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FROM MORPHOGENETIC DATA TO PERFORMATIVE BEHAVIOUR

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Abstract. This paper presents part of CORK'EWS, a research work developed within the framework of the Digital Architecture Advanced Program 2012/13 at ISCTE-IUL. The main goal of this investigation was to develop a parametric, customizable and adaptive wall system designed for environmental performance. Moreover, the system is based on standard industrial products: expanded cork blocks produced by Amorim Insulation industries. CAD/CAM resources were the essential tools of the research process, where fundamental and practical knowledge is integrated to understand the microstructure morphological properties of the raw material – cork – and its derivate – natural expanded cork. These properties were upscale and adapted to create a wall with an optimized solar control environmental performance. The result is a digitally fabricated prototype of a new customizable industrial product, adaptable to specific environmental conditions and installation setups being therefore easily commercialized. From microstructural morphology to macroscale construction, the research explores new application possibilities through morphogenesis and opens new possible markets for these customizable products.

Keywords. Morphogenesis; performance; shading systems; cork.

1. Introduction

Traditionally, materials are classified by their various properties – mechanical, thermal, electric, magnetic, optical and acoustical. On the other hand, it is also common to separate structural and functional materials. The former are exploited essentially for their mechanical properties, while the latter for their acoustical, thermal, shading and other specific properties or combinations.

Instead, in nature, there is no distinction between structural and functional materials! Through integrating the properties of two or more compounds, performance optimization is achieved. Frequently, these natural composite materials also have directional-based properties, i.e. they are anisotropic. Anisotropy is directly linked to materials microstructure (grain and fiber patterns and orientation). In digital form-finding processes, anisotropy may be used as an optimization tool for programming physical matter.

This research looks into cork anisotropy and its potential in a digital form-finding process to design and fabricate new applications for standard expanded cork products.

2. Issue

Expanded cork boards are currently used as simple anti-vibratic, thermal and acoustic insulation. Generally, in thermal and acoustic applications the cork boards are applied inside a cavity wall, behind a plaster layer or beneath the floor coating. In some more recent cases ink coated cork boards are the final layer. This usage of the expanded cork boards is nevertheless too limited. Being a noble and 100% natural material, with texture character, unique colour and odour sense, several architects and designers are now exposing this material in its natural state to the external environment. These new uses consist mainly in the application of the standard cork boards as the external coating of the building.

However, until now, the gain of using cork as external coating has been limited. A new formal expression is indeed obtained, but with no performance improvement compared to previous common uses.

The base question of this research is how an extended comprehension and knowledge of the cork raw material, its natural growth and compositional structure could be the key to improve the existing products or even create new ones. Environmental performance has been selected as the main driver for this search and upscaling from microstructure to architectural system was the process to implement it.

3. Hypothesis and goal

The fundamental hypothesis that supports this research is based in the observation and understanding of the cork raw material morphogenetic structure.

This research looked into cork anisotropy and it’s potential in a digital form-finding process to conceive and fabricate new possible applications and uses for the standard expanded cork product. It is intended that the material is not only integrated in the computational design, but also acts as one of its generative morphogenetic drivers. The microstructure of the material and the macroscale of the system are here conceived as continuums of reciprocal data flow, upscaling microstructural properties to architectural potential and environmental performance. This process drives us into a vast search space for design.

The natural structure and composition were related to the physical and chemical characteristics of the raw material. This knowledge was then the basis to understand the reasons behind the good performance of cork as insulation material with a very low thermal expansion coefficient, high compressive strength-to-density ratio, very low water absorption and high durability. This natural model was replicated to the scale of an architectural system to create a wall with an improved acoustic and solar performance. In this paper we will detail design issues related to solar shading. The design methodology used form-finding processes. A parametric definition included cork morphogenetic data, expanded cork characteristics and environmental parameters. This form-finding process enables the user to produce an environmental responsive material system.

So, the goal of this research was to developed two new types of additional applications for agglomerated cork boards, based on the specific compressive strength (strength to density ratio). So the target was to produce a thermal/acoustical panel that could be used as an external wall building system or as an independent architectural model such as novel self-structured solution.

4. Methodology

4.1. GEOMETRY BASED CORK MICROSTRUCTURAL COMPOSITION

Cork is an anisotropic material. Three different morphologies are identifed depending on the type of section being observed: Tangential; Transversal and radial. This constitution provides cork specific and unique characteristics. Its microstructural cells, also referred as Kelvin polyhedral (Fortes et al, 2004), are organized in a 1/3, 2/3 overlapping proportions. This situation is clearly visible in the transversal and radial sections. Instead, in the tangential section cells are mainly organized as a honeycomb assuming hexagonal forms. The six sides of each cell are in contact with two neighbouring cells (Figure 1).

Microscopically, cork's internal structure is made up of layers of alveolate cells, with cell walls that have a very low permeability and are full of gas. Total gas volume accounts for 85% to 90% of total material volume (Silva et al, 2005). This condition provides cork its resilience and very good insulation properties (thermal and acoustic), maintaining a reasonable light weight.

Figure 1. Cork sections – tangential [1]; transversal[2] and radial[3].

Cork compositional geometry suggests two possible approaches to explore through CAD/CAM methods (Figure 2): the first one (Figure 2- 1.0) leads us into a direct geometrical interpretation of the cells structure. This is a rational interpretation of the cork sections, exploring its geometry – such as the hexagonal structure of the radial section, which derives in a voronoi structure. The second approach (Figure 2- 2.0) is based on an interpretation of the morphogenetic composition of the cork, applying its microstructural features (cell volume, morphology and proportions, as well as cell wall thickness) to conceive a new geometry that potentiates the expanded cork agglomerate. Both approaches were explored using CAD/CAM processes (Oliveira and Rato, 2014).

After the primary CAD/CAM tests, it was concluded that the best anisotropic section to explore as a basis in agglomerated cork was the axial section. Indeed this is not a 'pure' section. Moreover, the final solution was explored combining the axial and radial sections. The Z proportions were explored through the radial section, introducing a new density to the boards of expanded agglomerate.

Figure 2. CAD/CAM experiences.

Using Grasshopper (Figure 3), a grid was defined, customizable in its limits, divisions and angular guidance. In this way, it is possible to contain and populate the grid with a previously defined number, size and orientation of cells. The first input clusters refer to rectangular-base grids enabling to redimension the architectural component. The second part of this first cluster is completely devoted to cells orientation . The form-finding process only gets to a final and sustainable biomimetics solution when obtained values respect the following relationships: (i) Final object scale/pattern scale; (ii) Area/number of cells; (iii) Proportion depth of material/depth of cells. In order 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. Control points are directly extracted from the geometry of the grid. This premise enables to automatically change the geometry of the cells through grid configuration, based on cork agglomerate values of mechanical strength and acoustic propertiesThus, the geometries are totally interdependent on each other. Moreover, it is necessary to replicate the common cell wall shared by two adjacent cells. This particular component of the axial section is essential to support the design geometry. It is this interior ‘loft' that provides for cork mechanical strength replicating micro to macroscale.

The third cluster of this definition aimed at creating volumes. In this third stage three possible types of panels were pointed out and prepared as parametric options. The first hypothesis (A) was based on a design interpretation of the geometric proportions of the cell radial section. The second hypothesis (B) developed the logics of the previous, adding the proportions of the neighbouring transversal section. In the final hypothesis (C) the structure is composed by the geometric composition of the radial section and a derivation of the proportions of the tangential Z values and volume (1/3 and 2/3) (Oliveira and Rato, 2014).

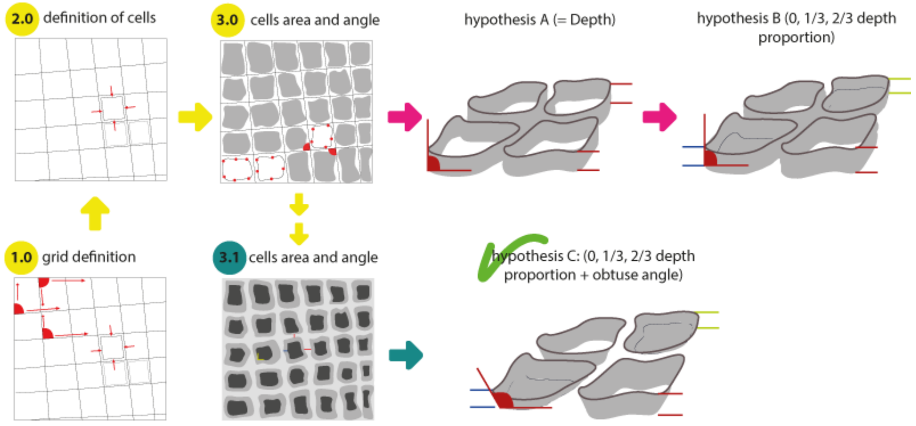

Figure 3. Diagram of the parametric definition – essential clusters (1.0 - base grid, 2.0 - cells and 3.0- 3D geometry and industrial standard panels).

4.2. INFORMING PARAMETRIC DEFINITION BY PERFORMANCE

To improve a 100% natural and industrial product arises the questions: “Which properties can be enhanced?”; “What are the most relevant features for the current and future markets?”.

4.2.1. Shading virtual essays – introducing Ecotect analysis through GECO

As referred above, the main goal were to customize and improve through performative behaviour the existing industrial product. The idea of providing to customers an environmentally optimized and customizable product, industrially designed and manufactured was defined as a starting point. Solar control and acoustic insulation was then considered as two important environmental requirements for external construction systems. In particular, solar shading would fit the objective of customizing the final product by adapting geometry to local solar radiation conditions.

To inform the parametric definition on shading control, virtual models were ran on Ecotect analysis software. Geometry was inserted in Ecotect through the GECO (Grasshopper plug-in).

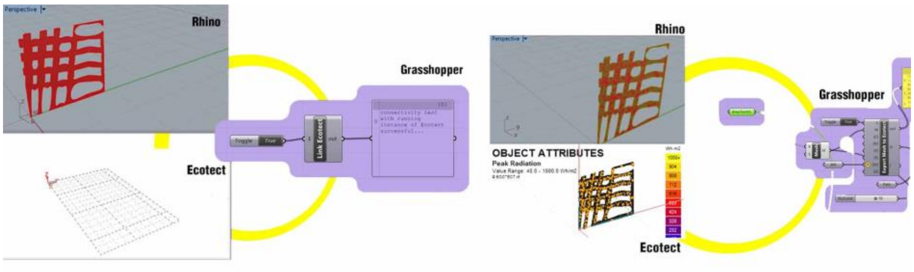

Figure 4: Rhino+GECO+Ecotec.

Having the three parametric models prepared, A, B and C refered above, and transformed into Mesh's, the first step was to settle GECO toggle, enabling the connection and recognition between the modeled geometries and GECO. The second step of this definition was to establish the recognition of the RHINO geometry into a Mesh recognized by Ecotect. This box also specified the type of material of the system so to inform simulations about the relevant properties (Figure 4).

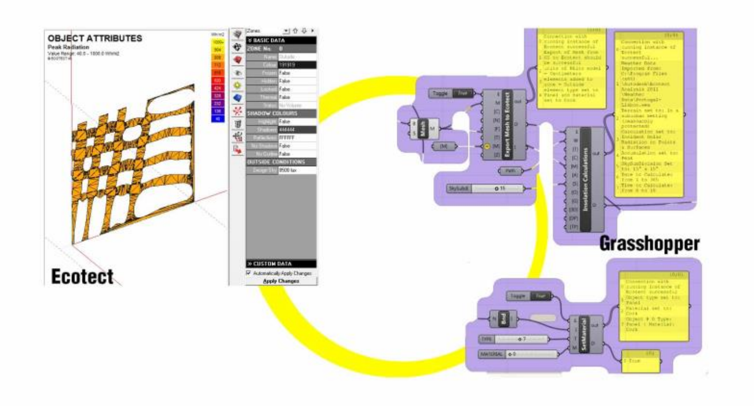

Figure 5. : GECO+Ecotec.

In the third step a box was set with the appropriate environmental information related to the location. With this box it is possible to define climatic data and variables to run the simulations, such as geographic coordinates, season of the year and humidity conditions (that are conditioned by vegetation) (Figure 5).

It should be noted that this information could also be loaded through the Ecotec workspace. However, it is important to concentrate the input information in one single tool what enables changes to be implemented instantly in all workspaces.

At this point the geometry was running in two different workspaces: first in RHINO+Grasshopper+GECO and in Ecotect. This is a progressive and iterative succession of data analysis. However, the intention was to have an integrated approach where the three workspaces would condition each other in an autonomous way. For instance, when introducing data in GECO, Ecotect responds automatically; this in turn gives feedback and makes this modification visible in the RHINO model, enabling to check the necessary changes in the geometry of the system. To implement this process it is necessary to create a 'translator' inside GECO. This translator "*Object Request*" will enable to settle an instantly loop between the three software's, creating automatically-generated and real time responses (Figure 6).

The material and its properties are again the main performative driver. Parameters such as density, compression strength and gas volume are essential to characterize the material. This data is inserted through GECO. Then environmental data such as humidity factors driven by sea proximity or local vegetation, as well as simulation criteria such as time period will determine several geometrical conditions.

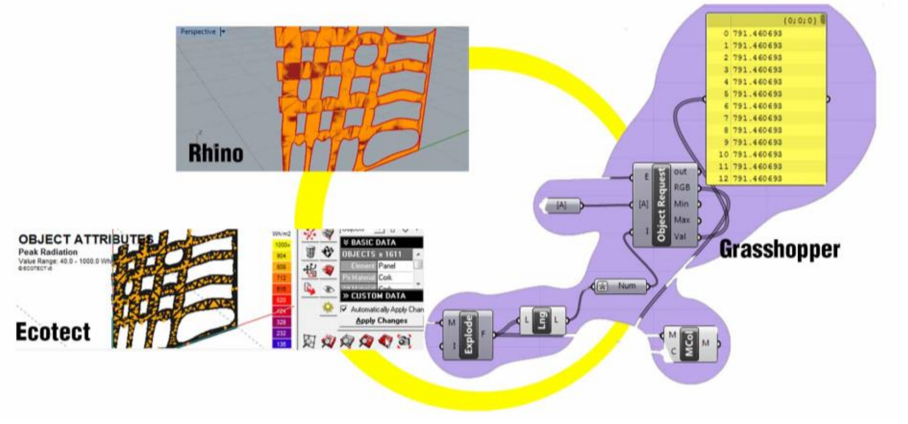

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Figure 6. : Rhino+GECO+Ecotec.

Through the simulations that were performed it was possible to determine the best orientation of the pattern, the best angle condition, and also to calculate the void fraction of the cork panel. This information is valuable not only to the overall performance of the system, but it may also be the basis for the personalization.

Having this GECO motor running all the necessary changes to produce the geometry are calculated through its performance. The cells areas, the thickness of the cells walls, the geometrical direction of the pattern, everything can be re-defined using environmental data as support.

5. Conclusions

This research is believed to open new possibilities for innovative applications and uses of the expanded cork agglomerate.

Moreover, biomimetics prove to be one valuable way to produce/improve industrial materials. During this research, cork microstructure was analyzed, physically tested, and even improved with the integration of specific parameters. Therefore CORK'EWS (Figure 7) is not a mimesis of the natural cork microstructure, it is an upgrade of its natural microstructure, applied to expanded agglomerate and improved by environmental data.

Figure 7. : CORK'EWS panel.

The focus on the possibility of integrating these CAD/CAM processes in an industrial environment was also a driver in the development of this system. The parametric definition proved to be a convenient methodology for this kind of users; however the number of parameters needs further improvement to lower complex inputs by non-specialized operators. This work looks to the material microstructure and macroscale production as a possible relationship. Linking microstructural properties to a specific intended performance, using CAD/CAM methodologies and parametric procedures we believe to have (re)created a potential new improved product.

Biomimetic, Bionics and organic architecture could lead the way to produce and build more innovative and powerfull energy passive solutions to our buildings and cities.

6. Endnotes

1. http://vinospasini.blogspot.pt/2012/04/metodos-de-cierre-del-vino-corcho-parte.html
2. http://www.teknorint.com/icerik/tr/genel_bilgiler.aspx?id=68

7. References

Benyus, J.: 1997. *Biomimicry: innovation inspired by nature.* HarperCollins Publishers Inc, New York, US.

Fortes, M. A, Rosa, M.E. and Pereira, H.:2004. *A Cortiça*, IST Press, Lisbon.

Menges, A., Reichert, S.:2012. Material Capacity – Embedded Responsiveness. In *AD Architectural Design Magazine*, Vol. 82 No. 2, Wiley Academy, London: 53-59. ISBN: 978 0470973301.

Oliveira, M.J. and Rato, V. 2014. A Geometrical Composition Based Cork Morphogenesis. *In proceedings Geometrias'14*, pp: 97-105. Lisbon, Portugal 17th-18th May.

Oliveira, M.J. and Rato, V. 2014. CORK'EWS: From microstructural composition into macrostructural performance. *In proceedings 2nd International Conference on Biodigital Architecture and Genetics*, pp: 320-330. Barcelona, Spain 4th-7th June.

Oxman, N.:2010. *Material-based design computation.* Ph.D. dissertation, Massachussetts.

Oxman, R.: 2007 Performance-based Design: Current Practices and research issues. *In International Journal of Architecture Computing*, issue 01, volume 06: 01-17,

Oxman, R.: 2010. Digital tectonics as a Morphogenesis Process, a special issue on Morphogenesis. *In IASS: Journal of the International Association for Shell and Spatial Structures*, 51(3) pp. 195-207.

Silva, S. P., Sabino, M. A., Fernandes, E. M., Correlo, V. M., Boesel, L. F. and Reis, R. L. *Cork: properties, capabilities and applications.* In International Materials Reviews 2005 Vol. 50 Nº 6.