INFLUENCE OF CONSTRUCTION TECHNOLOGY ON THE THERMAL PERFORMANCE OF VERNACULAR HOUSING

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The canton of Zapatillo, located in the south of Ecuador, has a hot climate that has led the population to use endemic materials in the construction of their homes. These materials provide a comfortable indoor environment for the inhabitants, with earth, wood and stone being the main structural components of traditional houses. These vernacular houses represent years of empirical research and testing by local builders who have developed unique construction techniques. However, these houses have been overshadowed by new architectural typologies that use modern materials and construction systems with lower thermal performance. In the current landscape of Zapatillo, remains of the first settlements in the area can be found, blending into the overall landscape with contemporary constructions. Therefore, the aim of this research is to analyze the bioclimatic performance of vernacular houses in the canton, focusing on the technical and constructional study of selected cases, seeking to identify parameters that contribute to indoor comfort in relation to local climatic conditions. The research visualizes the energy characteristics of vernacular housing, highlighting the solar protection provided by the use of portals and terraces, as well as the comfort of the raw earth construction system to mitigate the effects of high temperatures during periods of extreme heat. The energy analysis programs Revit Insight, Rhinoceros, Grasshopper and Lady Bug tools are used to measure these variables, with the ultimate aim of rescuing vernacular values and adapting them to new projects, thereby revaluing the concept of traditional Zapatillo housing.

Keywords: Traditional architecture, Bioclimatic, Architectural heritage, Zapatillo.

1 ARCHITECTURAL HERITAGE IN ZAPOTILLO

The Zapatillo canton is located in the extreme southwestern part of Ecuador at 152 meters above sea level (Lat.- 4° 23’ 16.65”; Long.- 80° 14’ 37.50’). The site has an extensive history since it was founded in the sixteenth century, although it has maintained a moderate urban growth. The climate is semi-arid tropical (BSH) according to the Köppen classification, with average year temperatures between 23°C and 26°C, being February, the warmest month reaching maximum temperatures of 34°C, and August the coldest month with a minimum temperature of 18°C. Rainfall is not abundant, but in some months, it can reach an average of 286 mm. Relative humidity is usually between 60%-80%. The characteristics of vernacular architecture combine qualities typical of pre-Hispanic cultures such as the use of local materials (mud, reeds and straw), with the Hispanic spatial distribution, highlighting the porches and the use of the courtyard or zaguas as the most characteristic elements (Moncayo 2010). Constructively, the typologies articulate a structure
of load-bearing earthen walls and an inclined framework of local wood to define the roof. In this way, techniques such as adobe masonry, compressed earth walls and wood and reed latticework covered with mud called bahareque were identified. The walls are partially buried in the ground and stone bases are not used as foundations, on the other hand, their finishes are made with mud mortars and are plastered with lime, only those houses farther away from the population center present a bare bahareque in the kitchen area (Figure 1) although this typology is almost no longer inhabited. The floors are covered with mud or stone paving stones, the internal partitions are made with the same technique as the exterior walls, and no ceilings are used. In the past, the roof was made of a wooden framework covered with leaves of cade or straw that are very breathable, but later clay tiles were used due to their durability and resistance to sun exposure.

Figure 1. Housing typologies in Zapotillo, on the left a typology located in the periphery of the city-abandoned, on the right, an urban typology currently inhabited (credits: authors).

2 METHODOLOGY

A historical study of the settlement and its architectural changes was carried out. In order to define the sample area, files were prepared to identify those houses with heritage characteristics and collect their technological information, selecting five urban typologies called: T1 adobe, T2 Rammed earth; T3 Bahareque, T4 Bahareque and adobe. Subsequently, virtual models of the case studies were made in Revit, which were later exported to Rhinoceros (Robert McNeel & Associates 2022).

The Climate Consultant V6 software (SBSE 2022) was used for the climate analysis, facilitating the visualization of the climate characteristics and their relationship with the psychometric diagram of the area. The program interpolates weather data from any particular area, compiling a history of that data. This data is contrasted with the meteorological yearbooks retrieved from the national database (INAMHI 2017), allowing the corroboration and validity of the data generated in Meteonorm software. This first phase made it possible to relate the qualities of the climate to the architectural-constructive characteristics of the typologies surveyed in order to determine the bioclimatic strategies. The quantitative analysis of the typologies was obtained by simulating the accumulated insolation, natural ventilation and thermal performance, and was carried out for the hottest day and the coldest day.

2.1 Bioclimatic Features

Applying Givonnii's Psychometric chart, it was determined that only 11.9% of the hours of the year the outdoor climate is in the comfort range, and the comfort diagram suggests strategies such as solar protection for windows, cooling by natural ventilation, dehumidification and refrigeration. Regarding the characteristics of the environmental use of the typologies, houses generally orient the main facade towards the south or north, and also incorporate elongated eaves that generate a
portal that helps not to expose the walls to the sun. The walls have thermal mass and their earth cladding helps to delay the passage of heat. The roofs are vapor permeable on the inside and on the outside to ensure a sufficient slope to evacuate rainwater. The houses use intermediate spaces between rooms as shading spaces, these are exterior portals, patios and corridors open to the interior (Figure 2), these spaces are complemented with plants contributing to evaporative cooling. No water collection elements such as wells were identified, although in some cases rainwater is collected superficially in containers. The houses usually have small windows with a very low window-wall percentage; thus, the doors are the element with the largest opening and usually remain open during the sunny hours, allowing cross ventilation; the slow urban growth also implies that the users have a greater relationship with their community, evidencing their direct relationship with the exterior through the doorways. Finally, the roof allows internal air transpiration, achieving vertical ventilation of the house.

![Figure 2. Arrangement of patio and porch in some housing typologies: (a) front-rear porch and courtyard; (b) front porch and back porch; (c) front porch and backyard; (d) front and side porch; (e) single front porch (non-urban housing) (credits: authors).](image)

### 2.2 Using Revit Insight and Grasshopper-Ladybug for Bioclimatic Analysis

The Insight plugin for Revit (Autodesk 2022) was applied to visualize the accumulative isolation of the surfaces according to the latitude where the typologies are located. A second phase of analysis was applied by exporting the models to Rhinoceros where characteristics such as wind incidence, average internal illuminance and thermal behavior were tested using the Grasshopper-Lady Bug environment and the Honeybee Therm and Open Studio plugins (Ladybug Tools LLC 2022). The versatility of the aforementioned tools made it possible to introduce attributes of the virtual models such as thermal loads, geometry information, thermal properties of the materials and to relate them to the climatic database previously obtained.

Finally, the information collected both in Revit Insight and generated in LadyBug, will be analyzed together to explain the thermal performance of the typologies, setting a comfort zone recommended by the Ecuadorian Construction Standard (MIDUVI 2018). Figure 3 shows the summary of the methodological process used.
3 RESULTS

In general, the simulated houses have a similar thermal behavior, however there are cases that respond better in both climate conditions, the summary of average temperatures of the houses is shown in Figure 4.

Among the common characteristics that define the thermal behavior of the typologies, we find the influence of the porches and courtyards, which intervene in reducing the accumulated insolation by increasing the shaded surfaces (Figure 5) and reducing the temperature of the air entering the dwellings. However, considering the external temperature peaks above 30°C, despite not being air-conditioned, the typologies allow a temperature decrease of between 3°C to 5°C, when the external temperatures are not so aggressive, the houses reach an average of 60% of the comfort hours in the year. In this warm season, dwellings tend to maintain the comfort zone for the evening and early morning hours. On the other hand, it is observed that the houses base their behavior on the thermal capacity of the walls, being better in those typologies that use thick walls as in the case of rammed earth and adobe, typologies T1 and T2, respectively, while in the bahareque typologies the behavior is less effective, even if we observe the results of typology T4 that has a mixed technique, it shows better results in the first floor that is made of adobe. These construction systems contribute to delay thermal gains during the day and stand out for their more regular behavior compared to other systems. In the case of the coldest day, the typologies tend to maintain more hours of comfort. In this case, the outside temperature is very close to the comfort zone, while the inside temperature of the houses remains close to this range. The portal, protected from the sun, acts as a social space thanks to the shade and the wind currents, so that the facades are aligned parallel to the wind currents, improving the cooling sensation in the portal, where the wind fluctuates between 2-3m/s on the lower floors and reaches 4m/s on the upper floors.
Figure 4. Thermal performance simulation chart. T1, T2 and T3 simulated in single floor; T4 simulated in two floor P1 adobe and P2 bahareque.

Figure 5. Insolation simulation on Revit Insight.
4 CONCLUSIONS

The different construction strategies and decisions, play a fundamental role for the thermal conditioning of the building. For the cases studied, common strategies such as the use of portals and patios is a fundamental characteristic to air condition the house, but on the other hand, the construction techniques of greater mass such as adobe and compacted earth, offer complementary qualities to reach the comfort zone in the hottest days, unlike lighter techniques such as bahareque. The vernacular architectural typologies show simple characteristics of environmental use, such as the use of patios, porches → verandas and local materials. In the warmer months, the average temperature in Zapotillo is considerable (over 31°C) and it is reasonable that in all the cases studied the houses do not manage to reduce the temperature to reach the comfort zone in all hours (21°C-26°C), but they do generate a reduction in the hottest hours. On the other hand, during the coldest months, the houses maintain their temperature in the comfort zone most of the time. In the cases studied, abundant direct ventilation is not considered because of the hot outside air, the openings are small and favor ventilation from the courtyard, the roofs take up most of the solar gain surface but the walls are not exposed thanks to the gables. Using Rhinoceros and Ladybug, it is possible to generate different energy simulations and control the parameters to understand which aspect mainly affects the performance of the model. The different construction strategies and choices play a fundamental role in the thermal conditioning of the building. For the cases studied, common strategies such as the use of portals and patios are a fundamental feature to condition the house, but on the other hand, the construction techniques of greater mass such as adobe and compacted earth, offer complementary qualities to reach the comfort zone on the hottest days, unlike lighter techniques such as bahareque.

The energy characteristics of the Zapotillo vernacular dwelling have been studied in this study, but it is necessary to continue with complementary studies that can make feasible rehabilitation or energy optimization projects for this type of dwelling. On the other hand, the qualities of the construction technique could be specifically analyzed in terms of their impact on the energy performance of the dwelling. Another focus of future research could be to highlight the influence of modifications in vernacular dwellings on their thermal behavior, in order to evaluate measures that could guide designers and builders to preserve the bioclimatic qualities of the dwelling and adapt new uses to current needs.

References


