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UNDERGROUND CONTEMPORARY BUILDINGS - PORTUGAL AND TURKEY

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T.2. Actuality and prospects for earthen architecture in Asia and other regions of the world
S.T.2.2. Architectural design and sustainable development

Keywords: underground housing, environmental impact

Abstract

Using nature itself - on prehistoric caves - or as inspiration for their artificial constructions, man always looked for underground earth shelters. The North of Portugal is characterized by a disperse territory occupancy, what is problematic due to infra-structures and transport environmental costs. This reality has diverse causes: accented topography, division of soil due to multiple transmissions of property, an intensive labor and delocalized small industry. The generalized access to individual transport in the last 30 years accentuated this phenomenon, that is now irreversible, but economic paradigm is now changing drastically, with small industries closing and increasing unemployment, what is now impelling the return to individual means of subsistence, such as private poultry. But a lot of soil surface is now blocked for agriculture; due to the existence of small disperse buildings that pop up on territory, limiting accesses and insulation to potentially productive soils. This is especially critical for South oriented slopes, more adequate for agriculture. Increase density is now utopia for this region, so a strategy proposed for dealing with this reality can be to integrate new constructions on terrace slopes, leaving the housing immediate vicinity soil and even roof more easily available for agriculture or at least reducing visual impact of buildings on landscape. The advantages and disadvantages of underground buildings are discussed, with some examples comparing Cappadocia in Turkey with Portugal. Portuguese underground contemporary housing buildings are presented as case studies.

1. INTRODUCTION

Underground housing is usually associated with archaic, unhealthy, poor conditions. However, underground buildings have many qualities including low temperature oscillation, better acoustic performance and higher protection against intruders in comparison with conventional upper ground buildings. Global warming and violent social convulsions announce a forthcoming era where security and protection will become major concerns. In this paper different types of underground housing are presented and some contemporary examples in Portugal are analyzed.

Villages began to develop during the Neolithic age, in Minor Asia, such as Çatal Hüyük in Turkey (6.700-5.700b.C.). This settlement consisted of houses joined together so that the roofs formed a continuous surface from which the interior could be accessed by stairs. In fact this was not an underground village, but most of the houses of this village behave as being underground, as they are protected by other attached houses from all sides. Underground settlements are characteristic of several regions in the world. The most abundant examples are located in China, in Hunan, Shanxi, Shaanxi and Guansu provinces with approximately ten million people living in underground houses. Dwelling caves are found mainly in northern Shaanxi Province, in Yan'an and Yulin. hey are built in the Loess mountain slopes. Cappadocia in Turkey is also known...
by its underground constructions which are still being built nowadays using the same constructive system as in the past. Figure 1 a) shows an example of a recently built hotel in Göreme, Nevşehir province in Central Anatolia. Other important examples of traditional dwelling caves can be found in Iran, Tunisia and Spain.

![Underground Hotel in Cappadocia](image1)

**Figure 1 a) Underground Hotel in Cappadocia**

![Lithological diversity in continental Portugal](image2)

**Figure 1 b) Lithological diversity in continental Portugal (Brito 1994)**

2. GEOGRAPHICAL CHARACTERISATION OF PORTUGAL

Geographical physical characterization is important to understand the possibility of using underground housing, especially regarding the climate and the soil properties. In terms of climate there are three regions in Portugal: Atlantic (wet Iberia, at the Northwest), “transmontano” (dry Iberia, at the Northeast) and Mediterranean (arid Iberia, at the south of the Tagus) (Ribeiro et al., 1987). From the topographical point of view the Tagus River separates two regions: the northern (with predominance of high relief) and the southern (with a predominance of plains). The lithological characteristics of the soil are also important to understand the feasibility of underground construction and the most suitable types to be adopted. Seven tenths of the Portuguese territory belongs to the “Hisperic” massive. It presents erosive and metamorphic rocks such as: granite, schist, marble and some quartzite outcrops (Brito, 1994). This massive contacts only with the Atlantic Ocean in the west coast, from Ovar to Sines and in Algarve, as it can be seen in Figure 1 b). The rest of the territory present two distinct types: in the west and south predominates calcareous, margin and sandstones, but also clays and conglomerates; in the basins of the Tagus and Sado rivers predominate clays, sandstone and conglomerates.

3. UNDERGROUND CONSTRUCTION IN PORTUGAL - VERNACULAR ARCHITECTURE

In recent years, the growing energy efficiency requirements led to a new approach, focusing less on the economic cost per se and more on environmental and material costs. Using local heavyweight materials, needed to increase thermal inertia and acoustic protection, begins to be considered in order to allow a compromise between pre and post occupancy environmental costs. As referred previously, intensive labor can be interesting not just for environmental reasons but also because it stimulates local economy. So, it can also be a more sustainable approach from the social point of view. Since the first buildings documented in the Portuguese territory, and until at least
50 years ago, the constructive systems used in housing buildings in Portugal were mostly mixed in terms of weight. These were characterized by heavyweight envelope structural walls, i.e. with approximately 1000Kg/m² considering an average thickness of 0.40m of massive stone – like an evolution of natural caves. In areas where the stone was not available, adobe was used, what could be considered as an evolution of artificially dig constructions. The floors and roofs were lightweight, made of timber - about 50Kg/m² the floor and 50 to 150kg/m² the roof. By the lack of efficient means of transport, materials used in the walls of traditional houses, were closely associated with the local availability of raw materials and manpower. Thus, the materials used for its construction correspond directly to the lithological characteristics of the soil, shown in Figure 1 b). Apart from the materials, with particular emphasis on the characteristics of the envelope, the morphology of housing contributed significantly to the evolution of the thermal performance of houses.

All primitive buildings were no more than shelters in the current sense of the word. It should however be made a distinction between shelters and primitive buildings. According to Veiga de Oliveira et al. (1969), shelters are buildings with very limited occupancy, temporary or even occasional, in some cases mobile, with rudimentary forms and systems or styles with regional characteristics; the primitive buildings had permanent occupancy, well defined building systems with sharp typological or regional differentiation. Construction progressed to a traditional architecture, gradually from the sixteenth century until the mid-twentieth century, when the presence of a uniformity of typologies could be verified. Some typological differences grew between North and South and between costal and inland, beyond the inevitable differences between urban and rural areas that could be noticed. The first shelters that man used to protect against the harsh climate and weather, present themselves in various forms, corresponding to different stages of evolution. Some examples remained in Portugal until today, or until the last century, including the following types:

- natural shelters - caves, grottoes and limpets;
- Semi-natural shelters - take part of rocks or soil and build inside these, as in the example shown in Figure 2 a);
- Artificial shelters - in stone, in stone and vegetable materials, entirely with vegetable materials.

The artificial shelters in stone with roof also in stone, appear in some areas of the country, like “Trás-os-Montes”, “Beiras” and especially in mountainous areas. These are small buildings in overlapping stone, as shown in Figure 2 b), used as shelters for shepherds, farmers or camp guards. This type of construction is based on the dolmen, and eventually stones or parts of these constructions may have been used. In some cases the artificial shelters with stone take advantage of walls and terraces for at least one of the walls. Artificial shelters of stone in circular or square plan exist also with false dome. The coverage was made with rows of stones that get closer to the centre as they develop to the upper part, to form a false dome. Constructions of this type can be seen on Figures 2 c) and 2 d), with circular and rectangular plan, respectively. Huts, with circular plan in stone walls and conical coverage made of vegetable materials still exist in some areas, particularly in Algarve Mountains and in “Alentejo”. They are used now as barns, but there are still reports of some been inhabited till about 100 years. "(...) These are very poor forms of housing, where people lived in large - sometimes total - discomfort, that could be hardly accepted today, and are therefore doomed to disappear, voted in the general contempt that they deserve, or integrated into contexts that have evolved beyond" (Veiga de Oliveira et al. 1969).
The relationship between housing and the immediately available resources only has an absolute value in the early stages of human habitat. Moreover, even at those levels, there are always plenty of scope for architectural changes, giving freedom to the conventions and local ideas to find their own expression (Keesing 1961). The relationship between materials’ availability on soil and primitive buildings is direct although, according to this author, leave some space for maneuver. What allows the presence and determines the types of underground construction are mainly the characteristics of the soil, as well as the culture and climate.

5. UNDERGROUND CONSTRUCTION - NOWADAYS

With industrial revolution the transport of people and goods generalized. Building materials started to result from industrial processes taken up in factories and then transported to store places and to site works. Because of this fact, the link between the availability of materials in the soil and their use in construction changed, becoming significantly diluted. Economic issues are those that almost exclusively began to influence the types of materials used and thus also the constructive systems. Industries started to be located near raw materials extraction, more for economic than environmental reasons. This centralization of production increased the average distance of building products from the extraction to the work sites – with consequences on transport energy costs. Also the industrialization of construction materials, though more economical, is actually much more energy demanding and pollutant that the construction using intensive manpower and local materials. This happens in traditional underground constructions in Cappadocia / Turkey. Using only a digging hammer, one man can take between two weeks to eight weeks (depending on the hardness of the soil) to dig a compartment for a 20m² dormitory. The economical cost for constructing a compartment of this size using a conventional constructive system (hollow brick /
concrete) is approximately 500€/m², not considering the cost of soil. Following a survey that the author took on Cappadocia recently, considering only handwork, the cost of digging an underground compartment is between 50 and 250€/m², meaning that this type of construction can be significantly more economical. The same comparison could be made about constructions in South of Spain (for example in Guadix), where the soil and the dryness of climate, allow the use of directly excavated spaces.

Underground buildings can be found in: different urban layouts (from entire neighborhoods to isolated dwellings), with different uses (houses, hotels, offices, museums, libraries, etc.), and in several topographies. In relation to this last issue, it can be stated the existence of at least four types:

- **Type 1**: Underground building in a vertical plan - Figure 3 a). In Cappadocia, Turkey, people lived for many years in underground cities. In a very mountainous region and with the enormous power of adaptation of human beings, started up to inhabit the caves and develop techniques of excavation, and thus shape their habitat. In this type of construction, the rock generally serves as a structural element. No example of contemporary houses of this type was found in Portugal;

- **Type 2**: Underground building in the horizontal plan - Figure 3 b). There is a relevant example in Cappadocia, Derinkuyu, an entire underground city from the 8th–7th centuries B.C. In Portuguese territory, this type of construction is more adequate to the South territory geographical conditions. Although the example presented here is a house in the north: “Bouçós” farm house (2007) in Valença do Minho, by Arch. Nuno Brandão Costa;

- **Type 3**: Constructions integrated on terrace slopes - Figure 3 c), where ground and roof sometimes intermingle. It is typical from the northern Portuguese territory, because of its topography. “S. Torcato” house is a project by the first author - Paulo Mendonça. It results from the excavation of a very inclined slope, forming a sequence of ramp roofs that allow the access to the upper part of the property. “Tóló” house in Vila Real, by Arch. Álvaro Leite Siza Vieira is a house located in a hill that instead of “fighting against nature”, absorbs it. The main entrance is at the top and the house develops its program down the slope;

- **Type 4**: Constructions that simulate artificial topographies - Figure 3 d). Guadix, an entire village in Granada, Spain and Future Systems’ house in Wales - England (1994) are international examples of this type. The authors from this last example referred: “Our objective has been to minimise the visual impact of the building and to site it in a way that makes the house appear a natural part of the landscape” (Future-systems, 2009). This type adapts to almost the whole Portuguese territory. One example is “Labruge” house (1989-1994), Vila do Conde, by Arch. Carlos Prata. It is a small holiday house near the sea, with just 70m². It has only one facade to the outside, facing west, to the sea. “Dune” house (2009), from Pereira Miguel Architects is also an example of how to minimize the visual impact near the sea, integrating the house in an artificial dune.

The idea of underground building appears under the primary concept of shelter, based on the protection that it must provide. An underground construction uses the directly excavated ground to protect itself from the outside elements. It offers additional benefits when compared to conventional upper ground buildings.
Figure 3 a) Sheme of Type 1; b) Sheme of Type 2 (left), “Bouçôs” farm house section and plant (right) (FG, 2008); c) Scheme of Type 3 (left), “S.Torcato” house section and view (center) and “Tolô” house section (Alvaro Leite Siza Vieira) and view (right) (FG 2008); d) Sheme of Type 4 (left above), section (left center) (Carlos Prata) and view of “Labruje” house (left down), “Dune” house section (right above) (Pereira Miguel) and view (right down) (FG 2008).
5. ENERGY EFFICIENCY IN CASE STUDIES

One of the main advantages of underground construction is energy efficiency; due to the large heat store capacity of the soil it presents a high thermal inertia. The soil temperature remains relatively constant throughout the year, near the average annual outside air temperature, so the building does not present large daily and even seasonal temperature lags. Bury the buildings also creates high acoustic protection from the outside. This yields a more protected environment inside, which makes possible to build in places near sources of noise, where conventional buildings would be unviable or too expensive to give them the same level of acoustic insulation. Another positive aspect to consider is the integration that this type of construction has with nature. It hardly emerges as a strange element in landscape, presenting a neutral integration. It is however important to use an efficient ventilation, since the relative humidity is always high. The Portuguese climate and soil characteristics need waterproofing of walls on excavated constructions. This creates vapor barriers, not allowing the recommended absorption / dissipation of humidity that soils rich in clay or conventional breathable walls can provide.

Daylighting

The visual comfort can be considered as a psychological factor that reflects the degree of satisfaction of individuals with their visual environment. The existence of natural light is essential, it is appropriate if it allows the development of visual tasks that are performed during the day. Together with acoustic and thermal comfort is one of the fundamental aspects that contribute to the overall feeling of comfort inside buildings. There are many advantages by using natural lighting in buildings. It presents a graduate and continuous variability that helps to create a more pleasant environment than the monotonous one produced by artificial lighting. To evaluate the natural light available inside the buildings, should also be considered the availability of natural light outside. Daylight factor (DF) describes the ratio between outside illuminance and inside illuminance, expressed in percentage. A higher DF represents more natural light available in the room. It is expressed as such:

\[ DF = 100 \times \frac{Ein}{Eext} \]

Where:
Ein - inside illuminance at a fixed point
Eext - outside horizontal illuminance under an overcast (CIE sky) or uniform sky.

The levels of natural light indoors depends on the conditions of cloudiness in the sky, on the time of day and year, the geometrical characteristics of the building and compartments, the size and spectral-photometric characteristics of glazing, the external obstructions, and the reflective properties of interior finishing surfaces. There are several ways to take advantage of natural light to illuminate the interior of buildings, which by principle represent a higher difficulty in getting natural light, as there present less exposed areas available to place natural light capture devices. In all the examples presented there are similar façade exposure then in conventional buildings, and in most cases conventional direct gain windows are explored to achieve a good penetration of natural light. These systems are especially interesting for Types 2 and 3 presented, and are explored in “S. Torcato” house – Type 3. Measurements of DF in the middle point of main compartments were made on the case studies and presented in Table 1. The results were satisfactory on “Labruje house” and excellent on “Dune” house - both Type 4.
In what concerns the south vertical openings, shading devices should be placed horizontally. In high windows it is recommended to have overhangs above the line of sight, dividing the glazing in two sections, one on top, called "daylight opening" and one at bottom, the "open vision". The top should have a high reflectance finishing: such as glass mirror or highly polished metals to be more efficient. These can be used for types 1, 3 and 4. The “Labruje” house – Type 4 and the “S. Torcato” house – Type 3 uses simple forms of this system – external venetian blinds and fixed overhangs. North vertical openings don’t need shading devices, and other orientations should be avoided, but when it is necessary they should present vertical shading devices.

Another option is the skylight. It consists of an opening located in a horizontal or slanted roof. The skylights allow natural light to reach the spaces below; however it is necessary that the building has the roof in direct contact with the outside. This system was explored in “Labruje” house – Type 4.

But even in more deep underground solutions, there are devices that can allow the entrance of natural light. Lighting ducts are the most used system to capture natural light in these cases. The lighting ducts (and its variants) allow the capture of daylight and their conduction to areas and interior spaces of buildings not directly connected to the outside environment. Generally, the interior surfaces of lightning ducts are coated with materials with high reflectance in order to direct and spread the natural light "down" with some effectiveness, including mirrors and prismatic components.

From a previous study by the first author (Mendonça, 2005), it could be concluded that higher values of daylighting does not mean better overall energetic efficiency. The central question in this issue is to decide between direct gain strategy and indirect gain strategy:
• Direct Gain - the estimated values for thermal gains are usually higher in a direct gain strategy, but the temperature and glare due to the excessive solar radiation penetrating occupied areas can be a source of discomfort. On the other hand, the excessive solar exposure can lead to furniture and other equipment degradation. Additionally, with this strategy it is normal to have a great asymmetry in the radiant temperature between the exposed glazing and the interior walls, which is also a cause of discomfort. These facts can lead the building occupants to constantly operate the existing shading devices and, consequently, block the required thermal gains, as well as the natural illumination;
• Indirect Gain - in spite lower thermal gains estimated values, an indirect gain solution can, more effectively, guarantee that the forecasted values are closer to reality, since there is a more efficient control of the thermal gains. Then, the strategy chosen for the proposed design was an indirect gain strategy.

**Table 1. Daylight factors on case studies (measured on the middle of compartment)**

<table>
<thead>
<tr>
<th></th>
<th>&quot;Bouçós&quot; house Type 2A</th>
<th>&quot;Labruje&quot; house Type 4A</th>
<th>&quot;Dune&quot; house Type 4B</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF</td>
<td>1.2</td>
<td>2.9</td>
<td>5.1</td>
</tr>
</tbody>
</table>

**Thermal efficiency**
Thermal fluctuations in the ground are minimal, guaranteeing not just a reduction of daily, but also of annual thermal lags. This is due to the great thermal inertia assured by the thickness of soil. This means that almost no thermal insulation is needed and the needs for mechanical equipment are reduced, especially for cooling. In cases where thermal gains are needed, a greenhouse can be created in direct contact with the construction, allowing heat to be later retained inside the building – this system was explored in S. Torcato house bedroom areas – Type 3. This type of solar passive heating works as an indirect system, with lower theoretical gains then direct gain
systems (used in all other case study types presented). However it guarantees a better compromise between thermal and natural lighting comfort. As there is no direct radiation penetrating the compartment – there are no need to close shutters for lighting comfort when there is occupancy, what could compromise project predicted gains (Mendonça, 2005).

The acoustical insulation is also assured by the existence of buffer zones, what is intrinsic to the indirect gain system. This system pretends also to explore a greater flexibility in the use of interior spaces, allowing a 30% increase in flexibility, when compared to a conventional system. This system was explored on “S. Torcato” house.

Measurements of temperature were made on “Bouçós”, “Labruje” and “Dune” house, between March and June 2009. Results of these measurements are presented on Table 2. As it can be seen, $\Delta T$ (daily thermal lags) on the interior were just between 1 and 2,5 °C, what is specially relevant on houses located more far from the sea, what was the case of “Bouçós” and “Dune” house. “Labruje” house is very close to the sea, that’s why the exterior $\Delta T$ was very low.

### Table 2. Measurements of temperature on case studies

<table>
<thead>
<tr>
<th></th>
<th>“Bouçós” house Type 2 Temperature (°C)</th>
<th>“Labruje” house Type 4 Temperature (°C)</th>
<th>“Dune” house Type 4 Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>exterior</td>
<td>min 12</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>max 27</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>$\Delta T$ 15</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>interior</td>
<td>min 16</td>
<td>18</td>
<td>13,5</td>
</tr>
<tr>
<td></td>
<td>max 17</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>$\Delta T$ 1</td>
<td>2</td>
<td>2,5</td>
</tr>
</tbody>
</table>

**Relative humidity**

Humidity is a major problem on underground buildings. To prevent problems of durability of materials used inside and on the air quality, ventilation strategies should be used for reducing the moisture content in the interior environment. However, despite the high humidity, it does not mean that there is cold condensation in walls, because these cool very slowly (due to high thermal inertia) assuring these don’t easily reach dew point. Apart from a good ventilation, the best way to assure a low relative humidity is the election of a soil type that has significant amounts of clay (35% or more). This kind of soil is very rare in the portuguese territory, so the excavated buildings are in general inserted on rock soils. In this context, and before proposing an underground construction in Portugal, it is recommended to make a study of groundwater level of the site, what must force to use materials like asphalt for waterproofing. In this case the excess of humidity should be expelled in the form of water vapor. It is therefore very important that the other surfaces, including walls, roofs and windows can breathe, and to use materials to facilitate this phenomenon. Sheet metal, waterproof concrete or windows without ventilation grids are solutions to avoid the other elements that confine the underground space. It should be considered the use of some vapor permeable façade and vapor absorptive interior dividing walls. In the “S. Torcato” house – Type 3, adobe walls and ceilings are used. The lighting and solar passive gains systems, mentioned above, may also function to create air pressure differences over the housing (solar chimneys and other openings). In “Bouçós” house – Type 2, the high opening ventilation allow the dissipation of humidity. Relative humidity was measured in “Bouçós”, “Labruje” and “Dune” houses, and in all cases it was between 60% and 70%, what is similar to conventional portuguese buildings, as presented by Mendonça (2005).
6. CONCLUSIONS

The advantages and disadvantages of underground constructions were discussed. Some existing examples of North Portuguese contemporary houses were presented as case studies. Some of these examples were measured regarding thermal comfort parameters. The results were used for optimizing an underground housing unit project, “S. Torcato” house, projected by the first author. It pretends to be a future model occupancy strategy for urban sprawl territories, such as the existing in the north Portuguese territory.

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