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Sustainable Construction as Getting Dressed of Place: Two Experiences in the Tropics

La construcción sostenible como vestirse de lugar: dos experiencias en el trópico

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ABSTRACT

This article addresses the environmental impact of building materials resulting from construction and demolition waste and debris. It presents the potential of material resurrection through recycling and reuse, which enable the production of optimally performing and affordable building supplies. In addition to the production of materials with a lower CO2 footprint, such practices allow for the integral management of sustainable construction processes that optimize resources and minimize the waste of energy, water and material inputs such as prefabricated structures or concrete. The study aims to apply research results to present the concept of sustainable construction and architecture as "getting dressed of place", i.e. recognizing contextual variables to determine the aesthetic and technical guidelines that must be considered for the materialization of a project. It also shows how contextualized design of buildings can promote comfort and efficiency through bioclimatic strategies, as well as how the people involved in building activities must have decent working conditions, which includes everything from formal hiring to the provision of protection and industrial safety elements, an often neglected precaution in Latin American countries. Finally, relevant reflections are considered throughout the article, including the thoughtful use of water, the promotion of rainwater harvesting systems in buildings, and the understanding of sustainable construction activities as holistic issues, which recognize the integrality of the trade.

Keywords

context; contextualized design; housing; materials; sustainable construction

RESUMEN

El presente artículo aborda el tópico de los materiales y su impacto al generar escombros y otros residuos de construcción y demolición, pero también expone el potencial de resurrección matérica que les corresponde a través del reciclaje y la reutilización, confeccionando elementos de óptimo desempeño y costo asequible. A la producción de materiales con menores huellas de CO2 se suma la gestión integral mediante procesos constructivos sostenibles, que optimizan los recursos y minimizan los desperdicios de energía, agua e insumos tales como prefabricados y materiales como el concreto. Es una investigación aplicada que muestra el concepto de la construcción y la arquitectura sostenibles como aquello que se "viste de lugar", es decir, que reconoce las variables del contexto para determinar los lineamientos estéticos y técnicos que se tendrán en cuenta para la materialización de un proyecto. Así mismo, muestra cómo desde el diseño contextualizado una edificación puede propiciar confort y eficiencia mediante estrategias bioclimáticas. También se muestra cómo las personas involucradas en la actividad edificadora deben tener condiciones dignas de trabajo, lo que incluye desde una contratación formal hasta la disposición de elementos de protección y seguridad industrial, que en países latinoamericanos suele ser un aspecto descuidado. Por último, la reflexión también abarca un uso reflexivo del agua, propiciando sistemas de aprovechamiento de aguas lluvia en edificaciones. Una actividad constructora sostenible es un asunto holístico, que reconoce la integralidad.

Palabras clave

construcción sostenible; contexto; diseño contextualizado; materiales; vivienda.

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INTRODUCTION

A growing debate has recently arisen in architectural research regarding the negative environmental impact caused by the construction of buildings and civil infrastructure, as these degrade territories due to the extraction of non-renewable materials through open-pit mining and the final disposal of waste generated by construction and demolition processes, known as Construction and Demolition Waste (CDW), which includes debris (Acosta, 2009). For example, more than seven thousand tons of CDW are generated daily in Medellín and its metropolitan area, and twenty thousand in Bogotá, three times more than the ordinary solid waste taken to sanitary landfills (AMVA, 2024).

In his book *Qué significa construir: claves conceptuales sobre la ingeniería civil* (What It Means to Build: Conceptual Keys to Civil Engineering), Miguel Aguiló outlines the functional and cultural reasons for constructing bridges, roads, or buildings (2013), raising questions such as why a country like Spain has more than twenty international airports while Germany, by far Europe's dominant economic power, has far fewer (even though Germany nearly doubles Spain's population). This invites reflection on the environmental, economic, and social pertinence of the scale at which we build (Rahim et al., 2023), considering that the global population has grown from 2.5 billion to 8 billion people in the last fifty years (Fernández, 2023). This increase implies greater demand for food, energy, water, and construction materials for housing, which in turn generates more emissions into the atmosphere, more discharges into water bodies, and more waste on the Earth's surface. Furthermore, the world's prevailing economic model is based on the linear consumption of resources and the disposal of products that, while still physically and functionally viable, become waste due to planned and perceived obsolescence.

Thus, while housing provides shelter and a sense of belonging, it carries a dramatic ecological footprint due to the embodied energy in its materials—from the extraction of raw materials, mostly through open-pit mining, to the manufacturing of components for columns, slabs, beams, walls, doors, and windows. These processes require the transformation of minerals at high temperatures, involving fossil fuel consumption and CO_2 emissions into the atmosphere. For example, producing one ton of cement emits an average of one ton of CO_2 (Pedroza Pallares & Arenas Páez, 2019). In Colombia alone, approximately thirteen million tons of cement are produced and sold annually. Additionally, the environmental impact of buildings can be even more critical during their lifespan if they are not designed in harmony with contextual variables to create energy-efficient spaces, such as solar radiation, winds, rainfall, and relative humidity (Stagno, 2006). This can reduce expenses for residents by lowering utility costs, positively impacting household sustainability.

So, is the alternative to stop building? Perhaps this is a fundamentalist principle since the thinking biped species continues to grow and demand materiality. Is there another way to build? Yes. Construction can become a reciprocal exercise between society and nature. Examples of such an articulation can already be seen in academia, neighborhoods, country homes, and parks. If construction and engineering can "do it all", they should acknowledge that it is time to move beyond quantifying the cosmetics of works to rescuing the poetics of the built environment.

METHODOLOGY

The casuistic method was chosen for this study, focusing on two design and construction cases in different climatic zones: one in a temperate climate and another in a cool climate. However, this method does not disregard theoretical principles (philosophical and cultural); on the contrary, it relies on what has already been built under sustainability premises to foster discussions around reflective construction and infrastructure practices. Before presenting each case, a contextualization rooted in utopia is provided, as a scenario to strive towards through comprehensive professional performance. Materials, water, energy, and comfort are variables addressed transversally, connecting functionality and the optimal technical and economic performance of the analyzed spaces, which include:

- An urban hotel (Medellín)
- A countryside home (Eastern Antioquia)

In both cases, the goal was the same: ecological sustainability and project viability. However, the design and materialization premises differed in response to the conditions of the context (Mustika et al., 2025).

RESULTS

Utopia: Language and "Idiom"

Language is music, and Argentina responds to it with the tango, Mexico with the corrido, Colombia with the cumbia, and Spain with Flamenco. Similarly, sustainability is the language, and its indicators must reflect the context. Oral and written language evolves into distinct idioms, with guttural tones influenced by relative humidity, altitude above sea level, and air currents specific to each site. In the same way, sustainable construction is a complex matter that "dresses itself in place". It serves as the language, while the strategies to achieve a sustainable built environment are its idioms, each pertinent to its specific site, though sometimes reflecting universal tendencies when socio-cultural appropriation recognizes their adaptability.

Colombia boasts construction methods recognized worldwide for their technical and environmental relevance. One notable example is the CINVA-RAM (Figure 1), a simple yet remarkable tool that allows residual soil and debris to be reclaimed from neglect and transformed into materials with excellent performance, affordable costs, and cultural significance (Peña Rodriguez, 2008). This tool produces soil-cement blocks (SCB), both solid and perforated, suitable for partially confined structures with reinforced concrete beams and columns. These elements integrate seamlessly into modern construction systems, maintaining seismic resistance and aesthetic durability, allowing interaction with consolidated materials like concrete, steel, and glass (Vásquez et al., 2015).

Figure 1. CINVA-RAM

Source: Bedoya, C. (2024).

Concrete, the most widely produced material globally and the second most consumed after water (Sakai & Naguchi, 2012), can be manufactured by substituting almost 100% of its non-renewable components with recycled materials, meeting national technical standards and current seismic resistance codes (Bedoya & Dzul, 2015). An example of this is Building 19a at the Universidad Nacional de Colombia, Medellín campus (Figure 2).

Figure 2. Block 19a in the Universidad Nacional de Colombia Campus Medellín; recycled concrete block walls

Source: Bedoya, C. (2024).

In crafting eco-materials such as soil-cement blocks and recycled concrete, we find a significant part of the answer to Colombia's and Latin America's housing deficit. Sustainable Social and Priority Housing (SSPH) has been a developing initiative since 2006 (Bedoya, 2011). Implementing recycling plants for debris and residual soil recovery can enable dignified and sustainable housing projects (Figure 3).

Figure 3. Soil-cement blocks manufactured using the CINVA-RAM

Source: Bedoya, C. (2024).

This requires rethinking how buildings are designed and constructed, shifting the paradigm from extraction and final disposal to Reverse Mining—a fair practice where all involved stakeholders benefit equitably. Additionally, projects should routinely incorporate solar energy for climate control and water heating, as well as rainwater harvesting systems (Aguilar, 2024).

Recycled materials not only comply with quality and seismic resistance standards but also offer costs comparable to or lower than conventional materials. They contribute to urban and rural ecosystems by reducing the environmental liabilities generated by open-pit mining and waste disposal. In other words, sustainable construction, which views waste as a new material through Inverse Mining, can foster solidarity-based economic models in which the State, constructors, and communities collaborate to create built urban environments that elevate the human spirit (Girardet, 2001) and foster a more humble and, therefore, perhaps more effective relationship with Nature to achieve the biological and social goal of preserving the species.

Figure 4. Housing built with SCB, guadua, wattle and daub and reinforced concrete

Source: Bedoya, C. (2024).

Figure 4 shows a house designed and built in Antioquia by architects Gloria Isabel Correa and Jorge Andrés Moreno, following sustainability principles from the design phase. This house integrates various materials and construction systems, utilizes thermal and photovoltaic solar energy, achieves comfort through bioclimatic strategies, and harvests rainwater for non-potable uses, which account for approximately 55% of total water consumption (Cano Restrepo, 2016).

The climate tells a story

To illustrate this aspect, an analogy can be used: humans choose their clothing according to the location they will be in. For instance, someone invited to spend a few days in Bogotá, Colombia, should at the very least understand the conditions they will encounter to choose the right attire. It's important to know that this Colombian city is located at 2600 meters above sea level in an area prone to rain. Additionally, being situated in the tropics and in an equatorial country, its climate is determined by altitude rather than seasons. Thus, its temperatures are cool during the day, cold at night, and almost freezing at dawn, with occasional morning frosts. Clothing must align with Bogotá's contextual variables: medium to heavy fabrics, sweaters or jackets, and synthetic or leather shoes to resist water from the frequent drizzles or breezes. An umbrella or raincoat should also be included, depending on whether sun or rain is more dominant. Upon returning to a residence at a lower altitude of around 1500 meters above sea level, lighter clothing, preferably cotton, would be more appropriate. Unlike in Bogotá, footwear could consist of breathable mesh to cool the feet and regulate body temperature.

Close to the city of Medellín is an area known as "Eastern Antioquia", situated at 2300 meters above sea level, while Medellín's valley area lies at 1450 meters above sea level. In just 30 minutes, one can ascend or descend 800 meters. A similar phenomenon occurs in southern Mexico, where one can climb from 600 meters above sea level in Tuxtla Gutiérrez to 2100 meters in San Cristóbal de las Casas in just a few minutes. Despite the minor differences in altitude, the situations are quite comparable in terms of thermal zones and travel time. Both cases are located along the tropical belt, where climate is determined more by altitude than by seasons or periods of the year.

Figure 5. Medellín and eastern Antioquia

Source: authors' comments on google maps.

Figure 6. Map of Tuxtla Gutiérrez and San Cristóbal de las Casas

Source: authors' comments on google maps.

Dressing or Designing for Heat: Terra Biohotel

First and foremost, regardless of the climate, it's important to recognize that there are variables over which we have no control. One of these is the sun, or the energy radiated from this star. Keeping this in mind, the Terra Biohotel project, located in Medellín at 1450 meters above sea level, has two of its façades facing west, which means they receive solar radiation for most of the day, accumulating heat on their walls. Traditionally, air conditioning systems are used to combat rising temperatures rising to uncomfortable levels, along with blackout curtains or screens to block sunlight from entering rooms and heating surfaces such as floors, walls, and furniture in indoor spaces like rooms, lounges, and offices.

This was the approach of the initial design. However, the project developers sought sustainability consultancy to explore the feasibility of implementing strategies to minimize energy and water consumption in the building. The consultancy team proposed expanding the report to include a preliminary review of the project in terms of design, execution, and logistics, which yielded positive responses. This review revealed several key issues:

- A design that did not align with the site's conditions: glass façades for a warm-temperate climate.
- Demolition and construction processes lacking reuse or recycling initiatives.
- Unsafe working conditions for personnel.

Below are some images illustrating these factors, which unfortunately are normalized in Latin American countries but should not be allowed to endure.

Figure 7. Unsafe and unsightly enclosure.

Source: Pineda, E. (2024).

Figure 8. Inadequate disposal of CDW at the construction site.

Source: Pineda, E. (2024).

Figure 9. Workers without occupational health and safety conditions.

Source: Pineda, E. (2024).

Once these conditions were presented, it was decided that sustainability should not only focus on economic aspects but also environmental and social dimensions. The contractor and their team were offered training and required to meet Colombian labor regulations. However, no agreement was reached due to cultural clashes. As a result, a different construction company was hired that could meet construction and labor demands and was open to training with consultants and advisors throughout the execution of the project.

Figure 10. New temporary site enclosure.

Source: Bedoya, C. (2024).

Figure 11. Compliance with safety and occupational health conditions.

Source: Bedoya, C. (2024).

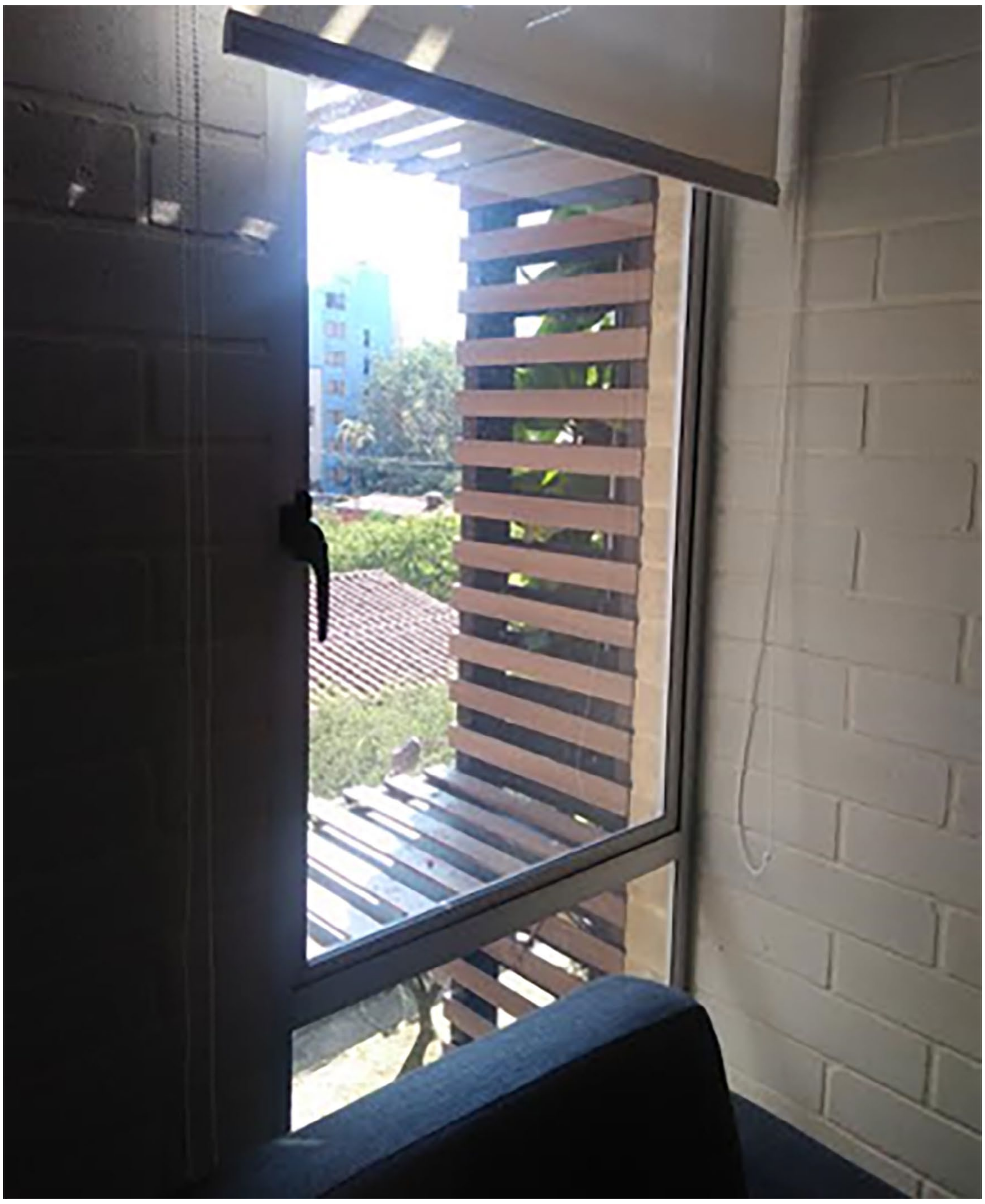
After establishing these improved working conditions, the building was architecturally redesigned, retaining its eleven superstructure levels and a basement for parking, technical rooms, and waste management. The glass façades were replaced with alternative materials to minimize direct solar radiation while allowing diffuse light, thereby utilizing natural daylight without overheating the interior surfaces of floors, walls, furniture, and equipment. The new design incorporated wooden louvers mixed with polymer, direct ventilation and lighting for rooms and bathrooms, and vertical gardens in humid areas. These strategies are shown below.

Figure 12. Façade with sunbreaks and landscaped walls.

Source: Bedoya, C. (2024).

Figure 12 demonstrates a passive strategy to minimize direct solar radiation (Arango et al., 2019). These louvers eliminate the need for blackout curtains in hotel rooms, allowing clear views from the inside out, as evidenced below.

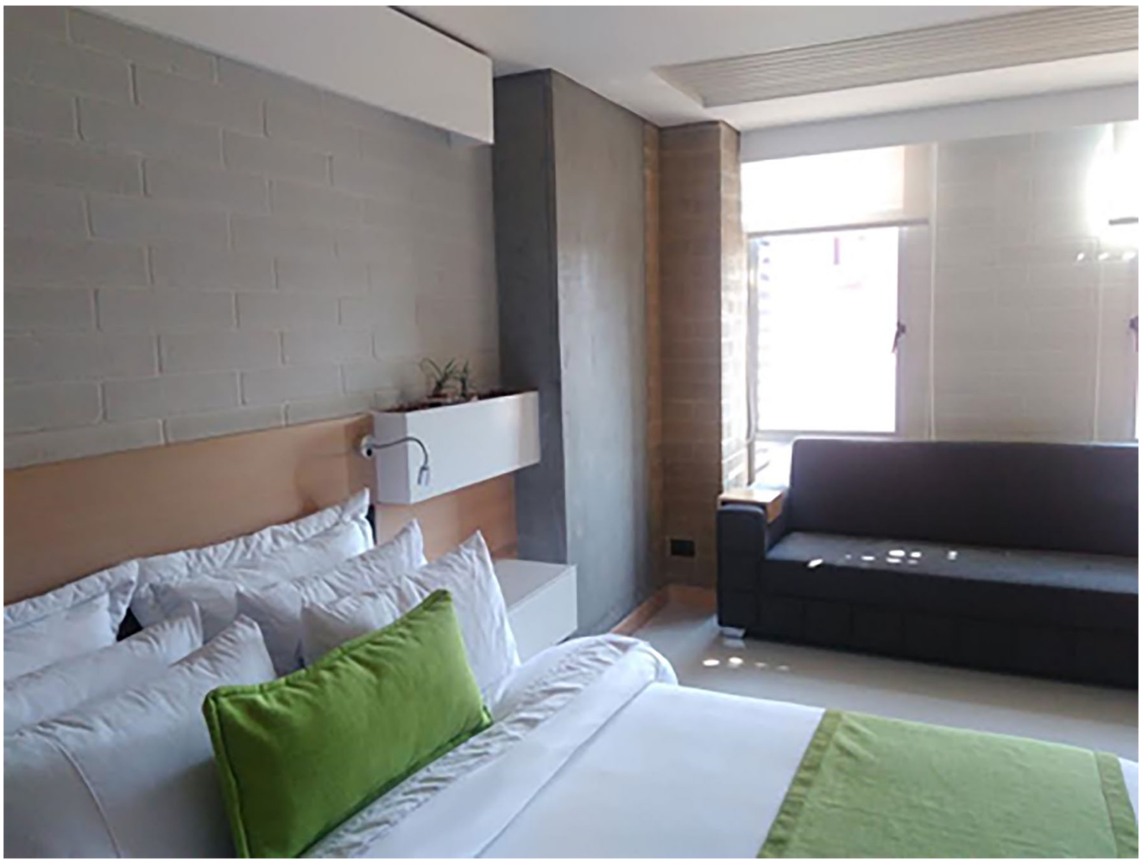
Figure 13. Façade sunshades for diffused light.



Source: Bedoya, C. (2024).

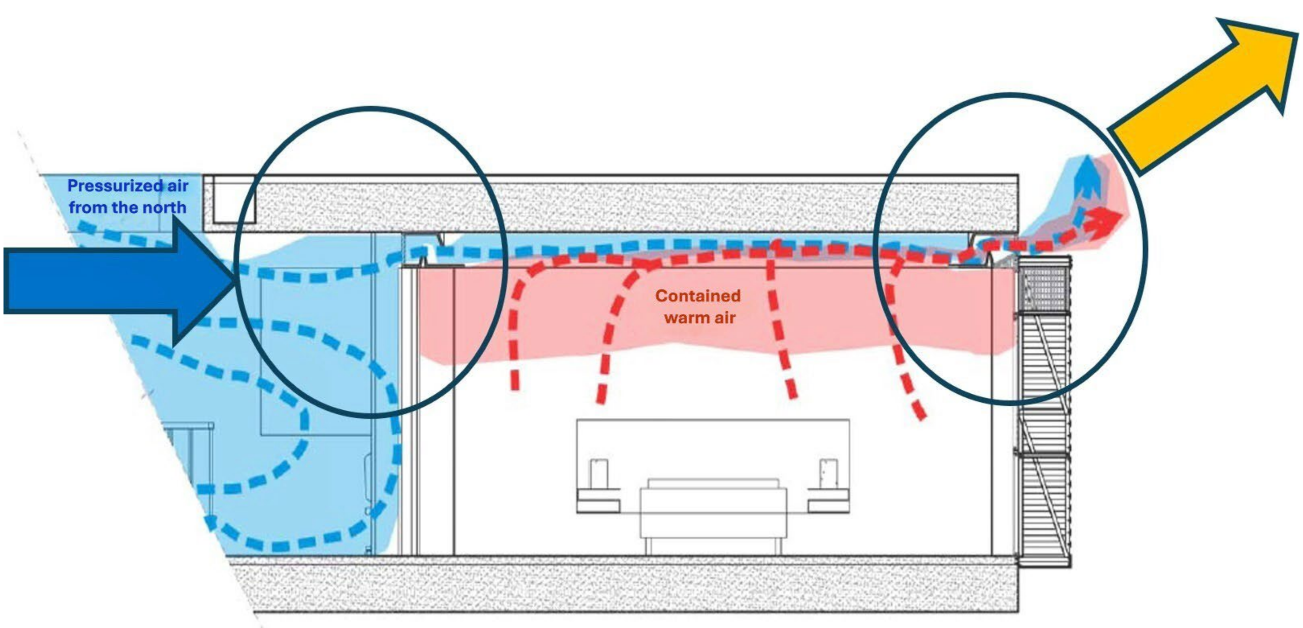
By implementing these passive design strategies, the interior maintained a comfortable temperature range for Medellín, between 22°C and 25°C (Soto-Estrada et al., 2019). This prevented the need for air conditioning systems, resulting in significant savings in operational costs throughout the building's lifecycle.

Figure 14. Solar controlled room with natural ventilation.



Source: Bedoya, C. (2024).

Figure 15. Section: Air flow in room.



Source: Isaza, J.; Arenas, C.; Bedoya, C. (2024), Figures 13, 14 and 15 summarize the implementation of premises designed for the tropical context of the project. The sunshade devices installed on the façade were particularly well received, having blocked the entry of direct radiation while keeping the view from the interior unobstructed, thus allowing a permanent connection with the exterior environment. Figure 14 shows that on the surface of the false ceiling there is a grille that, although it looks like a decorative element, it purposefully connects the interior environment with the exterior of the room, allowing the contained air, which has increased temperatures and generates hot and uncomfortable living conditions, to flow towards that carefully designed weak point to be exchanged with cooler interior air coming from the hotel's patio (See Figure 16).

Figure 16. Courtyard for fresh air renewal.

Source: Bedoya, C. (2024).

These architectural decisions, dressed of place, make more sense for the builder given that he is also the hotel's manager and must ensure its usufruct.

Dressing or Designing for Cold: Refugio Nasua

This case involves a house located in a semi-rural area in Eastern Antioquia, at an altitude of 2300 meters above sea level. The region enjoys a pleasant, cool climate, although nighttime temperatures can drop below 16°C and reach as low as 14°C in the mornings. In the Antioquian context, this is considered a cold climate. Unlike the previous case, the architectural design here seeks to allow solar rays to penetrate the façades and, where appropriate, the roof. Rather than aiming for maximum shading of walls and floors, the goal is to allow direct radiation to enter the spaces and heat wall surfaces and other radiant elements.

The design included façades with a balance between glass and opaque surface, such as glazed doors and windows, as well as a Trombe wall to store heat during the day and release it into the interior at night (Sacht et al., 2013). This wall was built with soil-cement blocks and clad in black slate stone, ensuring an aesthetic harmony with the site while achieving optimal bioclimatic performance.

Figure 17. Trombe Wall.

Source: Bedoya, C. (2024).

As shown above, the wall, initially built with soil-cement blocks (SCB), is clad in dark slate stone to absorb the sun's rays from the west and gain heat. The glass chamber creates a greenhouse effect designed to retain heat stored by the dark material. Instead of quickly transferring this heat to the surrounding air, the system gradually releases it into the interior through convection. For this purpose, vents are placed at the bottom and top of the wall, allowing heat transfer from the wall to the air. This convection process uses the air's lower density to circulate warm air into the interior space (Borbón et al., 2010).

Figure 18. Room orifices receiving warm air through Trombe wall.

Source: Bedoya, C. (2024).

In addition to achieving thermal comfort through passive strategies, the project's material properties included combinations of reinforced concrete for seismic-resistant structural confinement with soil-cement blocks made from residual soil sourced on-site. The reuse of this construction and demolition waste (CDW) reached 100%, as the residual material was repurposed as high-performing building material, avoiding its disposal in landfills (Bedoya, 2015). Over 3000 ceramic or concrete blocks were replaced by those made on-site, eliminating the need for energy-intensive kiln firing.

Figure 19. SCB made on site.

Source: Cano, E. (2024).

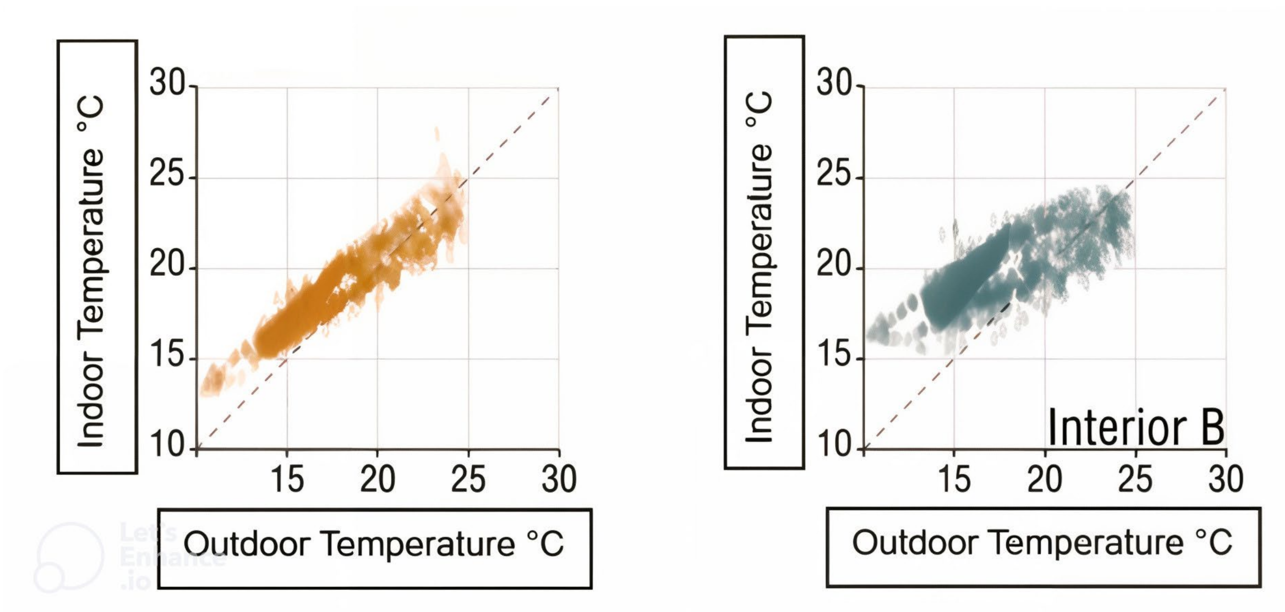
Figure 20. SCB and reinforced concrete beams.

Source: Cano, E. (2024).

The house, named *Refugio Nasua* by its owner, integrates harmoniously with its surroundings. Its materials are visually non-intrusive to the surrounding landscape, and the open façades regulate internal temperatures. The roof is also used not only as a protective structure against the elements, but also as an intermediary between the solar lighting and the bathrooms.

The exterior and interior temperature measurements have shown an optimal performance of the living comfort of this house, since while outside the temperature sometimes exceeds the comfort line of the area, inside it is cooler, and also, when outside the temperature drops to the point of feeling cold, inside it remains a few degrees higher.

Figure 21. Indoor and outdoor temperature between 11:00 a.m. and 3:00 p.m.

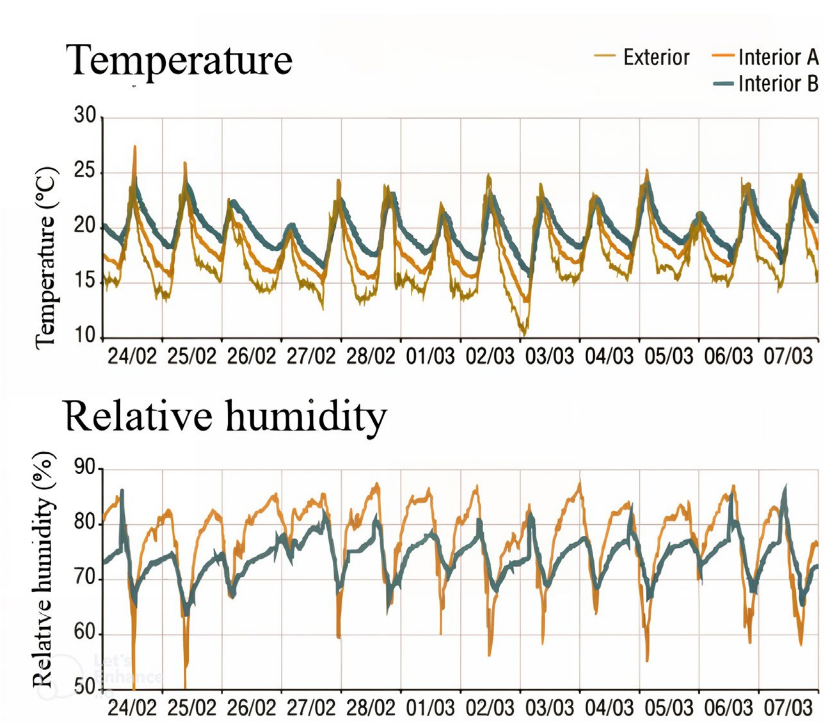


Source: Zuluaga, V.; Bedoya, C.; Mejía, C. (2024).

Figure 21 shows the correlation between the premises of design and construction of the house, with the behavior of temperature and relative humidity both outdoors and indoors, showing a more stable curve inside the building. Both the relative humidity and the temperature did not experience high and low peaks in the interior as those shown by the exterior environment.

Below, two photographs show the aspects implemented in the sustainable housing, both on the main facade and in the bathroom.

Figure 22. Temperature and relative humidity.



Source: Zuluaga, V.; Bedoya, C.; Mejía, C. (2024).

Figure 23. Main façade with good solar incidence.

Source: Bedoya, C. (2024).

Figure 25. Bathroom with natural lighting through the roof.

Source: Bedoya, C. (2024).

DISCUSSION

The two experiences presented in this article show that each territory is unique in terms of its climate and resource variables. That is why the design and construction of each building obeys the application of research in ecological and economic sustainability, where the science and engineering of materials become a project. In one case the material properties were designed from recycled concrete, given its location in the urban context, and in the other case their conception is accomplished by incorporating earth in the construction, taking advantage of the raw materials that occur on the ground instead of causing damage by open-pit mining.

Although both cases are closely located, their tropical condition causes variables such as temperature, relative humidity and rainfall, since their climate does not depend on a season but on the altitude above sea level of a given location. The hotel, situated in Medellin, experiences a temperate climate, which can result in suboptimal indoor conditions due to high indoor temperatures due to the exposure of its windows to the west in the afternoon. Therefore, strategies had to be implemented to reduce the entry of sunlight without compromising the view to the exterior landscape nor impeding generous natural lighting to enter the structure.

Refugio Nasua, on the other hand, located at a higher altitude yet in close proximity to Medellin, requires the exposure of its facades and windows to the west, allowing for the entry of radiation and ensuring a higher temperature indoors than outside. Observing the development of both cases, it is clear that while the Colombian tropics are not subject to extreme climatic conditions of cold or heat, conditions which require a deeper understanding of the conditions of any given project's location. However, sustainably designed projects offer unique possibilities to solve those issues, ensuring the construction of comfortable structures while using significantly less wasteful mechanical equipment, devices or processes.

CONCLUSIONS

The cases presented demonstrate that, despite being geographically close and within the tropical belt, their contextual conditions differ significantly. Consequently, the design approaches and material properties of each project responded differently, although both achieved the same objective: ensuring low environmental impact during construction and throughout the building's lifespan.

In both cases, the living conditions remained within comfortable ranges without requiring mechanical systems for cooling (in the warm-temperate climate of the hotel) or heating (in the cool climate of the house). This translates to significantly lower operational costs for the buildings, given the rising annual costs of energy and potable water in Colombia. Both buildings implemented rainwater harvesting systems, taking advantage of the ample precipitation in their respective locations (Monsalve Valderrama y Orozco Restrepo, 2022).

Sustainable construction is an environmentally, economically, and technically viable endeavor. Moreover, it inherently calls for architecture of high aesthetic quality. "Getting dressed of place" is an appeal to recognize, with sufficient scientific and intellectual self-esteem, the variables of each context without ignoring the universal elements inherent in the cultural expressions of various territories. The house, the building, according to Friedrich Hundertwasser (Sánchez R & Albo Cos, 2021), is the third skin, hence the need to defend the windows as the bridge between inside and outside, both in the heat and in the cold.

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