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THE CORK VAULT PAVILION

A Design Research through Practice

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Abstract. Today, the relationship between computational design and digital fabrication technologies has opened new opportunities in architectural practice that are challenging the relation between the academia and the industrial world. To investigate this condition, the ISCTE/IUL and FAUP created the Advanced Studies Course in Digital Architecture (CEAAD) to promote design-based research focused in the way new technologies interfere in architectural forms, structures and materials. With this goal, it was established a partnership with the company Amorim Isolamentos S.A. to support investigations on their material – cork. In the end of the academic year, the company challenged the CEAAD to design their Pavilion for the building construction fair Concreta showing new architectural possibilities for their material. In this context, the present paper describes and illustrates the development of the Cork Vault Pavilion, from its conception to construction. Computational design and digital fabrication technologies were used not only as conception and materialization tools, but also as a medium to collaborate with the company's staff. By describing this bi-directional dialogue between academia and the industry, this paper presents the Cork Vault Pavilion as an example of how productive research and innovation can be fostered from the exploration of design challenges and methodologies.

Keywords. Cork, Digital Fabrication, Parametric, Algorithm, Industry

1. Introduction

In the information age, the logics of digital workflows in architecture have begun to structure the way that architects design, the builders build, and the construction industry relates to innovation. The use of digital design and manufacturing technologies has enabled the possibility for flexible and accurate file-to-fabrication processes so that the design and the fabrication processes are integrated in a system where design decisions can be made while physical process is in progress (Malé-Alemany and Sousa, 2003); design goes beyond the representation to include highly precise sets of instructions used to drive manufacturing processes. Concurrently, algorithmic parametric processes are creating a reciprocal relationship between design concepts, geometric structure, material proprieties, methods of production, manufacturing cost, and assembly sequences (Marbel 2012). As Willmann (2013, pp. 14) puts it, “digital materiality is far more than a mere rhetorical figure in the digital discourse; it represents an architectural vision”. Researchers and the construction industry have been developing new opportunities for innovation in a creative way, based in the hypothesis of production full-scale prototypes and are orienting their research to post-industrial methods.

These topics were at the base of the creation of the Advanced Studies Course in Digital Architecture (CEAAD) in 2012, as a joint initiative between the ISCTE-IUL (Lisbon Universitary Institute) and the FAUP (Faculty of Architecture of the University of Porto). During one year, the students enrolled in practical courses on digital design, fabrication and interaction and concluded their studies with a comprehensive design-based research project. With the support of Amorim Isolamentos S.A., the world leader in the cork industry, three students developed the following research projects, looking for new applications in architecture for this material:

- CorkVault - the possibility to span vaults with cork alone;
- TransCork - a compound translucent cork material;
- Cork’EWS - a system for radiation and acoustic optimisation.

By the end of the year, the company challenged the CEAAD and these three research students to conceive their Pavilion for Concreta 2013, the building construction fair in Exponor. Seeking to merge the three research topics, the result was the production of a free-form pavilion entirely built in cork. Starting with an introduction to cork and its singular properties, this paper describes and illustrates the digital design and manufacturing strategies and processes behind this work, arguing in favour of the relations between academia and industry, as well as the sustainable and aesthetic potential of using cork with these advanced technologies in building construction.

2. On Cork and Architecture

2.1 CORK AND ITS ORIGINS

Cork is the material extracted from the cork oak tree, which is botanically called *Quercus Suber*. Suited to thrive in low-fertile soils and adapted to hot and dry summers and warm winters, the cork tree finds its natural habitat in the Southwest European and Northwest African borders in the Mediterranean Sea. Within this geographic area, Portugal emerges as the country with the vastest area covered with the cork tree, followed by Spain, Algeria, Morocco and France, Tunisia and Italy. Taking advantage of its natural conditions, Portugal is also the responsible of more than 50% of the world production of cork, which a major economic industry of the country.

Among wooden raw materials, cork has unique properties worth analysing. Overtime, it grows and forms a thick layer that can reach several centimetres around the trunk of the tree, protecting it from heat, loss of moisture, animal damage, fire and other hostile conditions. To allow for the desired thickness, the extraction occurs every nine years and, unlike other trees, it does not imply its death. The cork tree reveals a singular capacity for growth and regeneration, which opens "the possibility of using the cork oak tree as a sustainable producer of cork throughout its lifetime" (Pereira, 2007, pp. 7).

2.2 PROPERTIES, PRODUCTS AND APPLICATIONS

This interesting combination of properties also makes cork a unique natural material, as the studies of Gil (1998), Fortes et al (2003) or Pereira (2007) acknowledge. Its cellular structure and chemical composition defines the most important features and suggest, as a consequence, a wide range of applications. It is light, buoyant and viscoelastic. When under compression it absorbs weight by deforming with minimal lateral expansion and without breaking. It is also a low conductor of sound and heat and its sensorial and psychological properties are of particular interest for architects and designers: it has a particular odour, and its texture, colour and temperature convey the idea of warmness and comfort.

Raw cork has been known and used by man since the antiquity, in fishing nets, swimming aids, shoes and as a material to protect houses from both cold and hot temperatures. The Capuchos Convent in Sintra, Portugal, is a clear example of this insulation application. Several of its doors, windows, ceilings and stairs are covered by this material, which was also easy to transport from the forest due to its lightness. However, with the rise of science and industrialisation in the XIX and XX centuries, raw cork started to be used to create several different products and derives. With about 70% of the industry concentrated in the production of cork stoppers (natural and compound), the waste material is granulated to produce different kinds of agglomerates and composites, which are used in many areas, like decoration, product design or the aerospace industry.

2.3 THE EXPANDED CORK AGGLOMERATE AND ITS USE IN ARCHITECTURE

In architecture, cork is mostly used in insulation and floor covering applications, in agglomerate or composite formats. Among these products, the expanded cork agglomerate, internationally known as Insulation Cork Board (ICB) is an interesting building material for two reasons. On the one hand, it is 100% natural, which results from an agglomeration process through heated vapour, where the granules are bond together inside an autoclave (figure 1), without requiring the aid of any other extra product (Fortes et al., 2003). As a result, the expanded cork agglomerate is still 100% made of cork, which has an important influence on its performative and future recycling possibilities. On the other hand, unlike other cork products, this product is produced in a big block format, which is suitable to address the large scale of architectural applications.

Figure 1. High-steam production of ICB; ICB boards ready to be trimmed (photos by PAV)

By perceiving its interesting properties, Álvaro Siza proposed, for the first time, the external application of expanded cork agglomerate in the facade of the Portuguese Pavilion for the Expo 2000 in Hannover. Since the success of this first experiment, the application of expanded cork agglomerate has been used more and more often, as architects can employ a single natural and recyclable material to solve both insulation concerns (i.e. acoustic and thermal) and their aesthetic interests.

Despite this innovation, the expanded cork products are traditionally commercialised in standard flat rectangular shapes, with different thicknesses. Resulting from mechanical production processes, this fact constrains the use of this material in situations where customised sizes, textures and shapes could be interesting for the designers. To overcome this situation, Sousa (2010) investigated the introduction of different CNC technologies (e.g. laser-cut, water-jet cut, milling…) in the fabrication of customized cork products. Through a set of practical experiments, his research work demonstrates how digital manufacturing can be applied to this traditional and natural material, making it a viable option to address contemporary design interests concerned with geometric complexity, variation and customisation.

3. The Cork Vault Pavilion: from design to manufacturing

3.1 DESIGN CONCEPTS

The challenge proposed by Amorim Isolamentos S.A. to design their Pavilion for the Building Construction fair was considered by the CEAAD team as an opportunity to put in practice the ideas that were investigated throughout the year. Under the coordination of Professors Alexandra Paio and José Pedro Sousa, students Pedro de Azambuja Varela, Maria João de Oliveira and Emmanuel Novo designed a temporary structure that could highlight the qualities of cork, demonstrate its potential for building construction, and communicate the commitment of the company to embrace innovation. With an available area of 12x6m, the program required an interior space to provide an acoustic insulation experience, a bench area for sitting and showcase of material samples, a visual display area, and, like in the Pavilions of past editions, it had to be extensively made out of cork.

The foundations of the design took into consideration the material and technological resources available. The features of the expanded cork agglomerate, and the working dimensions of the CNC milling machine, were decisive to inform the whole design process, which was thus developed in a bottom-up fashion. For constantly negotiating the parametric design exploration with these fabrication and material constraints, the team explored a computational design approach using the Rhinoceros/Grasshopper platform which sustained a non-linear design process where formal, material or fabrication parameters could be changed at any moment of the process. To answer the programmatic requirements, the team decided to integrate the three cork research lines developed during the CEAAD: CorkVault, Cork'EWS and TransCork.

This intention prompted the design of a vaulted shape made out of CNC milled expanded cork agglomerate along with textured panels and translucent windows to filter light into the interior space. Spatially, there would be two feature areas: while the outside would provide circulation and rest areas (e.g. waving bench and sitting furniture), the inside would be like a tunnel for exhibiting material samples and visual information, serving also as a shelter from the trade fair harsh noise and lights. These conditions were merged in a continuous form, which grows from the ground level, provide a ramp access and a waiving bench and, ultimately, the covered area.

Cork's versatility prompted the design team to rely to this material alone in the construction process, contributing to its sustainability in regards to the material production and transportation contributions. As a result, the Pavilion itself becomes a demonstration of the multi-functionality of this material. The structure is smooth and soft, and has a very particular, but pleasant, smell. In the interior it is created a different environment, due to the strong change of the light and acoustic conditions. In the exterior, the insertion of strips of grass in the floor show the possibility of using cork in "living roofs". This option conveys the symbiosis of living plants and the cork bark, while responding to the client's goal of demonstrating a building system for cork insulated green roofs.

3.2 DESIGN AND FABRICATION

The algorithmic approach to the pavilion design was developed in Rhinoceros and Grasshopper, and the fabrication and construction strategy were funded in the possibilities of the available CNC milling machine. Running on three axis movements, this type of machine is capable of performing complex 3D subtractive operations; however, given that milling 3D surfaces take much more time than cutting contours, the team decided to approach the construction strategy in terms of this last fabrication technique to face the narrow one week available for fabrication. To optimize the process, the maximum height for milling was taken into account to determine the ideal thickness of the expanded cork agglomerate boards. In a structure point of view, all this information led to the shape as being designed as a sequence of arches 10cm thick, whose varying contour would modulate the continuous barrel-type vault.

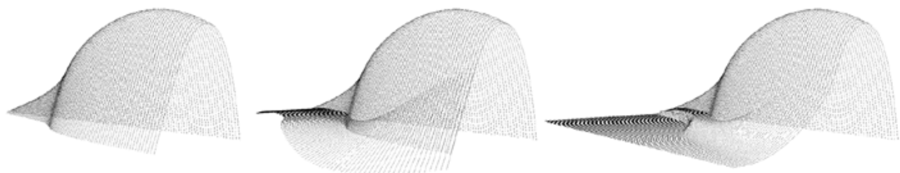

Figure 2. Catenary curves; bench generator; blended curves (images by PAV)

For modelling the design project, each section curve was programmed individually after a catenary (Block 2006). Thus, 120 catenary curves were parametrically generated from anchor points and curve length parameters. By controlling these variables with a smooth curve graph, the curvature of the global form could be perceived and controlled in a visual and accurate fashion. The design of the sitting area solves the smooth transition between the exterior floor space and the shell rising structure. Its depth and angle varies along the structure while getting blended with the floor and arch lines guaranteeing the tangential continuity along the pavilion. With the geometry of the outer surface stabilised, the (inner) thickness of the vault was designed by creating a second set of catenary curves with different parametrically variable assets such as an inner bench or a ramp (Figure 2).

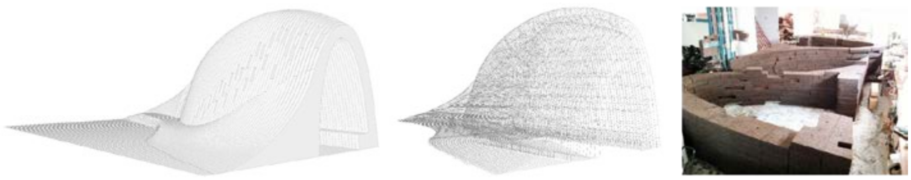

Figure 3. Final model; fabrication curves; arches fabrication (images by PAV, photo by AP)

For fabrication and assembly purposes, the 100mm thick (X axis) arches were subdivided (YZ plane) in a stereotomic fashion, following the normal direction to the catenary (YZ plane) in each joint. The fabrication consisted of five passes for the contour cutting, and one pass for the labelling. Taking an average of 1,5 hours to cut each set of 10 boards, the whole fabrication process took about 125 cutting hours, during 8 days (figure 3).

The TransCork panels were produced in 100mm wide panels starting by milling a 20mm thick MDF board to create a mould to be filled with a compound of liquid polyester resin and bottle glass powder. After filling the mould with this mixture, the cork granules were poured with the TransCork Printer Plugin: this device developed within the CEAAD to pour cork granules with the CNC milling machine allows to create variable density cork patterns in the panel.

Finally, the Cork'EWS panels were fabricated separately from the main structure as the axis movement directions were not compatible. Thus, the Pavilion structure was designed by leaving some space to accommodate panels of Cork'EWS, organised in clusters of three. Following the 100mm thickness matrix, these panels were designed and 3D milled to define acoustic and decorative textured patterns.

3.3 ASSEMBLY

The assembly of the Cork Vault Pavilion occurred in two phases: pre-assembly and in-site final assembly. The first phase occurred in Vendas Novas, in the Amorim Isolamentos S.A. factory: modules of three arches were fixed together so that construction time could fit in the three days window frame for the fair site assembly. Two trucks transported these pre-assembled modules from Vendas Novas to Matosinhos.

In the site, a base structure in MDF was built to serve as a base for the billets of wood in which the cork vault would sit and discharge its load (figure 4). Once laid out, the construction of the Pavilion proceeded, quickly giving rise to the full cork vault. The floor pavement was laid on site by employing pre-cut floor boards with 1000x100x20mm size, in the same material as the built structure. Its placement in the ground followed the 100mm modulation in continuity with the arches. The floor cladding left some empty spaces that were filled with the strips of grass.

Figure 4. Placement of arch base in wood billet; arch keystone placement; vault construction; flooring with gaps for turf rolls (photos by PAV)

3.4 RESULT

The use of CAD/CAM technologies enabled design flexibility and precision from the conception phase to the fabrication and assembly. Nevertheless, manual assembly tolerances created some slight discontinuities, which could be minimized by using a greater amount of fittings.. Moreover, a small number of fabricated components were missing on site and the workers had to manually create replacements by means of sawing and sanding. Both these setbacks are useful as reminders of the necessary interactive relation between the digital and physical, automatic and manual parts of a design and construction process.

Figure 5. Comparison between digital project and material realization. (image by PAV, photo by João Morgado)

In the end, the built Pavilion (figure 6) demonstrated an original use for cork, radically different from that presented in the company's Pavilions in the previous editions of the Concreta Fair. It was the first time that cork was used to bridge a span without the help of additional materials and structures, it featured an all new decorative and performative glazing system as well as new uses for cork walls, making this Pavilion a showcase of various uses of cork in architecture.

4. Conclusion

The design of the Cork Vault Pavilion demonstrates the symbiotic advantages of a close relationship between the academia and the industry. The key aspects resulting from this digital and collaborative experience can be summarized in three aspects: design creativity, material innovation and research methodology.

By using software that allowed for a parametrically driven algorithmic modelling, the design was developed in a horizontal order, allowing for more creative possibilities. The close connection between the modelling software and the fabrication strategy was key for a tight control of the materialization process, ensuring construction accuracy. This digital strategy led to a built Pavilion that demonstrates the productive collaboration that can emerge out of the academia and the industrial worlds. While the students can test their ideas in real scenarios, the companies can benefit from the creativity that breed in academia. The CEAAD is thus a pioneering post-graduate program in Portugal, seeking to stimulate this sinergy.

Figure 6. Final construction of the Amorim Isolamentos S.A. during the fair (photo by João Morgado)

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