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A PARAMETRIC COMPOSITION BASED ON CORK MORPHOGENESIS

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ABSTRACT

Inspired in nature's production system, the generative design processes enable designers to rethink architecture design procedures. The objective of this paper is to describe a geometrical composition based on cork biological constitution and growth. This research was developed within the framework of the CEAAD course, at ISCTE-IUL, during the 2012/2013 academic year. The goal was to develop a parametric, customable and adaptive geometric definition, using as starting point standard industrial products of expanded cork agglomerate and the biological morphogenesis of cork.

The reported work combines a rational and practical understanding of the micro-structural and compositional properties of the raw material - cork - and its derivate - expanded cork.

The result is a generative geometrical definition tool that is able to generate new products, totally adaptable to specific environmental conditions, personalized for its use and therefore, easily commercialized!

From micro-structural composition to macro-scale construction, this research explores new geometrical application possibilities through the implementation of design principles from biology - biomimicry.

1. INTRODUCTION

Patterns occur in nature as in man-made designs. Generally, patterns are described as recurring events and repetitive material formations. Natural systems patterns arise from self organization. These systems are based on the interaction / feedback between system elements and exchange of energy between open systems – Matter<> information<>environment. Man-made patterns examine the outcome data extracted from the observations of the self-organization growth of natural systems. This process, examining characteristics and principles, is currently named 'pattern recognition' [1].

Biomimetics can be defined as the implementation of the design principles extracted from biology. Biological principles can be applied

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either literally or through an approach oriented towards systems. On the other hand, an abstract approach emphasizes the main principles to be used making technology more powerful and pervasive. To produce engineering solutions with basic attributes of biological systems such as low energy, reutilization, durability and versatility is one of the most relevant goals of biomimetics approaches.

2. BACKGROUND

Among our history patterns have served as valuable instruments of description and construction, such as building systems that perform and relate with its environment through patterns. The development of new systemic forms in architecture has pursued computational tools for the construction of alternative models. These computational explorations have employed the development of generative patterns capable of creation, social interpretation, materials and spatial systems. The earlier example can be found in 1967 through the foundation of 'The Architecture Machine Group' (AMG) by N. Negroponte – to develop new digital tools for architecture - and the foundation of the 'Center for Advanced Visual Studies' by G. Kepes – a platform for Art and Technology. Both explored new concepts of constructions, science and technology, in an art/architecture symbiosys as an emerging new class design. At the same time the Experiments in Art and Technology (EAT) was founded by B. Klüver, F. Waldhauer R. Rauschenberg and R. Whitman. One year later Jasia Reichardt curated the exhibition 'Cybernatic Serendipity', bringing together architects, mathematicians, scientists, engineers and artists at the ICA in London; in the same year, Computer Arts Society is founded. This was a remarkable period where issues related with pattern recognition, participation, interaction, articulation, intelligence and evolution emerged. In 1977 in his pattern pursuit as an associative networked system, C. Alexander publishes 'A Pattern Language'. In this seminal book Alexander examined generative scenarios that he described in 253 unitary patterns based on traditional architecture. The AMG and Alexander radically influenced systemic design leading to what is currently known as MIT MEDIA LAB. In 1980, J. Frazer published 'An Evolutionary Architecture'. His work essentially explored computation as a conceptual modeling process. As an evolution of correlated systems of interaction, computation serves as a tool for the production of new forms of structured spatial organization based on material and behavioral patterns. [9]

3. GOAL

The main goal of this research was to develop a parametric definition based on cork biomimicry and applicable in an industrial context through Computer Aided Design and Computer Aided Manufacture (CAD/CAM) resources. This parametric definition aims at providing a generative line of products derived from the biological properties and composition of cork through the implmentation of design principles based on the material natural pattern.

The target was to develop a full scale façade prototype – 'CORK'EWS', designed and prototyped considering raw material formal composition properties and consequently performance and environmental behavior. These factors will be determinants on the design of the final object. Like in nature, the pure essence of the material performance is not only determined by its own structural and functional composition. Environment is one of the most important conditions. It influences growth, formal topology, compositional pattern, natural performance among others characteristics.

4.METHODOLOGY

The methodology used to develop the 'CORK'EWS' pilot product included five stages. Stage 01: Cork Gestal addressed morphogenesis structure and its behavioral compositional form, as well as a specific characteristic – the material anisotropy; this was done by an understanding of cork microstructure. Stage 02: Cork Basic Properties studied, in a generic way, the chemical and mechanical properties of the basic cork material. Stage 03: Expanded Cork Agglomerate targeted the characteristics, properties and applications of the derivative material expanded cork agglomerate. Stage 04: CAD/CAM System included the parametric + NURBS design and the production of the first prototypes. Stage 05: Prototype fabricated the final prototype. Each stage was informed by the results of the previous ones as a validation and comprehensive process.

STAGE 01: CORK GESTALT

Material properties are intimately related with material structure.

Cork was one of the first materials that Robert Hooke (1635-1703) observed on the optical microscope. This microscopic observation allowed Hooke to identify a base unit of the structure of plants and biological tissues. In his book 'Micrographia' (1664), Hooke shows drawings representing the structure of cork. Hooke detected the material anisotropy and designed two separate sections of the cells. A first section more or less isotropic and a second section representing elongated walls, arranged in contiguous rows. This unit was referred to as cell.

The cellular materials are formed by hollow cells, open or closed. In the cork specific case cells are closed and the cells walls volume fraction does not exceed 15%. This solid fraction is a composite that includes polymers as suberin, lignin and cellulose. New cork cells are formed by protoplasm (cytoplasm + core) that is dwarfed by the cell membrane.

This thickening is derived from the deposition on the cell membrane of layers with different structures and chemical compositions. Generally it is considered that the cell wall is composed by primary, secondary, and tertiary walls, individualized and with different chemical compositions. So, it is not wrong to say that cork is a vegetable material with exceptional and particular environmental qualities: a renewable and recyclable resource, non-toxic and durable with excellent physical and mechanical properties. Microscopically, cork's internal structure is made up of layers of alveolate cells, whose membranes have a certain degree of impermeability and are full of gas which occupies 85% to 90% of its volume. According to its three-dimensional organization in space, cork draws an anisotropic condition that varies according to its several sections – Radial; Tangential; Axial. Actually, in one tridimensional structure, constituted by a many cells, the number of vertices (V), edges (E), faces (F) and cells (C) are related by Euler's Law,

$$C + E = F + V$$

where C: cell; E: edge; F: face; V: vertex.

In a simplified way, the cork cells can be described as raw hexagonal on average, grouped in columns or rows, whose axis is in the radial direction. The cells of the same column are generated one after another by the same felogeneo cell. In this simplified model, cells are all equal (hexagonal prisms, all with the same height), and each side of a given cell is in contact with a cell base in the adjacent column. Therefore, each of the six sides of each cell is in contact with two neighboring cells. Each of the two bases of a cell is also in contact with a neighboring cell in the same column and therefore the total number of neighboring cells of a given cell is 14: 12 side faces and 2 bases.

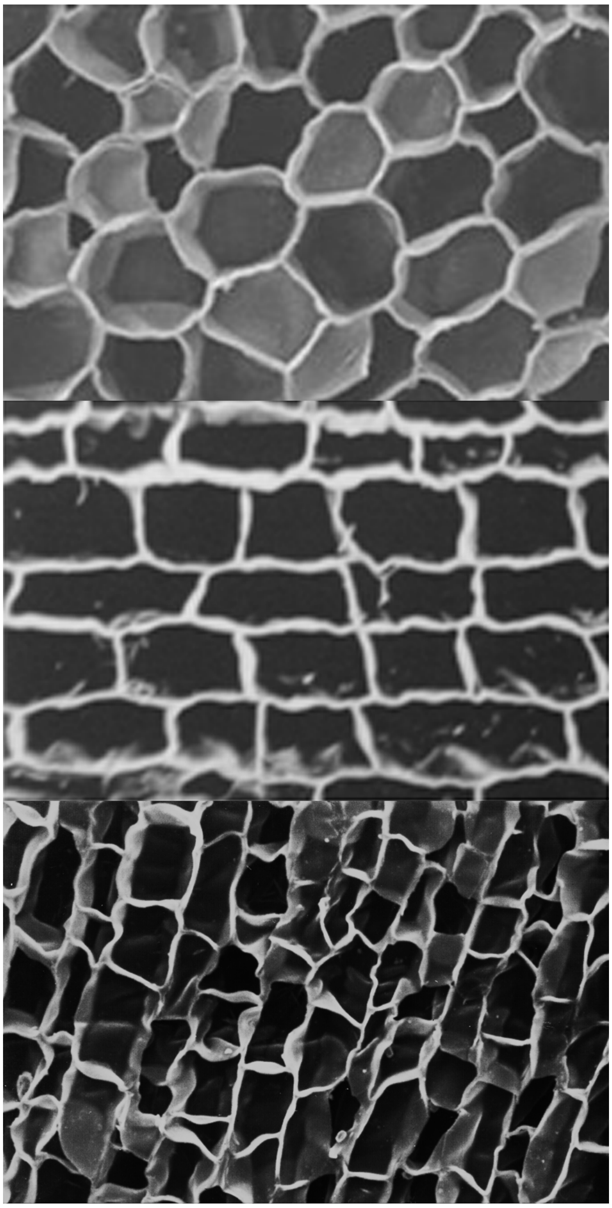

Fig.1 - A: cork tangential section – honeycomb [10];
Fig.1 - B: cork transversal
section - brick-like composition [11]
Fig.1 - C: cork radial section – brick-like composition [12].

The three sections are quite different from the geometric point of view: while the tangential section features a honeycomb type structure, transverse and radial sections exhibit a brick structure (Fig. 1).
In the transversal and tangential sections, neighboring cells overlap by a relation of 1/3 and 2/3 of the face length.

STAGE 02: CORK BASIC PROPERTIES

The main chemical component of cork is the suberin. This component has a lipid structure of polyester and is the main responsible for the elastic properties and the very low cork permeability. In many of its applications, cork and cork agglomerates are subject to compression, and more rarely to tension. The most common situation is that of uniaxial compression. Several important elastic and non-elastic properties are obtained with uniaxial compression tests. Cork is an anisotropic material what would make it necessary to perform its assessment in the three main directions - radial, tangential and transversal. However given the material structure, similar properties are expected in the non-radial directions. In this way, only the compression in radial and in any non-radial directions may be considered.

STAGE 03: EXPANDED CORK AGGLOMERATE

The expanded cork agglomerate is essentially composed of virgin cork and remains of amadia cork. Known for its extraordinary characteristics, such as thermal, acoustical and vibration insulation, the expanded agglomerate cork is a 100% natural product. The elasticity of cork is the basis for a good acoustical performance and vibration isolation.
Besides the good performance insulating airborne sound, the expanded cork agglomerate admits an easy penetration of sound waves and reduces the reverberation time due to its porous structure. With regard to water absorption, boiled cork absorbs up to 1.3 times its dry weight. The corresponding increase in volume is minor, not exceeding 15% after long periods.

EXPANDED CORK AGGLOMERATE APPLICATIONS

Main applications for expanded cork agglomerate are essentially in the construction market. Common uses include thermal and acoustic insulation in the external envelope of the building,

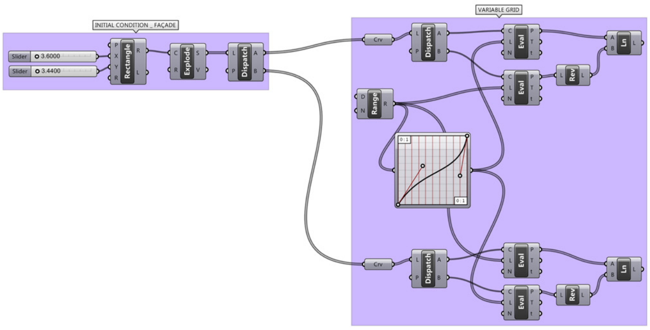

Fig. 2 - CORK'EWS definition: first cluster – the base grid

core material in prefabricated wooden panels, expansion joints and, more recently, external finishing in walls. Besides the construction industry, a new application field is the use of expanded cork agglomerate in product design. Several designers and architects are exploring the physical, mechanical and aesthetical properties of cork. CAD/CAM technologies are introducing value in this new kind of products. The personalized potential and the easy dialog with the industrial production are attracting designers to these new logics.

STAGE 4: CAD/CAM BIOMIMICRY GEOMETRY

After some CAD/CAM tests, it was concluded that the best anisotropic section of cork raw material to design with agglomerated cork was the radial section.

The process of form-finding was performed through a parametric mesh that was based on the geometry of this radial section.

Using the Grasshopper, a grid was defined, customizable in its limits, divisions and angular guidance. In this way it is possible to contain, open, and populate the grid with any number, size and orientation of cells. The first input clusters refer rectangular base grids (taking as base the rectangular section of the agglomerate expanded cork panels) that enable to re-dimension the architectural component.

For example if designing with the expanded cork pattern for an internal wall, the base grid should have that precise dimensions (Fig. 2). The second part of this first cluster is completely devoted to cells orientation. Again all limits and boundaries are reconfigurable. This total reconfiguration should be cautious. The cluster was designed to accept all kind of values. However, the form finding process only gets to a perfect and sustainable biomimetics solution when a number of important relationships are respected. These relationships are final object scale / pattern scale, the proportional equilibrium between area and number of cells, material depth / cells. So, to define the degree of magnitude and direction of the grid, a MapGraph was introduced, to control and inform the geometric composition.

Having a parametric grid defined, it was necessary to develop the cells. The cells have a meandering form, with varying degrees of curvature. To simulate its rebuilding it was necessary to use several control points. The control points are directly extracted from the geometry of the grid. This premise enables to automatically change the geometry of the cells through the grid configuration form. Thus, the geometries are totally interdependent of each other.

As the base is the geometry of the radial section of cork, it is necessary to replicate the interior of the cell, which represents the face shared with the neighbouring cell (Fig. 3).

This particular characteristic of the radial section is essential in the support of the projected geometry. It's this interior 'loft ' that provides the reinforcement of the mechanical resistance of the

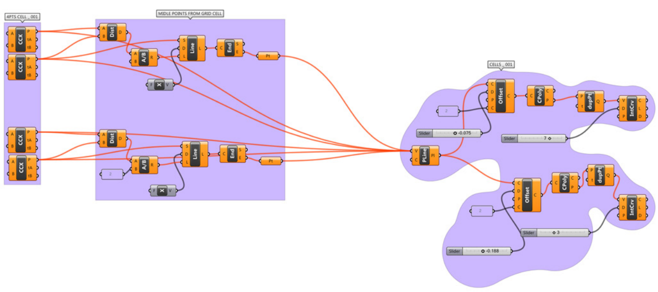

Fig. 3 - CORK'EWS definition: second cluster – the cells!

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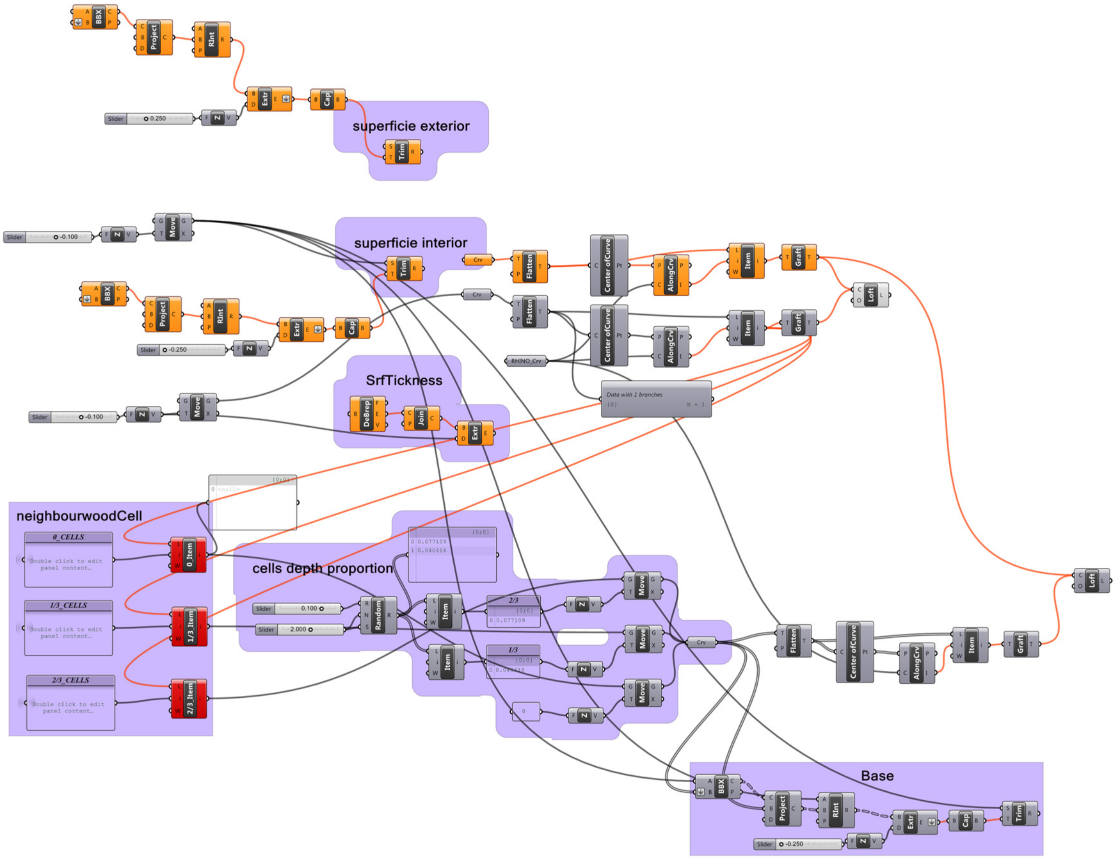

Fig. 4 - CORK'EWS definition: third cluster – 3D geometry and industrial standard panels!

transposition from the micro into this macro scale. The third cluster of this definition aims at creating the volumes. In this third stage three types of panels are developed. The three solutions had to be prepared and treated as a parametric option. The definition is therefore prepared to support three different pattern logics. The first option is related to an interpretation of the transversal section of cork. The outline of the cells entirely drills the material, offering only two different dimensions, 100 mm or 0 mm. This solution proved to be extremely successful for potential new structures to be used in both vertical and horizontal panels. However the very low flexural strength makes it only adequate for light structures with very soft environmental conditions.

The second option explores the same logic of the previous, adding some diversity in the transition of the dimensions of the cells. So the cell has different configurations at two different levels. Thus, a 'loft' is used for the connection, which provides higher resistance to the compositional structure. This geometry is intermediate in its morphogenetic interpretation.

Exploring exactly the same concept of cork cells, it however ignores quota switching that occurs in tangential section. The third option is pure biomimetics. In this option cells have two different outlines aligned in *zz*. The depth of each cell is configured to mimetize the cork cells geometry, unifying itself in order to never have a neighbour cell with the same depth. Cells are also organized with the 0, 1/3 and 2/3 logics (Fig. 4).

The developed parametric design definition, emphasis the possibility of new possible applications and uses for the expanded cork agglomerate. Combining expanded agglomerate acoustical characteristics and performance behavior, and exploring thermal and shading design properties possible exterior applications, two virtual essays become essential to inform and validate our parametric geometry - acoustic and solar shading performance. In order to substantiate choices and (re)draw conclusions, it was necessary to re-

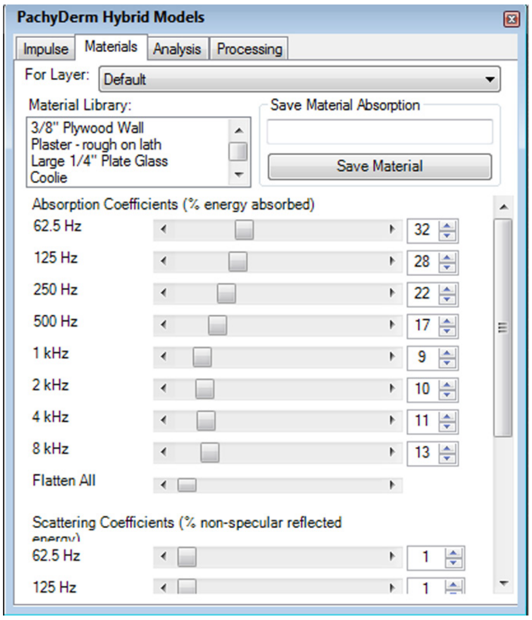

Fig. 5 - CORK’EWS – Setting Cork material properties; Right Fig. 85 - CORK’EWS – Running .hz analysis

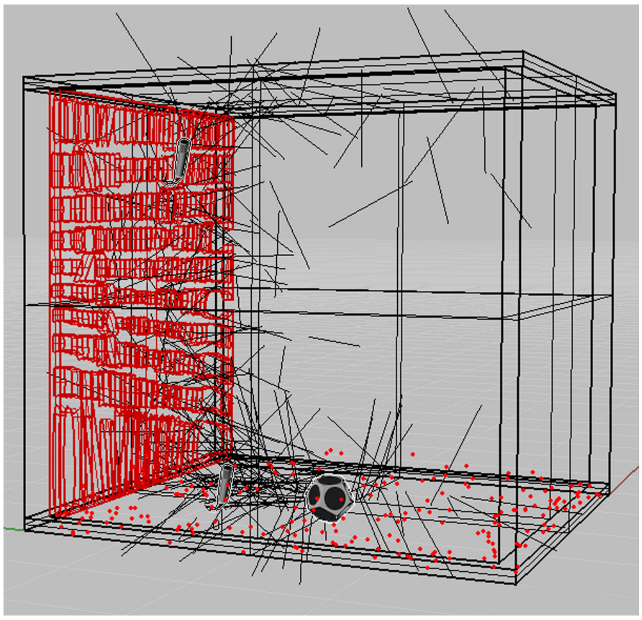

Fig. 6 - CORK’EWS – Pachyderm simulating acoustical behavior and repercussion (perspective view).

sort to Pachyderm acoustic analysis plug-in for RHINO and to GECO to transfer the geometric model from Grasshopper into Ecotect (Autodesk).

PACHYDERM

Pachyderm was an important aid to understand the implications of this new pattern in acoustic performance. Among the several panels, the one with best results was the third option, the biomimetic pattern of cork. . Based on this simulation (Figures 5 and 6), CORK’EWS product proved to have a good sound absorption capacity. The comparison of the several geometries was consistent with the well-known fact that irregular shapes contribute to a better acoustic insulation because of the progressive absorption of different sound frequencies.

ECOTECT + GECO

Through the use of GECO, it was possible to establish a link between Grasshopper and Autodesk Ecotect environmental analysis
Ecotect simulation allowed for the extraction of important information about the solar shading properties of the geometric patterns. (Fig. 7 and 8).

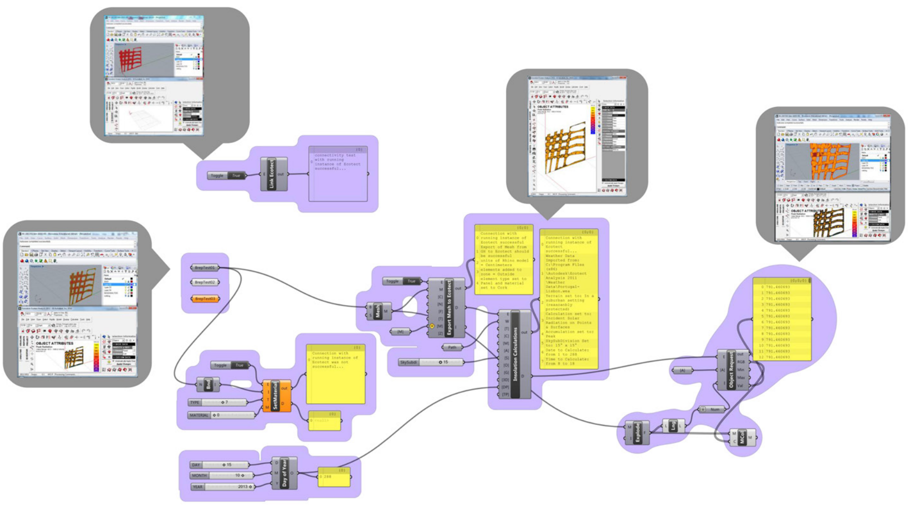

Fig. 7 - CORK’EWS definition: GECO definition+Ecotec.

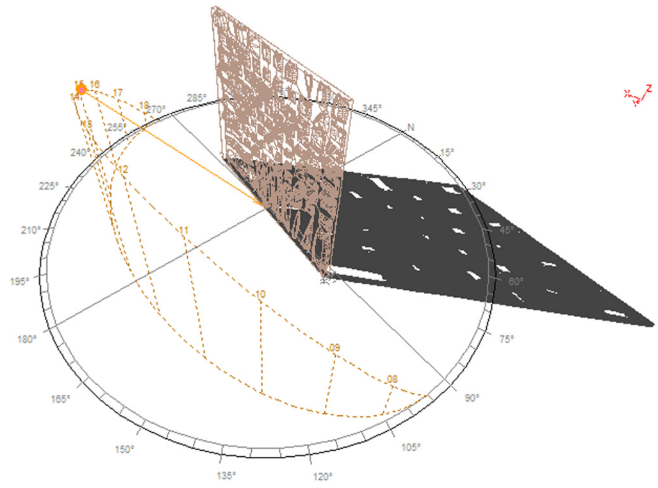

Fig. 8 - Solar shading – simulation at 3:30 PM, using .WEA of Lisbon.

5. RESULTS

After a detailed set of acoustic and solar simulations the standard typology chosen for the final object was the option 3.

The final prototype was going to be installed in an exhibition room and therefore the acoustic performance was considered as more relevant.

Having set a parametric pattern, with the necessary scale to function as a sound system, the final step was to define the most convenient form form for the object about the exhibition room has 80 m^2 and two open floor levels. Construction elements are based on reinforced concrete and brick masonry. Echo is a predominant characteristic. An object was conceived, negative of itself, because its performance was intended to improve the environment around it.

Designed on a fully parametric logic, integrating inputs from the raw material, solar shading properties and acoustic performance, CORK'EWS is the first full-scale prototype (Fig. 9) that demonstrates and validates the potential application of this performance-based parametric methodology.

Fig. 9 - CORK'EWS final prototype.

6. CONCLUSIONS

Based on the performance simulations, the final prototype proved that biomimicry-based pattern definition, with the topological characteristics of cork, delivers added value for improved acoustic insulation and solar shading.

This research showed that the mimetic of microstructural composition, when adequately designed and applied (considering scale and topology), allows an improvement of the system performance. In this specific case, a new expanded cork agglomerate product was designed and fabricated. Applications may differ from external and internal solar and noise control to simple reorganization of hybrid spaces.

. Moreover, the final output reveals adequate conditions for the self-assembly of expanded agglomerate cork panels without any other kind of external material or glue components. This particular issue needs further development, exploring geometries and processes of self-assembly components.

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