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SUSTAINABLE ARCHITECTURE APPLIED TO THE DESIGN OF THE HOUSING CORE

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This article presents the results of research focused on the design of core housing as a product, process, and continuous transformation system, achieved through a unified space, as a recurring solution since the origins of humankind and an alternative for small spaces. The proposal for affordable housing in Cuenca for low-income populations is based on an approach that involves not only the housing solution but also the relationship with people's ways of living, bioclimatic criteria, and the study of a sustainable construction system. Qualitative research methodologies and transdisciplinary workshops were used to create spaces for discussion and verification with the participation of various stakeholders. Therefore, the research work integrated people's ways of living, the use of local materials, and indoor comfort conditions. After tabulating the gathered data, the design of the core housing was carried out, enabling the design to accommodate the ways people live, rather than the other way around. Ultimately, enabling appropriation according to specific needs of diverse family compositions, in addition to a sustainable construction system as an ecological and economical solution.

Keywords: Bioclimatic criteria, Comfort, Sustainable construction system, Local material.

1 INTRODUCTION

Commonly, terms such as environment, context, habitat, and place are mentioned when discussing the space where human beings live, but there is often a lack of deep reflection on the needs of users seeking affordable housing through mass construction today is not only due to economic limitations but also to the lack of reflection and absence of participatory design involving the user. This should consider the emotional and affective connections that link people to their place of habitation and consider aspects of constructive and environmental sustainability. In the case of Cuenca, the focus is on vernacular techniques with applicable characteristics of semi-industrialized systems, giving priority to the initial capital investment over operational and maintenance cost. In general terms, sustainable architecture is based on the optimization of resources, the reduction of energy consumption, the use of alternative energy sources, the decrease of waste, emissions, and building costs, as well as the maintenance, operation, and usage expenses, while increasing the quality of life for occupants. It involves aligning our construction values with the principles of sustainability, prioritizing the initial capital investment over operating and maintenance costs, and thereby extending the lifespan of a building (Plúa Molina 2012).

Furthermore, it entails a shift away from conventional systems; this does not mean going back to the past but rather entails producing and examining the project from social, economic, and environmental perspectives. These concepts establish three important areas: the environment, the material, and the construction system, which are interconnected and, together with applicable tools, seek to achieve lower energy consumption and improved user quality of life, constituting sustainable architecture and construction.

The "Design Guide for Energy Efficiency in Social Housing in Chile" describes that the user's quality of life and environmentally friendly development of housing are achieved through energy efficiency, considering the economic aspect due to the user's vulnerability. A key point is the selection of appropriate materials, which implies a 20% energy savings. Regarding the life cycle, sustainable construction should be characterized by a balance between the manufacturing of materials, the use of natural resources, and their consumption during construction.

"An optimal strategy to minimize environmental impact is to use solutions that reduce the effects that materials produce on the environment, meaning the energy consumption in their production and installation, the waste they generate during manufacturing and installation, and the direct and indirect pollution they produce" (ADARVE 2023). Therefore, it can be stated that an important aspect for material selection is the life cycle analysis to understand their environmental impact.

After having understood the principles of sustainable development, it was necessary to put them into practice by transforming them into construction methods. For this purpose, the study analyzed the most commonly used construction systems and materials in housing construction in the city of Cuenca. The goal was to evaluate and determine which one would be selected for the project's implementation, one that would respond to the efficient management of natural resources. Since the project was aimed at people with low economic resources, it was essential to analyze the relationship between the housing and its inhabitants, understanding which materials and construction system they are familiar with.

The proposal was to develop a new alternative applied to affordable housing with local materials, which would also have a positive impact on the local economy and employment rates.

2 MATERIALS USED IN BUILDING CONSTRUCTION PROJECTS IN CUENCA

In the study, it was necessary to identify the most commonly used materials in Cuenca and its expansion areas, as these were the ones currently available in the market.

Table 1. Total number of private households with occupants by type of flooring, wall, and roofing material.

Most commonly used materials in Cuenca				
FLOOR	**Hardwood, parquet, plank, or floating floor**	**Ceramic, tile, vinyl, or marble**	**Untreated wood plank**	**Brick or cement**
	39,14%	36,12%	12,08%	10,84%
	Soil	**Other materials**	**Cane**	
	1,26%	0,55%	0,01%	
WALL	**Brick or block**	**Adobe or rammed earth**	**Concrete**	**Wood**
	84,72%	8,93%	8,93%	1,55%
	Coated cane	**Other materials**	**Uncoated cane**	
	0,22%	0,13%	0,02%	
ROOF	**Asbestos**	**Roof tile**	**Concrete (slab, cement)**	**Brick or cement**
	39,14%	36,12%	12,08%	10,84%
	Zinc	**Other materials**	**Palm, straw, or leaf**	
	1,26%	0,55%	0,01%	

The results were based on information obtained from INEC (National Institute of Statistics and Census) (2010), corresponding to the latest census in 2010. Table 1 presents the materials obtained for floors, walls, and roofs.

It is worth mentioning that, according to the Ecuadorian construction norm NEC-11 (Chapter 13), for energy efficiency in construction, architectural requirements state that 20% of the materials used must meet the following parameters: Use of recycled materials, use of local materials, modular in nature, high-tech materials, low toxicity materials, and renewable natural materials (MIDUVI 2011).

3 CONSTRUCTION SYSTEM - SOCIAL HOUSING PROGRAMS IN CUENCA

Housing projects that have been carried out in Cuenca were selected, where the construction system and materials used in the buildings are always conventional. According to the current regulations of MIDUVI (Ministry of Urban Development and Housing), as stated in Ministerial Agreement No. 0013, Article 12: "In the case of single-family homes, the construction system must guarantee possibilities for expansion. The promoter may offer any structural system as long as it complies with construction and earthquake resistance standards.".

However, the main problem with the typologies designed by MIDUVI, with minimum modules of $36m^2$, is that they do not allow for growth or expansion due to the type of structure and materials used.

In this stage, materials have been considered with a focus on life cycle analysis, where the main pollution phases are manufacturing and transportation. In this particular case, these phases were analyzed for the housing projects of MIDUVI in order to establish the amount of CO_2 emissions generated by the most commonly used construction materials (Table 2). Therefore, for the project's design, the goal was to minimize the number of emissions generated by the materials that will be used.

Table 2. The emissions (CO_2) generated by the materials in the MIDUVI housing.

CO_2 Emissions ($36m^2$)			
Materials	**Manufacturing**	**Transportation**	
STONE MATERIALS	0,14 tons CO_2	**Jubones river/Santa Isabel (75,2 km)** 0,237 tons CO_2	**Río Paute river /Paute (27 km)** 0,085 tons CO_2
CONCRETE	3,81 ton CO_2	**Holcim/Guayaquil (212 km)** 0,082 ton CO_2	**Guapán/Azogues (61,9 km)** 0,024 tons CO_2
STEEL	0,99 ton CO_2	**Adelca/Alóag** 8,93%	**Andec/Guayaquil** 8,93%
LARGE BRICK	4,22 tons CO_2	**Susudel (88,3 km)** 0,061 tons CO_2	**Cuenca (0 km)** 8,93%
WOOD	0,14 tons CO_2	**Sevilla – Morona Santiago(342 km)** 0,022 tons CO_2	**Cuenca (0 km)**

Based on this, materials have been recommended for each construction element, and as an example, natural materials like earth and wood were mentioned. These materials do not require any or minimal processing.

4 PROPOSAL FOR CUENCA – SUSTAINABLE CONSTRUCTION SYSTEM

In general, it was determined to follow certain sustainable criteria for the proposed construction system to encourage standardization and semi-industrialization, dry assembly, the use of local materials, preservation of traditional techniques, waste reduction, and flexibility in the unit space.

The construction system for housing design in Cuenca was selected, considering foundations, horizontal and vertical enclosures. Based on this, materials have been recommended for each construction element, and as an example, natural materials like earth and wood were mentioned. These materials do not require any or minimal processing.

4.1 Foundation (Natural Stone Foundation)

As part of the sustainability criteria established previously, it has been decided to use lime mortar, which offers great plasticity, strength, and ease of application. Moreover, it is much more flexible and less prone to cracking compared to cement-based mortars. The mortar mix consisted of: lime + clean sand + water (to achieve a workable mass). As the foundation base, a compacted layer of sand was provided, and the minimum depth of the foundation was 60 cm.

4.2 Horizontal Enclosures (Floors) (Dry Prefabricated Flooring)

These are dry, prefabricated, and lightweight floorings that transmit loads unidirectionally. They are composed of pine boards and OSB structural panels, which close the structure using self-drilling screws and adhesive cords. Thermal and acoustic insulation properties are achieved through the simple structure, which can be further enhanced with the use of multiple layers. The flooring can support an additional load of 407 kg/m^2, still within the limits of elasticity. These floorings are designed in a way that generates minimal waste due to their modularity.

4.3 Vertical Enclosures (Modular and Prefabricated Bahareque Panel)

This panel preserves traditional construction techniques, utilizing local, recycled, recyclable, reusable, and biodegradable materials. These panels contribute to environmental conservation by reducing CO_2 emissions by 80% and offer new opportunities for low-income individuals to obtain decent housing.

Wet Areas: The same panel is chosen for the shower area, composed of a wooden frame covered with glass, acting as a blind window. On one side, the clay wall is visible, and on the other side, it is covered with waterproofing and glass. The wood used in the panel is radiata pine, sourced from planted forests that do not contribute to deforestation issues. Two wooden planks of 10x240cm are used, joined by wooden dowels or transverse firebreaks (8mm pegs), with box and spline joints, avoiding nails and facilitating assembly by unskilled labor. Earth is used for coating, thanks to its characteristics and ease of obtaining. The panel utilizes cabuya (fiber extracted from the sisal agave), used to prevent disintegration and cracking during the drying process, instead of straw, which is scarce and only found in the highlands.

4.4 Horizontal Enclosures (Roof)

After analyzing local materials for roofing in Cuenca, it was determined that curved tiles would be used, requiring a minimum slope of 30% for the roof. To improve comfort conditions inside the house and address the thermal oscillations in our city, the choice fell on a dry prefabricated flooring system. On top of this, wooden strips and the curved tiles will be placed. This system simplifies the construction process, enhances thermal insulation, and lightens the roof (Figure 1).

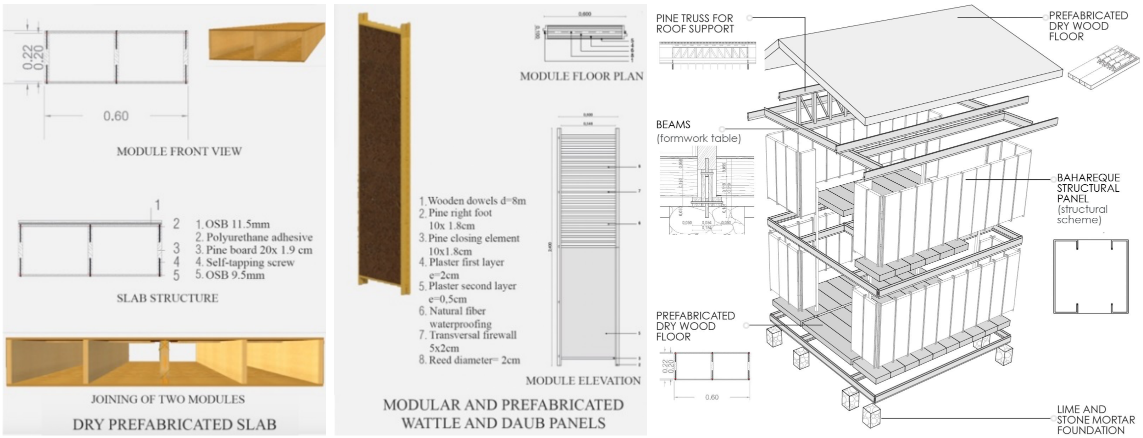

Figure 1. Construction system and structural schemed.

5 CONCLUSIONS AND RECOMMENDATIONS

During a process of learning and research on government responses to the housing deficit, the lack of progress in the search for solutions and the scarce innovation in construction systems that are both economical and sustainable over several years was alarming.

The fundamental premise focuses on creating a system built from environmentally friendly materials, either because of their low energy impact or their reduced emission of pollutants during production and transportation, also incorporating applicable aspects of industrialized systems. This philosophy is based on two essential pillars: transport of materials and materials manufacturing process.

Thus, it is concluded that in the specific context of Cuenca, when designing a house that meets sustainability criteria, it should use materials with low environmental impact, not represent a risk to human health and the environment, and be compatible with sustainable strategies, considering the following aspects:

- **Foundations:** Surface foundations, such as isolated and spread footings, were evaluated based on the prevailing soil in the city. The need to resist not only horizontal stresses (such as wind and earthquakes) but also compressive, shear and tensile stresses was emphasized. The findings indicate that point foundations are more economical due to a significant reduction in material waste. In addition, the use of stone and mortar based on earth, lime and gravel were analyzed and proposed as viable alternatives.
- **Horizontal Enclosures (Floors):** For floors, the need was identified for a material that not only meets strength and durability criteria, but also presents a low environmental impact. As a main recommendation, it is suggested the use of prefabricated wood systems that offer thermal and acoustic insulation characteristics, thus forming a lightweight and sustainable system.
- **Vertical Enclosures:** The research showed that vertical enclosures should be economical, modular and versatile, without requiring specialized labor, being able to resist earthquakes and reduce costs. The use of prefabricated wattle and daub systems is proposed, facilitating

their assembly, reducing energy costs during use and promoting sustainability through family or community construction.

- **Horizontal Enclosures (Roof)**: Regarding the roof, it is important to insulation and capture by means of the roof roofing. A pitched roof with tile covering is recommended, highlighting its low environmental impact compared to other materials. In addition, traditional techniques associated with vernacular housing are rescued to improve waterproofing, fire and wind resistance, and to promote its ecological and recyclable character.

Future recommendations emphasize the importance of researching and innovating in alternative and sustainable construction systems that maximize the qualities of local materials. It is essential to consider the design of roofing systems that not only address internal environmental aspects of the building, but also ensure environmentally friendly manufacturing processes, thus maintaining a balance between architectural functionality and respect for the environment.

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