surrounding surfaces. Likewise, the walls composed of bamboo panels with an inside layer of quinche, 12 cm thick, contributed only 9.7% of all heat gains. In fact, the largest percentage of gains came from artificial lighting and from heat generated by users and appliances (Figure 4b). Solar gains accounted for only 18.5%, suggesting that the orientation on the east-west axis, the bamboo elements of protection and the high form factor of the dwelling enhanced the benefits of cool shade. Of all the heat that the dwelling encounters from internal and external sources, only 31% contributes to the perceived heat gain indoors. The negative effect of increased night-time temperatures due to thermal inertia was reduced by cross ventilation and constant air renewal, which reached an annual average of 151.8 ren/h and a minimum stagnant time of 0.16 seconds before being evacuated. Natural illumination was widespread through the house and every space enjoyed high levels of natural lighting even under cloudy sky conditions.



a)



b)

Figure 4: a) Annual comfort hours; b) Annual heat gains

Conclusions

Mirroring the global phenomenon, the last decades have unfortunately witnessed a rapid devaluation of the identity of traditional houses. The novelty of the market for industrialised materials, together with the deteriorated image of bamboo, has had a negative impact on the natural environment of the Ecuadorian coast and its inhabitants.

The traditional building culture in coastal Manabi is rooted in local and accessible usage, where endemic species provide the key raw material for vernacular builders. From all the materials used in the past, bamboo stands out for its versatility and the sustainable character it conveys to housing.

The social prejudices that discredit bamboo houses are based on a misguided notion of wealth and status, which downgrades organic materials in favour of industrialised ones. With the proper knowledge of bamboo, coupled with good harvesting and construction standards, it becomes possible to elevate its virtues and present it as one of the most sustainable materials.

The housing design proposal confirmed the value of bamboo by attaining outstanding results in its annual performance. Despite the hot humid environment and lack of active systems, indoor conditions remained comfortable over 98% of the year with ±2.5°C fluctuations during extreme summer and winter periods.

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