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Landscape, Memory, and Sustainability: A study of Troglodytic Architecture in the Canary Islands (Spain)

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Abstract

Troglodytic heritage represents a significant global legacy, found across diverse regions from the Americas to Asia, Europe, the Mediterranean Basin, Africa, and notably the Canary Islands. Famous examples such as I Sassi di Matera (Italy), Les Eyzies in Dordogne (France), Cappadocia (Turkey), and Guadix in Granada (Spain) have become international benchmarks for the conservation, rehabilitation, and promotion of this unique architectural style. In contemporary contexts, troglodytic spaces are increasingly recognized for their potential in high-end tourism or as viable alternatives to large-scale urban housing and horizontal developments like the garden city model. This is largely due to the human fascination with returning to primitive habitats, particularly caves, which drives contemporary efforts to revive this architectural heritage by adapting ancient living spaces to modern lifestyles. This research aims to provide a conscious approach to the values of troglodytic architecture and its potential as an alternative model for preserving architectural heritage. As a modest and historically rooted habitat, troglodytic dwellings make use of natural terrain resources, creating a unique synergy between architecture and environment, which can be considered a precursor to modern bioclimatic design. The thesis highlights the typological and constructive features of these excavated dwellings, which reflect historical, social, and economic shifts in their surrounding contexts. These dwellings, with their mimetic architectural language closely tied to the landscape, present exceptional potential for contemporary residential living. Given the widespread existence of such settlements worldwide, the study begins with a general overview before focusing specifically on the Canary Islands. A comparative analysis is also undertaken with southern Italy to understand shared characteristics and differences. The research proceeds with an in-depth historical review of troglodytic habitats in the Canary Islands, addressing current challenges related to these dwellings and proposing constructive solutions to preserve and revitalize them within modern urban planning and heritage conservation strategies.

Keywords: *troglodytic; conservation; bioclimatic design; Canary Islands; cultural revitalization*

1. Introduction

Troglodytic architecture, with its ability to harmoniously integrate into the natural environment, offers a valuable opportunity for the renewal of rural fabrics today. These structures, which have proven to be sustainable over time, take advantage of the characteristics of the terrain and local climatic conditions, making them exemplary models of bioclimatic design. By utilizing indigenous materials and construction techniques adapted to the landscape, these dwellings not only minimize environmental impact but also promote a lifestyle in tune with nature. In a context where urbanization and unchecked expansion threaten cultural identity and architectural heritage, the recovery of these troglodytic structures emerges as a viable strategy for revitalizing rural areas. By reimagining and adapting these spaces to contemporary needs, it is possible to foster sustainable development that respects local history and culture. This approach not only preserves architectural legacy but also contributes to the creation of resilient and dynamic communities capable of facing future challenges. Research in this area is crucial to understanding how these constructions can be reintroduced into the social and economic fabric of rural regions.

2. Bioclimatic design in excavated architecture

Over the years, a true and unique "art of construction" has been developed; a symbiosis between the local climate, the characteristics of the physical environment, and the construction materials, based on the regional character specific to each place. The typologies, forms, construction techniques, components, and materials used, all reflect formal solutions of "architecture without architects," the result of human intelligence and a deep understanding of environmental factors.

The cave house in the Canary Islands continues to be one of the forms of habitation within its broad traditional architecture in rural areas, thanks to its favourable thermal conditions.

Bioclimatic architecture, understood in generic conceptual terms, is based on the adaptation and positive use of environmental and material conditions, maintained throughout the design and execution process of the project. It follows a logic that starts with the study of climatic and environmental conditions and the adaptation of architectural design to protect inhabitants by utilizing various natural processes. These include taking advantage of available resources such as sunlight, vegetation, rainfall, winds, and the earth to reduce environmental impacts, aiming to minimize energy consumption.

Although it appears to be a new concept, bioclimatic architecture has traditionally been used since ancient times. Excavated architecture can boast of adapting perfectly to the climatic conditions of its surroundings through specific, traditional construction elements and solutions that are sensitive to environmental impact, attempting to minimize energy consumption by using locally sourced materials (zero-kilometer houses), thus contributing to a reduction in environmental pollution.

Conventionally, the main difficulty of bioclimatic design in a built home is providing an integrated solution for the hygrothermal conditioning, both in winter and summer conditions. That is, to self-regulate in order to remain within the comfort zone despite external conditions, not too cold (where heating is necessary), nor too hot (where energy expenditure is required for cooling). However, the cave house, as a bioclimatic model, is very close to achieving perfect environmental conditions, with suitable temperature, humidity, airflow, and indoor air quality, all while integrating into the environment and promoting environmental sustainability.

The bioclimatic strategies used in troglodyte architecture are very diverse; below we list the most important ones.

2.1. Thermal regulator

Its high thermal mass acts as a good insulator, self-regulating the temperature inside the space thanks to heat and humidity. Due to the thickness of its envelope, temperature fluctuations are imperceptible indoors, achieving thermal stability. Indoor temperatures closely approximate the annual average of the local air.

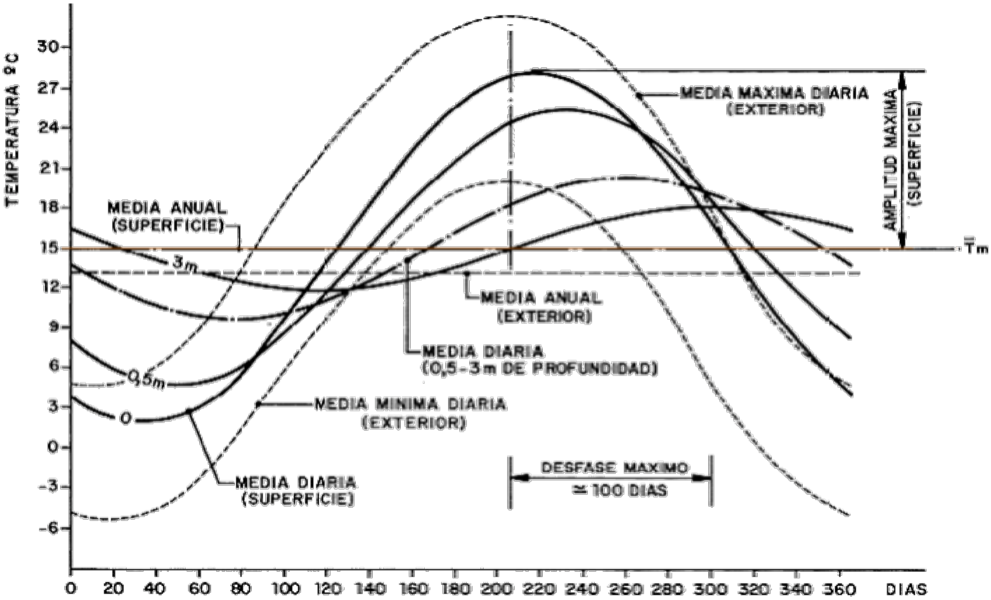


Fig. 1 – *Graph showing the variation of ground temperature as a function of depth* (Esteban Sainz, 1986).

"It is commonly believed that at a depth between 0.5 and 1.5 meters, the temperature does not vary throughout the day and coincides with the daily average. At 15 meters, the temperature does not vary throughout the year" (Farfán Manzanare, 2013)

However, as we will see later, these conditions could be modified by the practice of openings in the enclosure as a strategy necessary to address other factors such as ventilation and lighting inside the cave.

It is important to make a distinction and highlight the difference between the concepts of thermal inertia and thermal mass of materials. Thermal inertia is understood as the property of a material that indicates the amount of heat it can retain and the speed at which it gives off and absorbs heat. This depends on the material's thermal transmittance (surface area), conductivity (thickness), etc. However, thermal mass refers to the ability of a material to store heat depending on its characteristics: density, heat capacity, and thickness.

Fig. 2 – *Photographic image and section sketch of the courtyard in a cave house in Gran Canaria* (Author).

Therefore, in the case at hand (cave houses), we will refer to the concept of thermal mass. Unlike conventional enclosures, the large thicknesses that constitute this model dissipate, before reaching the interior of the cave, the heat accumulated on its surface. This capacity allows the ground to absorb the heat generated by occupancy, equipment, and internal lighting during the day, achieving a sense of comfort.

2.2. Humidity and ventilation

The Canary Islands enjoy a subtropical climate, both dry and humid, with a dominance of the Trade Winds. These winds are very constant, blowing from the east-northeast, with a frequency of up to 90%, while in winter this proportion drops to 50%. The uniqueness of these winds lies in their stratification into two layers: one low and humid, and another high and dry. This circumstance generates a thermal inversion that prevents the rise of humidity, so the lower layers of the atmosphere have a high relative humidity, especially between 500 and 1,200 meters. The location of these settlements benefits from this climatic advantage, ensuring a constant and slightly higher humidity inside compared to the outside.

Another strategy used in cave houses is the application of lime on the exterior facade. Lime is a permeable material that allows the substrate –the ground– to transpire, absorbing water during rain and evaporating it during heat periods, keeping the interiors cool. Meanwhile, ventilation plays a fundamental role in ensuring the evaporation of excessive moisture, both from the ground and generated within the construction itself.

In Gran Canaria, inhabited caves are located on the slopes of the rugged landscape surrounding them, where natural ventilation is ideal. Additionally, the typological configuration around a courtyard, acting as a cooler accumulator thanks to the shade and humidity of the vegetation, helps regulate the temperature of the interior spaces.

Externally, small openings in the facade help, through differential pressure, to allow air to enter and circulate. Wooden joinery ensures constant air renewal inside the cave due to its low airtightness, thus maintaining its salubrity. In the past, the absence of joinery facilitated airflow between all rooms, but today this traditional strategy has been affected by the enclosure of many alcoves, where moisture condenses, leading to the formation of patinas on the substrate. Solutions adopted in other typologies include a vertical shaft that allows air to exit, thus eliminating excess moisture.

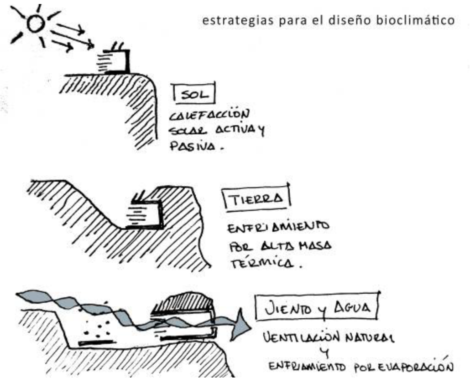


Fig. 3 – *Diagram of bioclimatic design strategies based on the position of the buried house* (Calvi Rollino, 2011)

2.3. Lighting

To address lighting issues in an underground inhabited space, two traditional techniques come into play. On one hand, there is the pursuit of light colors on the interior surfaces of the cave, either through whitewashing or whitening the walls. On the other hand, excavation in supports whose tone favors the reflection of light inside, such as the cream-colored pumice materials typical of the southeast and south of Tenerife, is employed.

It should be noted that the typology of homes in the Canary Islands typically features no more than two rooms in depth, with the farthest rooms from the facade being the sleeping quarters, which do not require significant lighting.

2.4. Protection from sun and wind

The orientation of the excavated architecture is a crucial factor in its design, as the use of solar energy and wind in different seasons is a determining factor when choosing the location,

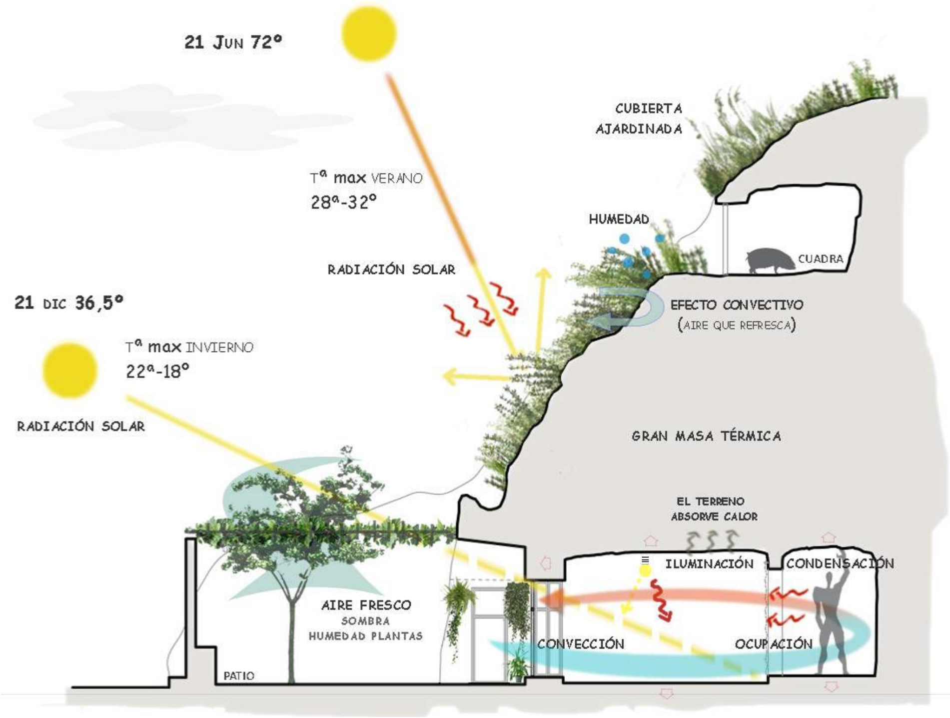


Fig. 4 – *Bioclimatic strategies in a "typical cave house" in Gran Canaria* (Author).

preferably on the southern or southwestern slopes. However, finding the ideal location is not always easy, and caves are sometimes found in positions meant for other functions (storage, production, livestock, etc.).

2.5. Acoustic insulation

Thanks to the thickness of the surrounding support material in a cave house, its insulation from external noise is ensured, which is particularly important in areas where the constant sound of the wind could cause discomfort.

2.6. Recycling of Construction Materials

When constructing a cave, many advantages arise from recycling the excavated material, which can be used in elements like the cave's enclosure, leveling the ground, or making furniture and decoration for the cave or adjacent buildings. In the Canary Islands, the material extracted is reused, either to condition the land in front of the cave entrance or for its agricultural use, placed on certain crops, thereby helping conserve moisture.

2.7. Relationship with territorial resources

Troglodytism has maintained a close relationship with the available resources in the territory since ancient times, forming the basis of the economy and the way of inhabiting the rural landscape.

Its adaptation to the environment, occupying the driest and most barren areas and leaving the more fertile land for exploitation, makes it an excellent example of symbiosis between the natural environment and the human-modified landscape, minimizing the energy impact necessary to achieve the best comfort conditions required for survival.

P01_E03 Vivienda_01	
	Edificio objeto
Nombre	P01_E03 Vivienda_01
Planta	P01 Planta_baja
Tipo de uso	Residencial
Clase de higrometría	3
Área	36.47 m²
Altura	2.25 m
Volumen	82.047 m³
Tablas de actividad	Vivienda_01 (Ocupación, Iluminación, Equipos y Infiltraciones)
Temperatura de verano, con ocupación	25 °C
Temperatura de verano, sin ocupación	27 °C
Temperatura de invierno, con ocupación	20 °C
Temperatura de invierno, sin ocupación	17 °C

Fig. 5 – *Screenshot illustrating the starting data specifications for the evaluated model. Extracted from the trial with EnergyPlus software.*

3. Case Studies

In this research, the testing and simulation of a three-dimensional model for each of the caves under study have been carried out, in compliance with the CTE (Spanish Technical Building Code) and comfort parameters, to verify if the cave-house model meets the efficient model.

3.1. Methodology

For the selection of the case studies, at first, we have created a table of all the caves inspected throughout this research (more than 200 units), each of which has undergone a detailed architectural study (Table 1).

The caves were classified based on common parameters such as orientation, material, surface area, number of excavated and built rooms, existence of a bathroom (excavated, external), private quarry for extraction, existence of a kitchen (excavated, built), presence of a patio (open or closed), cistern/water tank, number of floors (levels), and cave use.

Once the table (Excel) was created, a 50th percentile formula was applied, allowing us to determine which caves, based on the number of parameters common to them, are the most representative. As a result, we obtained: in Gran Canaria, caves nº29 and nº51 from Juncalillo, Gáldar, and cave nº1 from Las Arvejas in Artenara. As the research was extensive, this short paper focuses solely on the results from one of the models tested. For full details, including all other models and their comparison to research conducted in Italy, please refer to the author's doctoral thesis. Once the caves were selected, preliminary files were created providing data on relative humidity and daily ambient temperature for both locations.

3.2. Software, calculations and results

The software used in this research procedure is CYPE Ingenieros CYPECAD MEP, a tool for verifying energy demand and consumption requirements of buildings. After creating the model, the EnergyPlus software was accessed for energy demand limitation simulation and to obtain verification and compliance results for the studied models.

Simulation involves creating a model of a real system and subjecting it to a set of conditions to understand the original system's behavior. In this way, the necessary strategies can be adopted to ensure the real system operates based on expected conditions.

Table 1 – *Table of resulting data (GC) from the analysis of values obtained in the trial conducted on Gran Canaria caves* (Author).

Cueva 29 Juncalillo	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	18.65	18.78	18.97	19.33	19.61	20.17	21.09	22	20.93	20.44	19.33	18.84	
Max	20.2	20.16	20.35	20.7	21.62	22.15	23.9	24.07	23.8	22.24	20.8	20.15	**3.61**
Average	19.425	19.47	19.66	20.015	20.615	21.16	22.495	23.035	22.365	21.34	20.065	19.495	
Cueva 51 Juncalillo Room 1	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	18.65	18.77	18.92	19.27	19.52	20.07	20.99	21.94	20.8	20.33	19.23	18.81	
Max	20.13	20.03	20.18	20.5	21.37	21.97	23.7	23.84	23.69	21.96	20.6	20.05	**3.5**
Average	19.39	19.4	19.55	19.885	20.445	21.02	22.345	22.89	22.245	21.145	19.915	19.43	
Cueva 51 Juncalillo Room 2	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	18.25	18.4	15.57	19.02	19.36	19.97	20.97	21.83	20.65	20.15	19.04	18.45	
Max	20.15	20.04	20.19	20.61	21.55	22.18	24	24.11	23.86	22.02	20.75	20.08	**3.77**
Average	19.2	19.22	19.38	19.815	20.455	21.075	22.485	22.97	22.255	21.085	19.895	19.265	
Cueva 01 Las Areyas Room 1	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	22.25	22.59	23.01	23.89	24.31	24.8	24.92	24.93	24.89	24.57	23.58	22.75	
Max	24.89	25.02	25.14	25.26	25.37	25.42	25.51	25.51	25.48	25.39	25.29	25.01	**1.6**
Average	23.62	23.805	24.075	24.575	24.84	25.11	25.215	25.22	25.185	24.98	24.435	23.88	
Cueva 01 Las Areyas Room 2	**En**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**	**Δ°C DIF**
Min	21.58	21.6	21.67	22.18	23.38	24.05	24.56	24.58	24.41	23.56	21.96	21.64	
Max	22.81	22.9	23.62	23.92	24.83	25.03	25.1	25.11	25.08	24.96	24.35	22.93	2.65
Average	22.195	22.25	22.645	23.05	23.605	24.54	24.83	24.845	24.745	24.26	23.155	22.285	

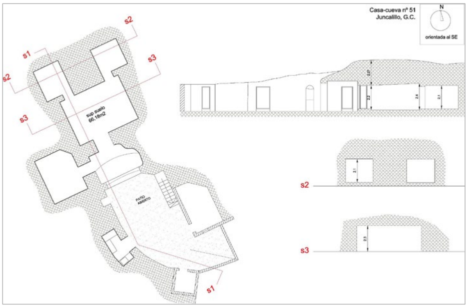
Figure 7 presents the data for one of the caves studied in Gran Canaria including a first document with starting data, floor plans, sections, dimensions, surfaces, and images of the excavated structure.

4. Conclusions

Based on energy simulation results, this research demonstrates that implementing setpoint data from specific building regulations enables cave house architectural models to meet the parameters established by their bioclimatic design strategies. They maintain nearly constant internal temperatures year-round, with differences not exceeding 4 °C. Therefore, none of the tested models exceed the limits required by the standard for indoor comfort, with a maximum of 27 °C and a minimum of 17 °C.

Consequently, the variations recorded do not require heating or cooling, as they remain within the ideal comfort parameters these dwellings autonomously provide.

The orientation of these prototypes plays an important role; almost always facing south, this architectural strategy helps mitigate low winter temperatures in settlements with significant seasonal climate variation.



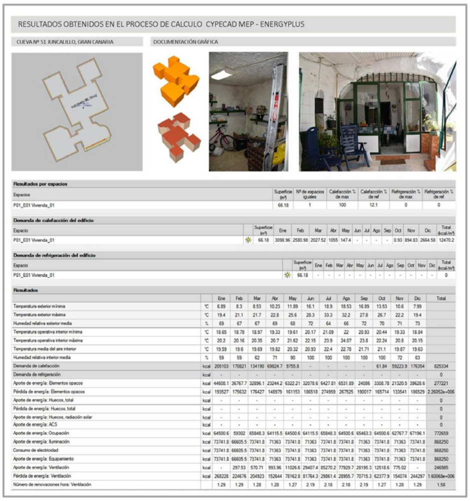


Fig. 6 – *Screenshot illustrating dates of model, from EnergyPlus software.*

Thus, cave houses, as primitive models, prove efficient due to their typological and construction configuration, intrinsically incorporating passive architectural design strategies that positively influence occupant thermal comfort.

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