Sustainable Building
Affordable to All
Low Cost Sustainable Solutions
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The use of Natural Fibres on Architecture: the local economy and the Arts and Crafts

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ABSTRACT: This paper presents a research work about sustainability of construction, based on the use of natural fibre materials on architecture. Several aspects will be presented and discussed, regarding social, economical and environmental issues. The objective is to propose an increased use of natural fibres on exterior facade walls of buildings, using as model the vernacular architecture. Wall typologies will be presented from an historical; a state of art and also suggesting future expected developments. The proposed facade wall types using natural fibres will be compared with the conventional hollow brick walls mostly used in Portuguese contemporary construction. The history of using natural fibres in Portugal, related with the geographic conditions and the available resources will also be described and some examples shown. Moreover, it will be pointed out the importance of the use of natural fibres on the local economy.

1 INTRODUCTION

Currently, our society faces the need to meet a response to a social requirement that has major implications in our production system and, specifically, in the field of construction materials: regarding to sustainable development (Cuchi, 2005). A sustainable society is an utopia, as since the Neolithic period that Man started to exploit resources more then nature by itself can give. This scenery got exponentially worst after the Industrial Revolution and especially on the end of the nineteenth century. A sustainable use of resources is nowadays only possible in those areas of the planet that were isolated from the consumer society, where the mutual relationship of man with nature allowed life in harmony with the ecosystems. Construction is one of the sectors that more intensively use materials.

Figure 1. Link between the availability of local materials and construction
The figure 1 makes a link between the availability of local materials and the construction in the periods of the Industrial Revolution and Post-Industrial Revolution. After the Industrial Revolution, which caused the massive production of materials and generating a strong energetic crisis, Man had as consequential choice return to the past, refocusing in the local material and artisanal techniques, in order to minimize the use of industrial materials, but additionally applying the new technologies. According to the World Watch Institute (WWI), the construction of buildings and infrastructure consumes between 45% and 60% of materials extracted from the lithosphere.

One of the Man characteristics is the ability to transform the raw materials available in nature and overcome the lack of biological tools available that other predatory species have (Dantas, 2004). The technologies that use natural fibres reveal knowledge, meanings and relationships that take together social groups, and the extinction of this knowledge undermines the identity and the own existence of those groups and those with which they interrelate. Human beings cannot exist without the integration with their environment: Homo Faber became conscious of their action on the nature and control the environment through actions, where the useful act, i.e., the tool using the technique, is of fundamental importance in this context (Cerqueira, 1994).

One may believe that it is still possible to live doing some things by hand, according to our own pace and with perfect knowledge of the overall process. The craft is one of several popular strategies, which enables intelligent men and women return back to scepticism and direct the work process as the design of their artefacts. The contemporary craft is necessarily peripheral relatively to the bulk of economic activity. Beginning in the seventies, it was easy to correlate the gross domestic product and energy consumption with the countries economic development. Moreover, a higher consumption means more synthetic fibres to meet the demands, larger displacement both of labour and leisure, more housing surface area and more services in general.

1.1 Materials on the first settlements

The first material produced by man to get a shelter was the woven and are rare the civilizations that did not develop some kind of braided natural fibres. The fragility of the material with respect to its preservation within the time, have left less traces of the emergence of the straw than the left by the pottery.

These huts or shelters were presented in various forms, depending on the conditions of the natural environment and resources or materials that were provided by nature (Veiga, 1967). The tents and nomadic dwellings are built from knowledge inherited and transmitted to new generations, with simple geometric shapes (square or circular), facilitating the manipulation by any member of the social group. This type of architecture is constantly changing as a result of its reuse over time and is closely related to the socio-economic group to which belongs, to the surrounding landscape, the aspects of lightness and transport, the natural elements and the easy assembly and disassembly (Finkielstejn, 2006). From the end of the Palaeolithic, in regions where there was no natural shelter under rocks, the man has raised small buildings with natural fibres. Those shelters are characterized as elements of low stability and durability and, consequently, have not left very significant traces; therefore its forms can be established only tentatively.
Only since the Neolithic period housing archaeological remains have started to be evident, the scientific and anthropological studies allowed a faithful reconstruction of the original dwellings, where can be seen the presence of covers made of natural fibres (straw coating over wood structure); as in the case of “Citalia de Briteiros”, in Guimarães city (Fig. 2).

2 NATURAL FIBRES

Plant fibres are flexible, have great resistance to abrasion and can withstand the heat and light from exterior exposure. Some can also withstand the marine environment. They are all biodegraded by the action of microorganisms, an advantage in certain situations. According to its consistency, natural fibres can become rigid, maileable after drought, or maintain their consistency and hard before being cut. Some natural fibre materials are commonly used in construction, apart from wood, the most common natural fibre used in construction cork and coconut fibres are nowadays common insulation materials.

2.1 Cork

The cork-expanded results from the agglutination of compressed granules and connected only with its own resin under the influence of pressure and temperature, without using any chemicals. It is presented in the form of plates and aggregates and their most common applications are thermal and acoustic insulation of roofs and attics; isolation of pipes carrying liquids with high positive or negative temperatures; thermal and acoustic insulation of interior and exterior walls; slabs isolation to the transmission of percussion sounds; vibration-isolation (industrial machinery).

The cluster expanded material is a long-lasting, rot proof, resistant to compression and high dimensional stability. It has the advantage of serving both the thermal and acoustic insulation, which does not happen in conventional polystyrene foam. Its application in plates is easy, since it can be cut with a common saw. It is a 100% recyclable material. The main raw material, is of natural origin, is renewable and is a Portuguese product, so its use also promotes the Portuguese economy. Although the plates have slots which can bring acoustic or thermal bridges problems during its place, if not filling the box tubes in totality. It is relatively heavy compared to other insulation materials. Cork burns, making it less suitable for some types of uses and their protection in the fire box-of-air must be safeguarded, especially in multi-storey buildings, to prevent the spread of fire between floors (Mendonça, 2005).

Portugal, while being a country of small size, produces more cork than the rest of the world, occupying the cork a large area of Portuguese territory and has a very important contribution to the economy and ecology of several Mediterranean countries. An analysis of cork distribution by country immediately shows that Portugal has around 33% of the world; where it is find mainly in the Alentejo (72%), Lisbon and Tejo Valley (21 %). However, little is known about the use of cork as a building material in the past. In the neighbourhood of Cortiçasadas, one can find traces of buildings where the cork was used as a building material (Fig. 3).

Figure 3. Wall made of Cork and Earth in Cortiçasadas.
2.2 Coconut Fibre

Originally from India and Sri Lanka, began to be introduced in Europe after the Portuguese arrival in India. It can be used as thermal and acoustic insulation, which is highly effective, especially combined with the cork-expanded. The use in the world of natural raw and renewable materials in large quantities, has several advantages, compared to the use of a material that would end lost, and that is transformed without detriment to the environment, placing the coconut fibre in the range of friendly products. Coconut fibre has many advantages in its use, in addition to being an environmentally friendly material and easily recyclable. Belonging to the family of hard fibres, its main components are cellulose and wood that give high levels of rigidity and hardness, being perfectly suited to the markets of thermal and acoustic insulation, due to its characteristics: strength, durability and resilience, making it a versatile material. Due to its exceptional acoustic performances, it contributes to a substantial reduction in noise levels, either of impact or air, ideal for many of the problems in the acoustic area greatly exceeding the results obtained with the use of other materials. However, its application is hampered by the difficulty of webs cutting, since the fibres are very tough and offer much resistance to the blades, as well as conventional drills, locking up and not letting them to penetrate the material. Because it has not fittings, if not placed with care can lead to the emergence of sound bridges. It is also a fuel, such as cork (Mendonça, 2005).

The use of different natural fibres in Portugal architecture was, in the past, closely linked with the characteristics of climatic regions, which differ over territory. As example of nowadays constructions, using natural fibres, in Portugal regions with different climatic characteristics are: a) a construction carrying out with primitive techniques in the North of the country (Gerês), a perfect example to promote an area of natural interest by means of traditional architecture (Fig. 4) and b) The “Empena” House in Madeira Island, in the form of inverted V, that in the past served to store agricultural products and nowadays is a tourist residential houses, very typical of the Island (Fig. 5).
3 BUILDING SYSTEMS FOR EXTERIOR WALLS

Housing is one of modern architecture’s most important areas of investigation, from urbanism to typologies and constructive technologies, but we can conclude that flexibility was not a decisive concern, as most buildings are badly adaptable to changeable living patterns. Investigation on flexibility got more importance in the recent past, starting in the late 80’s (Gausa, 1998), and also relating to refurbishment, due to a growing environmental concern. In contrast to traditional policies of rehabilitation or demolition and replacement carried out until now, the architects Frédéric Drout, Anne Lacaton and Jean-Philippe Vassal face these issues from an ingenious angle by proposing a radical transformation. Based on an interpretation of the pre-existing, they propose a surgical intervention with the aim of granting dwellings more space, more sunlight, and more freedom of use and more services available. Such a recycling operation turns out to be more economic than the usual policies of demolition and replacement (Druot et al, 2007).

Growing necessity to save material and energetic resources, allied to a growing concern over the environmental issues and incertitude on the evolution of the economy, has impelled minimalist-approaches to Architecture and Engineering, reducing to the minimum necessary expression the constructive elements. These approaches, by some authors called “Light-tech” (Horden, 1995) and Eco-tech (Slesser, 1997), bets on the introduction of more materially and energetically efficient solutions. But not always a material optimization corresponds to a functional optimization – reduction of weight generally implies functional problems. A lightweight housing building can be problematic from the point of view of comfort, because of the insufficient thermal inertia and acoustic insulation, due to the reduced mass, but if these problems are solved, they can constitute potentially interesting solutions from the point of view of sustainability. An heavyweight envelope does not necessarily means an high thermal inertia building.

Brand (1994) proposes a strategy for constructing adaptive buildings using traditional materials, attention to local vernacular styles and budgeting in order to allow continuous adjustment and maintenance. Building is composed by different elements that should be easily dismantled by durability layers: Site; Structure; Skin; Services; Space plan and Stuff. Its the constructive autonomy between the different layers that allow the functional life of a building to last more and thus its flexibility. Interior partition (Space plan) and also stuff are the components of a building that we should rely to increase adaptation, but we should also rely on the relation between these elements and the outer skin, especially in refurbishment.

Reduction of weight, by using the minimum material necessary, is a way to achieve eco-efficiency, allowing easy recycling, reusing and flexibility. This can be understood as an ecological approach to accomplish the function, weighting only a small part of what could weight a conventional constructive system.

Since the first documented buildings in the national territory, the construction techniques used in Portugal housing were mostly mixed, in terms of weight. They had an exterior envelope extremely heavy with an average thickness of 0.40 m in stone, brick or adobe. In the last 50 years the brick was introduced initially without insulation. Only in the eighties, double pane walls-s with thermal insulating material in the air gap were introduced. Later, in the nineties, with the introduction of a thermal regulation (1990) began to be compulsory to thermally insulate the building envelope in order to minimize the heat exchanges with the outside world; and the ETICS (External Thermal Insulation Composite System) appeared to better respond to those requirements. The ETICS system had the advantage of being applied to a new outside wall or to an existing; it was advantageous in the case of buildings with poor insulation, leaking or damaged aspect. Moreover, it could decrease the risk of condensation, treating somewhat the thermal bridges. In the construction of new exterior wall, the best solution is a combination of the ETICS and an interior single-wall with great thickness (Mendonça, 2005). But there are other comfort related aspects more difficult to characterize. In countries such as Portugal, with a daily thermal amplitude oscillating most of the year below and above the temperature of ideal interior comfort, insulation and shading of external facades are not, by itself, effective and can even be problematic.

Thermal inertia is very important in a solar passive housing on a temperate climate, as its absence can result in a night rapid descent of temperature and a resulting excessive daily thermal oscillation in the interior. Since the pavement or other elements such as external walls or inte-
terior furniture can take the role of thermal storage, the bet can be to optimize their performance by a thermal zoning of the occupancy. The magnitude and configuration of the thermal mass should be determined in order to store sun heat in agreement with the daily thermal widths and with the occupation type, for example to maintain an interesting interior temperature, during the night, in cold days (Bradshaw 1993).

3.1 Proposed and Conventional walls

The construction period environmental impact here presented is based on the sum of Embodied Energy (PEC) with the transport and the construction energy, converted in economical costs, that examines what goes from the extraction of raw materials until the completion of construction work. The assessments of sustainability include the study of the economic viability of the different façades developed through the quantification and comparison of PEC with the other constructive solutions existing in the market. Using this methodology, the sustainability of two proposed solutions, Natural fibre lightweight and heavyweight wall (Fig. 6a, 6b) were evaluated in comparison to conventional solutions (Fig. 6c, 6d). Lightweight wall (Fig. 6a) is composed of the materials: cement/wood shavings (12 mm), air gap, expanded extruded polystyrene, cement/wood fibre board (19 mm), black cork agglomerate, coconut fibre, air gap, 2 Gypsum boards carton (13 mm); and a heavyweight wall (Fig. 6b) is composed of: cement/wood fibre board (12 mm), air gap, black cork agglomerate, adobe, lime.

![Figure 6. Proposed walls: a) Natural fibres lightweight wall, b) Natural fibres heavyweight wall. Conventional wall: c) Simple Wall o the 90's decade; d) Double Wall of the 80's decade.](image)

The technical characteristics of a Conventional and Natural Fibres walls, obtained from a previous Social Housing study made by the authors (presented on the Conference “L’Architettura Sostenibile e le Politiche dell’alloggio sociale in Europa”, held in June 2009 on Naples, Italy), are presented in Table 1.

The characteristics of the walls, above mentioned, were compared; Thickness, Acoustic insulation, U value, Embodied Energy, Specific weight, Specific useful thermal mass and Specific cost were calculated for both; additionally the average of all those values was estimated. The Best and Worst Values are marked in the table. In the case of Conventional Walls, the simple one appears as better than the double in all the characteristics analysed.

The proposed wall using natural fibres are good alternatives to the Conventional as better results were obtained in all the compared characteristics, except in the acoustic insulation in the conventional simple wall; although this parameter is not the one that most affect the residents.
Lightweight Natural Fibre wall presents best values in terms of thickness, U value and Specific weight and Heavyweight wall, in the Embodied Energy, due to the higher mass, and the specific costs.

Table 1. Technical Characteristics of Conventional and Natural Fibre Walls.

<table>
<thead>
<tr>
<th></th>
<th>Conventional Walls</th>
<th>Simple wall</th>
<th>Double wall 15+11</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition</strong></td>
<td></td>
<td>ETICS + Hollow brick 22 + Plaster</td>
<td>Plaster + Hollow brick 15 + Air gap + XPS + Hollow brick 11 + Plaster + Clay Tile</td>
<td></td>
</tr>
<tr>
<td>Thickness (cm)</td>
<td>275</td>
<td>350³</td>
<td>312.5</td>
<td></td>
</tr>
<tr>
<td>Acoustic insulation Dn,w (dB(A))</td>
<td>53³</td>
<td>51³</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>U value (W/m².K)</td>
<td>0.42</td>
<td>0.49⁹</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Embodied Energy (kWh/m²)</td>
<td>858</td>
<td>1018⁹</td>
<td>938</td>
<td></td>
</tr>
<tr>
<td>Specific weight (kg/m²)</td>
<td>268</td>
<td>332⁹</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Specific useful thermal mass - Msi (kg/m²)</td>
<td>150⁹</td>
<td>89</td>
<td>119.5</td>
<td></td>
</tr>
<tr>
<td>Specific cost (€/m²)</td>
<td>63.15</td>
<td>73.35</td>
<td>68.25</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Natural Fibre Walls</th>
<th>Light weight wall</th>
<th>Heavyweight wall</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composition</strong></td>
<td></td>
<td>Cement/wood fibroboard 12mm + Air gap + Expanded extruded polystyrene + Cement / wood fibre board 19mm + Black cork agglomerate + Coconut fibre + Air gap + 2 Carton Plaster Board 13mm</td>
<td>Cement/wood fibroboard 12mm + Air gap + Black cork agglomerate + Adobe + Lime</td>
<td></td>
</tr>
<tr>
<td>Thickness (cm)</td>
<td>252</td>
<td>267</td>
<td>259.5</td>
<td></td>
</tr>
<tr>
<td>Acoustic insulation Dn,w (dB(A))</td>
<td>50⁹</td>
<td>53¹</td>
<td>51.5</td>
<td></td>
</tr>
<tr>
<td>U value (W/m².K)</td>
<td>0.40</td>
<td>0.44</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>Embodied Energy (kWh/m²)</td>
<td>442</td>
<td>171¹</td>
<td>306.5</td>
<td></td>
</tr>
<tr>
<td>Specific weight (kg/m²)</td>
<td>79¹</td>
<td>257</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td>Specific useful thermal mass - Msi (kg/m²)</td>
<td>22²</td>
<td>89</td>
<td>55.5</td>
<td></td>
</tr>
<tr>
<td>Specific cost (€/m²)</td>
<td>85.9²</td>
<td>46.55¹</td>
<td>66.23</td>
<td></td>
</tr>
</tbody>
</table>

¹Best values; ²Worst values.

The use of lightweight construction materials and systems can easily allow reach a good environmental profile. But a lightweight housing building in a temperate climate can be problematic, from the point of view of the thermal comfort because of the insufficient thermal inertia. The introduction of some thermal mass is thus essential to achieve comfort with the minimum use of mechanical heating and/or cooling systems and also from the acoustical performance point of view, as acoustic insulation relies essentially on mass, especially for the medium and low frequencies. That’s why a mixed weight system was proposed by Mendonça (2005), with an optimized mass use, in order to allow an intermediate weight between a lightweight solution and a conventional heavyweight solution. The proposed system also pretends to conciliate the thermal, acoustic and natural illumination performance. Apart from its functional efficiency, this strategy can be more consensus then the common prefabricated lightweight constructive systems (so-called prefabricated panels). It is important to refer the
fact that this proposal is a system and so the proposed solution here presented and evaluated is just one possible solution for this system.

4 CONCLUSION

In this paper the possibility to achieve more sustainable housing units replacing synthetic materials by natural fibres on exterior walls was demonstrated, having in mind that functional aspects can be safeguarded. Two alternatives for external walls using Natural Fibre materials were given and a comparison study with the Conventional wall solutions revealed that they present better values in almost all the characteristics analysed. The Natural fibre elements of the proposed Walls can also be made by using artisanal methods and techniques, in order to achieve a more sustainable production cycle. As natural material, Cork and Coconut are good applicable solutions already being applied.

In the past, Portuguese construction was strongly characterized by primitive techniques using the raw materials existent in the different regions over the territory. Nowadays, very little reconstructions can be found and the existent are in touristic areas such as in the Natural Park of Gerês and in Madeira Island. Cork, a 100% recyclable material, is a Portuguese product, so its use also promotes the Portuguese economy and local ecology. Indeed, Portugal produces more cork than the rest of the world, occupying the cork a large area of Portuguese territory. There are many cork applications, such as in Bottle Tops, Interior Design, Fashion Accessories (bags and jewellery, etc) and Stamp. In construction, it is used as thermal and acoustic insulation of interior and exterior walls.

Other sustainable strategy in Portugal is the Art Craft, one of several popular strategies, which enables intelligent men and women return back to scepticism and direct the work process as the design of their artefacts using natural raw materials and recovering past techniques or adapting new taking the knowledge from the old ones.

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