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# 2nd INTERNATIONAL CONFERENCE OF
## biodigital architecture & genetics

# CORK' EWS

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*preserved author's typography

# CORK'EWS

## From microstructural composition into macrostructural performance

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**Abstract.** The main goal of this research was to develop a new, adaptable and personalized cork industrial product for environmental performance applications. The project started with the standard insulation products from Amorim Insulation Industries. Inspired on natural growth and performance, it found its basis on the observation of the properties and composition of natural cork, and explored cork anisotropy in a digital form-finding process to design and fabricate. A full scale prototype was designed and produced by a personalized parametric definition, using the form-finding processes based on cork anisotropy to program the physical matter and the digital fabrication for an improved acoustical behavior. The results obtained contribute to an increasing and more diverse offer of expanded cork products, within the scope of the natural and sustainable products of Amorim Insulation Industries.

**Keywords.** Cork; Micro/Macroscale; Morphogenesis; Material performance.

## Introduction

Traditionally, materials are classified by their various properties. For example, structural materials are exploited for their mechanical properties. On the other hand, functional materials are mainly exploited for their acoustical, thermal and other specific properties or combinations of them. Instead, in nature, there is no distinguishing between structural and functional materials! The diverse properties of natural materials are integrated and optimized. Anisotropy (directional dependency of properties) is frequent and part of that optimization, being directly linked with materials microstructure. In expanded cork materials, anisotropy is directly linked to the geometry and the spatial distribution of cells. In the digital form-finding processes, anisotropy may be used as a powerful tool for programming physical matter.

This research investigates cork anisotropy and its potential in a digital form-finding process to conceive and fabricate new applications and uses for the standard expanded cork product. It is intended that the material is not only integrated in the computational design, but it acts as one of its generative morphogenetic drivers. Conceiving the microscale of the material make-up and the macroscale of the material system as continuums of reciprocal relations drives us into a vast search space for design.

## Main Goal

The main goal of this research was to develop a new, adaptable and personalized expanded cork industrial product for environmental performance applications. The fundamental hypothesis supporting this project is the upscale of the microstructure composition of the raw material into architectural macrostructure design features, based therefore on natural growth and performance. This new product was to be prototyped in a full scale facade model. Like in nature, the design process was informed by environmental conditions, influencing growth, formal topology, compositional pattern and natural performance among others characteristics.

## State of Art

Towards a biological emergent paradigm in architecture, new CAD/CAM technologies also emerge providing to architects the necessary tools to design new solutions for a contemporary social, economic and political context.

Performance is now the greater component of the architecture thinking process. To provide cities and buildings with sustainable and ecological construction, it is necessary to develop new tools and materials, but also to recover the fundamental premises of traditional sustainable materials and construction solutions, promoting their natural potential.

Digital fabrication enhances the design process of buildings creating new experimental tools integrated in the creation phase. The possibilities of prototyping during the conception stage reveal to be a precious component for the design process, enabling physical evaluation. More than just creating prototypes, digital fabrication produces and generates more complex and natural structures, through a meticulous and precise dialog between the various software's. Formative, additive and subtraction digital fabrication processes provide architects with the necessary tools to approach industry; equally important, it provides industry with personalization and adaptation capabilities in addition to its standardization characteristics.

Biomimicry is a keygen for this new rising architectural design processes. In nature we find all types of performance-based processes. Neri Oxman (2010) explores in her PhD thesis several natural performance-based procedures applying it to different materials and functions. Supported by morphogenesis, she proved to be possible, with new digital design parametric tools, to reproduce nature structural performance. Introducing VPD (Variable Properties of Design) Oxman, proved a valuable issue: Form, structure and material emerges simultaneously. Totally inspired in nature's production systems, the generative design processes enable designers to rethink the architectural design process. Instead of seeking for a certain imagistic output, the final result of architectural design may also be a direct consequence of the physical properties of matter in response to performance requirements. This makes the case for a real integration between idea and realization. Although this generative processes have been emerging more seriously during the last decade, many years before, architecture tried to use nature as a referenced model. But compositions appeared fragile and as pure homothetic results. Material morphogenesis can originate architectural structure, constitution, density, volume and appearance. Understanding why and how materials provide the necessary knowledge to build efficiently strongly contributes to more adequate design answers to each kind of

environments and inhabitants, without any kind of superfluous waste. Morphogenesis is the key for supporting form generation by performance.
Materials selection and optimization will definitely acquire a recently unsuspected significance. Its natural performance, based on the biological structure and components, is the basis of a new kind of environmental responsive and interrelated architecture – living systems. The morphogenesis and the digital generative design processes are leading architecture into higher sustainable and ecological systems. Materials are being explored, studied and developed to provide new responsive and natural constructions. Assuming a simultaneous emergence of material, form and structure, architecture is becoming naturally responsive. Using generative parametric design processes, material properties are used as variables of the design process. Confronting these variables with design environmental requirements (such as thermal or acoustical comfort), it is possible to simulate specific responses and optimize design outputs. This valuable feedback data flow is the corpus that enables the model to design and redesign itself, within a performance-based context. In this sense, performance-based design architecture is a morphogenetic system.
The contemporary social, economic and political conditions are stimulating architects to create new strategies for fully sustainable solutions. Further challenges arise with the need to comply with industrial production.
Digital fabrication of expanded agglomerated cork has been explored by José Pedro Sousa in innovative ways, exploring new forms of cork transformation (Sousa, 2004). The ability of cork to generate new sustainable, affordable and personalized industrial product was the motivation of this work.

## Cork Structure

Cork was one of the first materials that Robert Hooke (1635-1703) observed on the optical microscope. After this observation Hooke defined a base unit for the structure of plants and biological tissues, which he referred to as "cell". The microstructure of cellular materials is based on hollow voids (the cells) separated by material walls. In the case of cork cells are closed and its volume fraction accounts for 85%. Cells walls are a composite formed by natural polymers: suberin, lignin and cellulose.
During cell growing, cell wall membrane thickens. This thickening is derived from the deposition of layers with different structures and chemical compositions. Generally it is considered that the cell wall is composed by primary, secondary, and tertiary walls with different chemical compositions. In 1877, Von Hohnel proposed one of the first models to the structure of cork cell wall. According to this model, the wall that separates two cells is made up of five layers. Von Hohnel considered that the wall would be made up of intensely lignified cellulose.
Cork is therefore a vegetable material with exceptional environmental qualities. It is a renewable, recyclable, non-toxic and durable natural resource with excellent physical and mechanical properties.
Microscopically, cork's internal microstructure is made up of layers of alveolate cells, whose membranes have a high degree of impermeability. Cell volume fraction may vary between 85% and 90%. Cork topology draws an anisotropic condition. Euler's Law is observed:

C + E = F + V

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

Despite this common topological characteristic, the three typical sections (radial, tangential, axial) are geometrically different: while the tangential section features a honeycomb-type structure (Figure 1a), transverse and radial sections exhibit a brick-like structure (figure 1b and 1c).

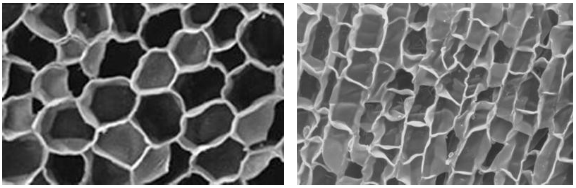


*Figure 1 - a) cork tangential section - honeycomb[1]; b) cork radial section – brick-like composition[2].*

The cork cells are arranged in space to form a three-dimensional structure. The direct observation of three-dimensional structure of cork is not possible; microstructural topology is therefore inferred from observations of flat sections.

### *Expanded Cork Agglomerate Fabrication Process*

Cork cells walls resilience is the reason for an extraordinary elasticity with reversible deformation. This property is the base for its known good acoustic performance, besides thermal and vibration insulation. The greatest acoustic insulation is related to frequencies between 1 kHz and 2 kHz (Salvador, 2001: 32).
Expanded cork agglomerate main applications are essentially related to the construction market. Main applications are in walls and roofs, prefabricated wooden houses, thermal and acoustic wooden panels and expansion joints.

## Loading Cork data into CORK'EWS

The study of compositional geometry of cork suggests two possible paths to explore. The first follows a purely geometric interpretation of its microscopic observation - a hexagonal grid (honeycomb structure) with many levels and layers of disturbances, which derive in a structure of voronoi. The second, exploring the mechanical capability, through its anisotropy in the radial section. Both options were explored using CAD/CAM processes.

## CORK'EWS: a parametric definition in order to improve customized expanded cork agglomerate products

After some CAD/CAM tests, it was concluded that the best anisotropic section to explore in agglomerated cork was the radial section. Thus, the parametric definition aims to define the structural basis of a parametric mesh in all its components. Using 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 a previously defined number, size and orientation of cells. The first input clusters refer to rectangular-base grids enabling to re-dimension the architectural component (Figure 2). 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 relationships (i) final object scale/pattern scale, (ii) area/number of cells, (iii) depth material/depth 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.

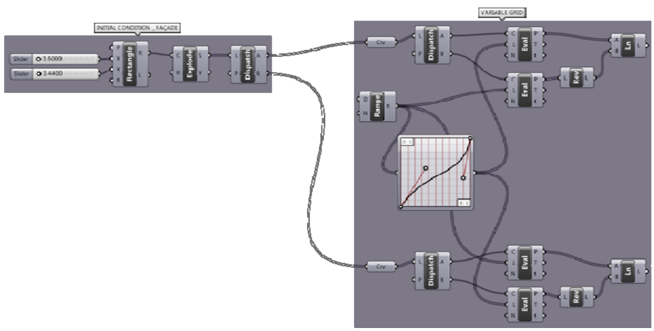



*Figure 2 CORK'EWS definition: first cluster – the base grid!*

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. Thus, the geometries are totally interdependent on each other. Moreover, it is necessary to replicate the common cell wall shared by two adjacent cells [Figure 3].

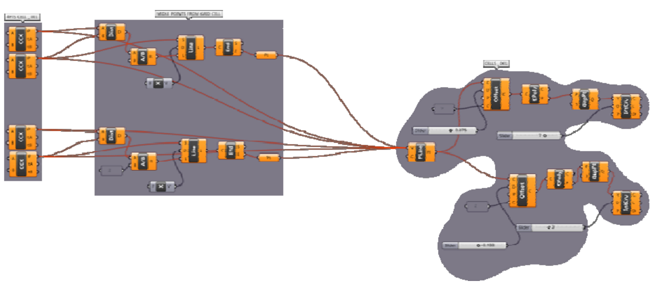


*Figure 3 CORK'EWS definition: second cluster – the cells!*

This particular component of the radial section is essential to support the design geometry. It’s this interior ‘loft' that provides replicates cork mechanical resistance from micro to macroscale.
The third cluster of this definition aims at creating volumes. In this third stage three possible types of panels are pointed out and prepared as parametric options.
The first option is related to an interpretation of the cross section of cork. Cells outline perimeter entirely drills the material. This solution proved to be extremely successful for vertical and horizontal panels. However, flexural behavior suggests that it can only be applied in light structures.
The second option further develops the logic of the previous, adding some diversity in the transition of cells dimensions. In this case, cells may have different configurations. This geometry is intermediate in its morphogenetic interpretation. 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 cork cells properties, assuring that each cell doesn't have the same depth as the neighbor cell.
This cluster was also defined to provide the subdivision of the pattern in standard Amorim Isolation product – 1000x500x100mm panels (Figure 4).

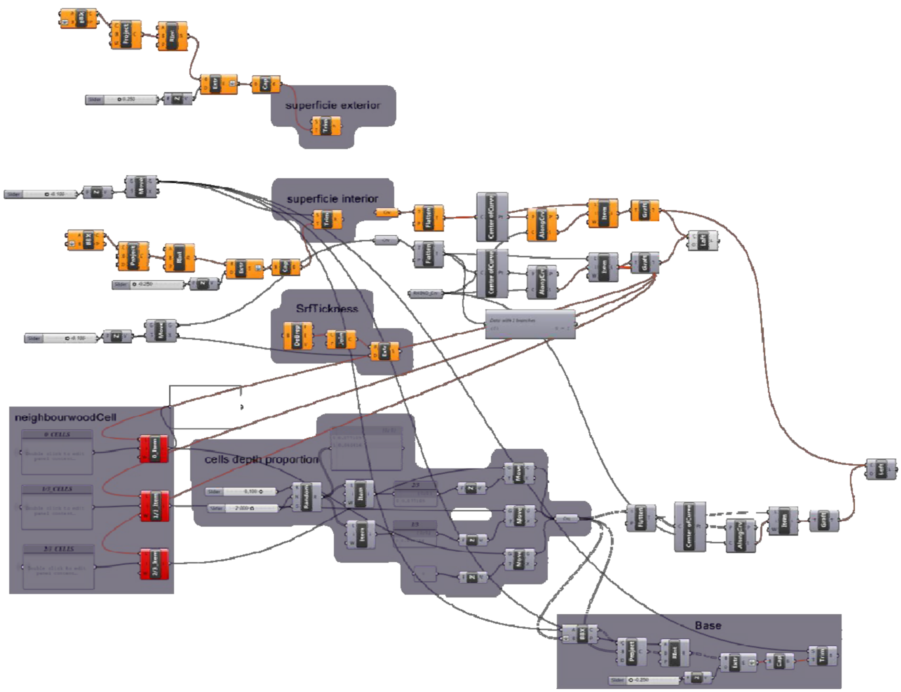


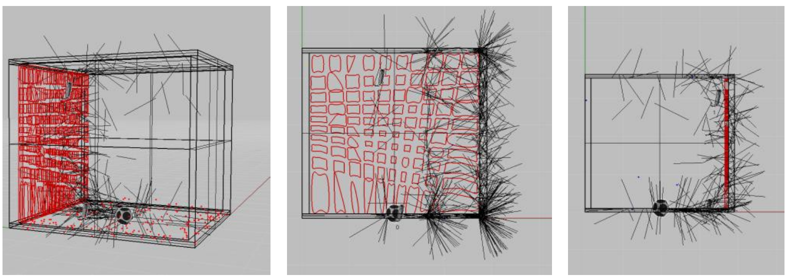

*Figure 4CORK’EWS definition: third cluster – 3D geometry and industrial standard panels!*

## CORK'EWS uploading CAD (informed by CAM) definition by performance

Supporting the idea of using this type of expanded cork agglomerate panels for light constructions and installations, two questions emerge as essential: Acoustic and solar shading protection. In order to substantiate choices and (re)draw conclusions, PACHYDERM (acoustic analysis plug-in for RHINO) and GECO (translating geometry from Grasshopper to ECOTEC) were used.

### *PACHYDERM*

To carry out the acoustic panels analysis, a surrounding straight angles box was simulated. One of the interior faces was fully covered with the panels under evaluation. Simulations were performed with a transmitter and two receivers with standard definitions of Pachyderm. Material properties input were density, reverberation and airborne insulation coefficients. Simulation results are available in function of sound frequency. One interesting feature of Pachyderm is sound reflections graphical representation. Sound intensity and persistence (or ephemeral presence) for specific locations may be analyzed. (Figure 5).



*Figures 5a, 5b and 5c CORK'EWS – Pachyderm simulating acoustical behavior and reverberation (3D, front and right view)*

Pachyderm was an important support to understand the effectiveness of the pattern that was designed. Between the various tested panels, the one with best results was the third option, the biomimetic pattern of cork. In this case, noise concentration has less strength and is more diffuse. CORK'EWS proved to be an extraordinary acoustic absorption product.

### *ECOTEC + GECO*

Directly connected to Grasshopper, GECO allows an environmental analysis by establishing a link to ECOTEC. Thermal performance calculation depends on the type of construction element, material properties and time span. Simulation results are imported to RHINO to allow for a model reconfiguration (Figure 6).

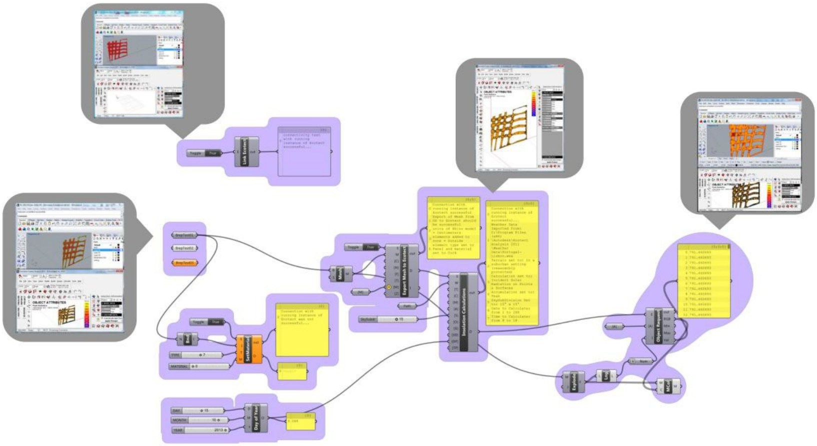
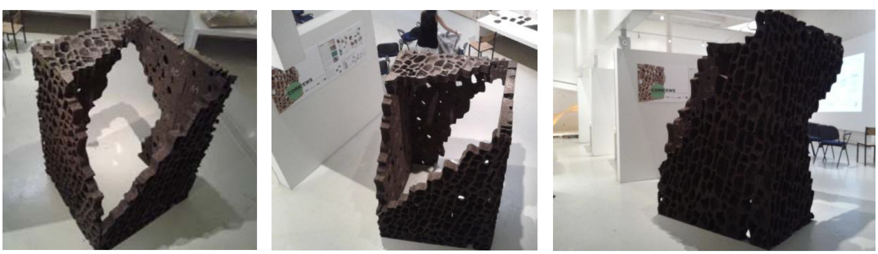


*Figure 6 CORK'EWS definition: GECO definition+Ecotec.*

## CORK'EWS: Final full scale prototype

After several acoustic and thermal tests, typology chosen for the final object was the option 3. Having a parametric pattern set, with the necessary scale to function as a sound system, the last variable to define was the most convenient form for the object, in relation to a specific location. The chosen experimental location is a space with 80 m2. The space has two different entries at two different levels, with doors made of steel and glass. Main construction system is reinforced concrete walls and ceiling. Therefore, reverberation is a predominant characteristic.
Designed on a fully parametric logic, the final prototype integrated inputs from the raw material and its thermal and acoustic performance. CORK'EWS is the first full-scale prototype that demonstrates and validates the potential application of this methodology (Figure 7 and 8). Not being a closed research, there is still a lot of issues to develop!



*Figures 7a, 7b and 7c CORK'EWS final prototype in place.*

*Figure 8 CORK'EWS final prototype.*

## Conclusions and future developments

The reported research opens new possibilities for innovative applications and uses of the expanded cork agglomerate.
Cork structure and functional properties, directly imported from the micro composition of the raw material, inputs value to standard expanded products. Exploring the natural pattern of the cork raw material, this research aims to add value to the commercial expanded cork products, extending the range of possible applications and uses, always maintaining the natural and sustainable product characteristics.
The developed work proved that the mimetic of microstructural composition, when adequately designed and applied (considering scale and typology), allows an improvement of the system performance. In this specific case, the expanded cork agglomerate microstructural properties were the basis for thermal and acoustic comfort. Moreover, this product has excellent conditions for potential reorganization of hybrid spaces. The geometrical and fabrication assembly investigation and tests reveal adequate conditions for expanded agglomerate cork self-assembly without any other kind of external material or glue components.
In the future a second aspect of this research will explore forms of assembly components, based on cork microstructure. The introduction of a fourth and fifth axis in CNC prototyping may bring added value, in particular linked to the manufacturing and production and therefore the final cost of the product.

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