Customized Cork Façade

A generative design process based on shape grammars

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Abstract. *The propose paper presents an ongoing research which main goal is to use cork in a customized modular façade system. Cork is used due to its ecological value, renewable characteristic, insulation properties and aesthetic value. The modular system design is bio-inspired in the microscopic cork pattern and the study aims at reproducing in the façade some of the natural characteristics that enable cork to be suitable for the function it plays in construction. Façades are design by a generative design process based on a parametric shape grammar which encodes shape rules and an algorithm to guide the generation. The developed cork modules are part of a back-ventilated façade system which is assembled upon a substructure that reproduces the cork cell structure and enables both the assemblage of the modules to the support wall and the connection between them.*
Keywords. *Shape grammar; generative design; cork; façade; digital fabrication.*

INTRODUCTION

The use of a generative design system enable the generation of multiple solutions based on different scenarios and requirements that would introduce different variables to the system.

Recently both the fabrication and the design process in Architecture are being questioned by the use of digital technologies for the promotion of more efficient buildings. Requirements such as good structural or thermal performance and customization are the cause of the arising of new generative processes.

Design assisted by generative processes such as shape grammars allows the customization and optimization of solutions by manipulating parameters. Combining these processes with new digital fabrication techniques enable new products to be design which are customized, respond to pre-defined requirements and still maintain production costs.

However architectural quality is not absolutely measurable, there are some specific qualities that are well measurable. Energy efficiency is one of those qualities. The use of materials with good insulation values and the optimization of window openings according to the site insulation characteristics will improve a specific type of building quality.

Kroes et al. (2008) state that the emphasis upon building performance brings the architecture world much closer to engineering design. According to Gruber (2011) the quality of a final project is defined by the quality of investigation conducted in the important stages of design. The challenge proposed is to combine the expanded vision of the architect with the fulfillment of specific variables using also quantitative criteria rather than just the qualitative criteria typically used in the architectural work.

Gruber (2011: 49) states that “in architecture, problems in design often affect many levels of the project, and often they are difficult to define.” As a consequence several tools are too specific to be use in architectural problems since they are usually not looking to all the levels of the problem but only to some of them. However, these tools may be suitable to solve specific design tasks and questions (Gruber 2011: 49).

DESIGN PROBLEM AND GOALS

The problem this research wishes to address is how to design a system to generate customizable façades with a natural material as cork without becoming to expensive.

The main goals of this research are:

- Use pure cork agglomerate as a building coating material and explore its thermal isolation and aesthetics potential;
- Define a generative design process bio-inspired in cork composition based on shape grammars which meets a visual-performative language;
- Define a modular cork façade system which meets a variety of thermal requirements considering different contexts;
- Define a substructure to support the cork modules in a back-ventilated façade system.

Besides those, other motives were to explore architecture performance and mass-customization, materials and construction technologies as well as CAD/CAM digital technologies.

FRAMEWORK

Cork pattern, materiality and visual characteristics

Cork is a natural, renewable and environmental-friendly product that comes from the renewable bark of the Cork Oak. Natural cork agglomerate is used in this research because of its excellent thermal isolation properties and because it has great properties to be used at exterior façades becoming lighter or darker according to weather conditions. Both natural and black agglomerate cork is used in construction because of its very good performance as acoustic, thermal and vibration insulation (Gil 1996). These materials are available in sheets or boards with variable thickness and their manufactured is mainly done with “granulates from cork stripping (virgin cork) obtained from pruned branches of the cork oak tree” (Gil 1996).

The microscopic pattern of cork (Figure 1) was used as an inspiration pattern for the development of the façade modular design with the aim of mimetizing Mother Nature’s harmony by using similar logics and principles of organization. Through Hooke’s observations cork was found to be made of cavities (cells) full with air which enable the material to float, be firm and yet compress under force. However there are also structures around the air cavities which support the material (Humes s.d.). This meticulous natural design has inspired and lead to differ-

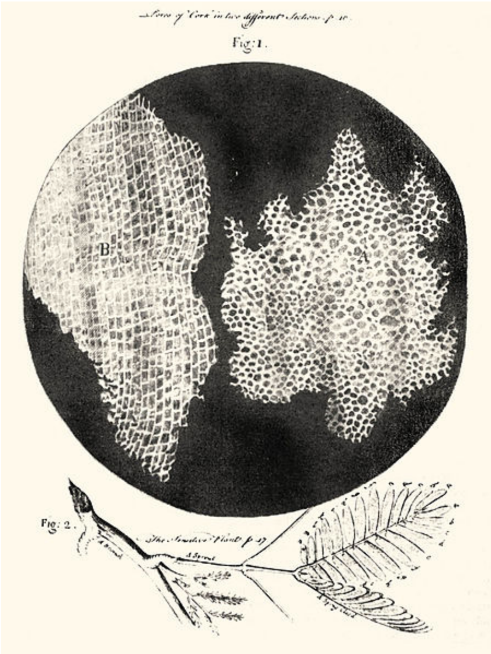

Figure 1
Drawing of the structure of cork as it appeared under the microscope to Robert Hooke (http://en.wikipedia.org/wiki/Robert_Hooke).

ent patterns in the proposed design.

The choice of materials in architecture have an immense effect on the behavior of the people using a space because of their functional performance and their image, brand, identity feel and the atmosphere they give to the space (Gagg 2012). Beside the enunciated measurable advantages of cork regarding its technical specifications and performance, its aesthetic may give a sense of warm and comfort to users which we want to explore when using it in new ways.

Generative design and shape grammar

Recently architecture and biology are overlapping fields of research by exploring different methodologies of translating knowledge gained from nature into technical solutions (Gruber 2011). Generative processes of design in architecture are being studied and the arising of emergent shapes represent a current research line both in architecture and other areas such as computation sciences and biology. Emergent patterns may be observed, recognized and extracted from natural patterns and mathematically explained through algorithms or parametric shape grammars. The goal is the generation of efficient architectural structures inspired by the logics of nature performance. Bio-inspired design can be used in architecture in different ways, from the use of stylistic and aesthetic nature's logic to the use of nature's performance potentials as the ability to use in an efficient way the solar radiation.

Shape grammars are generative processes developed since the 70s by George Stiny and James Gips (1971). They are "algorithmic systems for creating and understanding designs directly through computations with shapes, rather than indirectly through computations with text or symbols." (Knight 2000)

The generation process enabled by shape grammars allows for multiple designs to be generated, based on a single language but determined by different choices (Eloy and Duarte 2012). The use of a shape grammar enables to encode both the shape rules that explore the visual properties of the pattern (bi and tri-dimensional) and the constraints needed to design a façade. Shape grammar languages do not look for one solution to a given problem but for multiple solutions based on the same set of rules or criteria (Eloy 2012). In shape grammars, rules are used as mechanisms for generating designs.

DESIGN GENERATION

Phase 1: Cork as pattern

The process started by the use of the microscopy image of cork and with the identification of its pattern by visual analysis. From that stage a vector drawing was done over the cork image and a triangular module emerged as the simplest shape and the one which enabled the most infilling diversity.

During this phase different shape approaches have been followed resulting in different shape vocabularies and shape rules. It was considered since the beginning that the modular façade construction should consider two types and stages of work: a first stage involving industrial fabrication of the base modular pieces and a second stage involving a customized design and fabrication by digital tools on those pieces. These criteria lead us to develop the design grammar by using the simplest shape possible to the base modular piece that will be repeated. This triangle is use both for the surface pattern of cork modules and for the load bearing façade substructure inspired in the cork's air cells and edge structure discovered by Hooke.

It was our goal to explore the visual complexity dynamic of the microscopic pattern of cork and use it dynamically in a building façade to stress cavities (windows), dark/light or shades (material thickness) and strength (support structure).

Phase 2: Encoding the rules

The inference of shape rules was done by hand after analyzing the microscopic patterns of cork. In the first stage the geometric shapes were identified through the process of isolating possible combinations. The goal was that the modular shapes could be easily fabricated and assembled and simultaneously would enable the generation of multiple combinations of design. This was done by using a triangle as the base module. The adding rules that introduces a second triangle in the façade uses the left part of the rule and adds a new triangle by mirroring through one of its sides (rule 2 and rule 3, Figure 2).

After developing rules that fill the façade with the base module the second stage was the definition of the shape geometry inside the triangle. In between side by side triangles, these inside geometry should generate the polygons that are characteristic from the cork microscopic pattern. To both generate polygons and make them dynamically different from each others, a parametric rule was added to the shape rules 4 and 5 in Figure 2.

The third stage was the definition of several shape rules which encoded the thickness possibilities as well as rule conditions (Figure 2, rules 6 to 10e).

These rules allow the use of Euclidean transformations as symmetry, rotation and translation to the generation of different designs.

The developed rules obey to two main criteria: i) thickness differs with solar orientation of the facade; ii) one base module has always two different thicknesses.

Phase 3: Design generation

The generation begins in a vertex of the façade and the use of shape rules allows the all surface to be filled of modules. Rule's application follows criteria like: different thicknesses in north/south and east/west facades; diversity in the thickness in adjacent modules; non-repetition in adjacent modules; higher thickness in more exposed places of the façade; windows openings/voids position.

Figure 3 show a possible layout of façade that was generated through the developed shape grammar.

The coating cork modules are part of a back-ventilated façade system which is assembled upon a triangular substructure that disappears from the exterior face of the coating to the back in order to support it. This metal substructure, located at the borders of the modules, enables both the assemblage of the modules to the support wall and the connection between them.

Phase 4: Prototype

The final phase will be the test of the customized cork façade in 1/2 scale models by using CNC digital fabrication techniques. Two possibilities will be tested in triangular pieces, cork with 20cm of thickness and two layers of different cork with a total thickness of 20cm. The goal is to test the assemblage of the modules both between them and to the metal substructure and, if necessary, to go back and review unresolved situations detected during the fabrication.

CONCLUSIONS

At this point of research we can preliminary conclude that it is possible to interpret and infer patterns of nature using a shape grammar and that we can use this grammar to generate similar patterns.

The proposed design is bio-inspired by the microscopic structure of natural cork. The understanding of this pattern led us to re-interpret it and design the proposed façade in a two layer system considering the loadbearing structure (edges) and the infill/coating material (cells).

The use of a modular cork façade system which can be generated by a generative process allows a more rational design process since it enables multiple design to be developed but establishing modular standards that has to be obey.

By addressing an experimental issue this research helped to understand the potentials of relating bio-inspired design, generative process and digital fabrication techniques. With the use of these technologies more sustainable structures can be obtained which will meet nowadays and future requirements.

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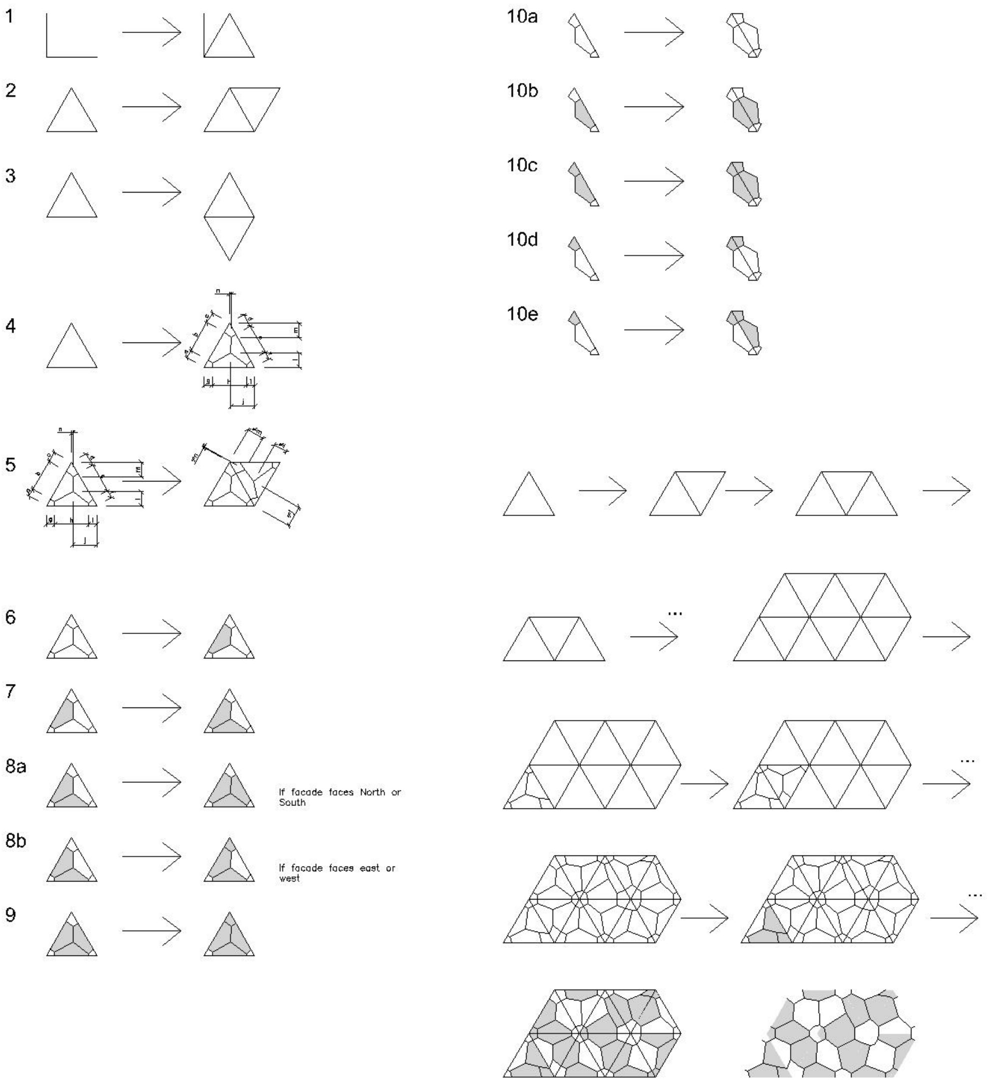

Figure 2
Simplified shape rules and sample derivation.

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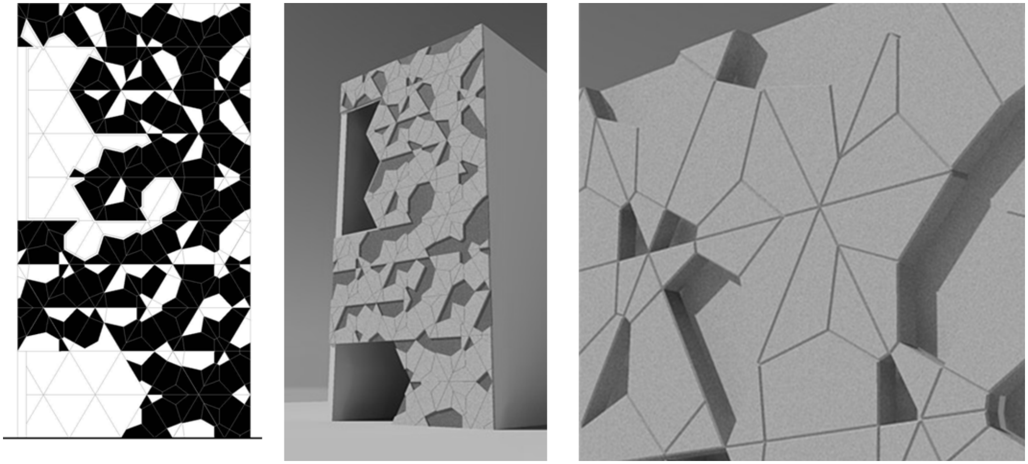

Figure 3
Examples of one final design of the customized cork system façade, with two different types of cork or just one.

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