Geometric Identity of Living Structures Translated to an Architectural Design Process

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Biological life manifests in space through a large diversity of physical structures perfectly bind and identifiable in the environment. This reveals that all share a common generative design process which allows them the same physical identity in all the shapes that generates. The human ecological design process used in architecture is not able yet to reach this design identity neither the spontaneous integration associates to it. Why? Because the geometrical design process used in ecological architecture and living structures are not similar. Thus, this paper proposes, through the identification of some geometrical characteristics from the growth mechanism of living structures, a process of shape generation through shape grammar. With this generation process is possible to generate, only in geometrical terms, a large diversity of architectural models with a common identity, that reveals some geometrical characteristics of spatial integration that living structures share with the surround environment.

Keywords: Ecology, Geometry, Bio-design

INTRODUCTION
This investigation presents initial results from an on-going research, which aspires to increase the knowledge in the development of an ecological design pattern able to decrease the formal border between human and living structures. This study, approach the ecological design pattern only in terms of geometry, more precisely, the geometric characteristics of the growth mechanisms. Through a design process, this investigation demonstrates how growth process and the geometric characteristics associated to it, are crucial to emerge in living structures a geometric identity with structural optimization and a spontaneous spatial integration. So this research start to review different ecological design processes (Nery Oxman, Rachel Armstrong, Joachim Mitchell, Achim Menges, Magnus Larsson, Sanfte Strukturen) and interpretations of natural geometry (Maggie Macnab, John Blackwood, Peter Pearce, D’arcy Thompson, Christopher Alexander). With this information is defined a set of geometrical characteristics which are translated to a shape grammar language. Finally, through shape grammar rules is developed a process of shapes generation. The generated shapes allow to reach the follow conclusions: 1) the design method is crucial to generate shapes that can reach some levels of spontaneous integration on the environment and 2) the spontaneous integration can only be reached
when the geometric compositions reveal structural optimization, which in geometry terms means that shapes can be only composed by the geometric elements that they need to exist.

**AIMS**

This investigation aspires to increase the knowledge on the geometrical complexity level of ecological pattern (Loehle, 2004). The choice of approach ecology by a geometric perspective arises from an idea defended by Alexander. He argued that the quality of the human architectural shape is directly related with its integration capacity in the environment. In his view, today's architecture is very poor, because it is completely separate from the nature design logic. Alexander defends that the most successfully architecture is the one that contain some of the geometrical characteristics of the living structures, i.e. characteristics from the maximum example of shape integration in the environment. To do these analogies, he defines a set of geometrical characteristics of the living structures identity. He concludes that architectural structures do not achieve the same integration ability in the environment like living structures have, because these geometric characteristics are not all present in the geometric composition of the architectural structures. So to "restore" the architectural quality, he proposes that human design process have to change to a similar to the living structures. In order to respond to that challenge, the main goal of this investigation is the development of a design process, only in geometric essence, able to generate architectural structures with the geometrical qualities of living structures identity. To reach that goal, this investigation aims the following points: 1) identify a set of geometrical characteristics of the living structures shape identity, 2) develop a design tool able to generate shapes that reflect simultaneously all these geometric characteristics in the same structure, 3) generate tridimensional models able to be used in human activities.

**SIGNIFICANCE**

The geometric design process developed arises in the ecological design field as a proposal to generate human structures through a biologic perspective. The reason to focus the ecological design by this field, is to inform that biological structures, which are the maximum ecological reference, are built with a specific kind of geometry that allow their easy identification in the environment, but also allows to achieve all ecological qualities related to optimization and spatial integration known. So if the aim of ecological design is to achieve the ecologic pattern, in our opinion, architecture must share the same geometric identity of living structures. In this investigation, the geometrical characteristics identify in the growth mechanisms of this particular geometry, allow us to develop, only in geometric essence, a design process able to achieve some of the geometrical qualities of spatial integration reveal by living structures and also reveal how living structures optimize the structural elements that use in their shapes. So, these successful achievements can be a reason to inform others research lines in ecologic design, that this kind of geometry can have some particular influence on their optimization goals, which in social terms, can be very relevant in ecologic and economic factors. In the academic terms, this geometrical design process can be introduced as a drawing tool that allows experimenting a different process of space conception. This may enhance our capabilities to create and explore different space solutions for human activities, which is one of the main goals of designers and architects.

**BACKGROUND**

In the last years have emerged, in the ecological design field, several research lines that develop human structures without copying directly natural shapes, but through the implementation of design processes based in structural characteristics of these shapes. These research lines can be interpreted through two distinct groups: digital morphogenetic (Hensel et al, 2006; Menges, 2012; Oxman, 2010) and living architectures (Armstrong, 2012; Larsson, [1]; Mitchell, [2];
The main intention of digital morphogenetic research line is to understand the relations between geometry and material optimization taking into account the materials properties, the climate factors and the structure purpose (figure 1). In the case of the living architecture the main intention is also the material optimization, but through a different perspective, by using living structures itself as constructive materials or using their metabolic qualities to produce materials able to generate the structures (figure 2). All these different approaches shows that material optimization reveal a change of geometry in the physical structures when compared with the ones that resulting through the human design processes used today. This geometry also shows other relevant qualities. The shapes reveal a geometrical identity closer to the one of the living structures and a more ability of integration with the environment. So, if the aim of ecological concept is to achieve the structural qualities of the identity shape on those living structures, then, in our opinion, one aims at unraveling what kind of geometric patterns and form generation process needs to be interpreted so that the human structures start reflecting in their structural compositions, patterns of optimization and spontaneous integration of the living structures.

The natural geometry has been studied through at least three different types of approaches: growth (Alexander, 2001; Thompson, 1992), identity (Macnab, 2011) and minimal inventory / maxium diversity (Blackwood, 2012, Pearce, 1978). Both Blackwood as Pearce, focus their research only in a geometric quality of living structures, the first deepening the symmetry and the second morphological character. All other features that they referenced are complementary to these. The same applies to Thompson, focusing only on allometry, i.e. the proportional relationships of forms during the process of growth and evolution. Alexander and Macnab already addressed the geometry of living structures in a different way. They look for a set of characteristics, in order that together they can reproduce the geometric identity of living structures. The big difference between the two is that Alexander argued that the identity of something is inseparable from the process as this generates, while Macnab interprets the identity of living structures as a set of geometric qualities additions. It will be Alexander characteristics set more complete that the others? Its set of geometric characteristics already includes in general, the geometric characteristics of other references. This means that the interpretation of geometric characteristics through a growth process, already encompasses concerns of identity and variation by diversification (figure 4).
RESULTS

Design process _ Geometrical characteristics

Being one of the research goals, the generation of architectural models with the geometric qualities of living structures identity, this intention will require a generation process that allows to create a wide range of shapes with the same geometric identity. According to Alexander, the phenomenon of life does it, but the geometric characteristics that his identity imposes only emerge in the structures if they are generated by growth mechanisms. Therefore, it seems clear that the adopt design process to generate models with the identity of living structures, one should support the geometric features inherent to the growth process of the same. Which are the structural requirements evidenced by the growth phenomenon? Growth always begins with something that expands and never ceases to be an integral part of the environment that contains it. It is, therefore, a process which comprises at least three parameters: origin, expansion and connection (figure 5).

Which particularities of formal design are associated with each of these parameters? The origin, regardless of its geometric configuration, is always the source of all the information that will give body to the structure. It will define the morphological character of the structure as well as the relations that need to exist between the elements given a particular purpose of structural cohesion. Therefore, the geometric characteristics associated with the origin, include the definition of a geometric vocabulary and the definition of the proportions ratios for the elements of the vocabulary and which are approached under the theme allometry (figure 6). The expansion, in turn, focuses on how the reproduction of the origin takes place and on the cohesive way in which this reproduction propagates in space. This requires as geometric characteristics the repetition and the gener-
Figure 6
Origin geometrical characteristics. 1) Geometric vocabulary - All living structure result from a combination between structural shapes and expansive shapes. 2) Proportion - The proportion ratio between adjacent elements have to reflect harmonious variations.

Design process _ shape generation
How is made the transfer of these geometric characteristics to the design process? By creating rules described with the graphic and algebraic languages of shape grammars (Stiny, 2008). This grammar will divide the shape generation process in four distinct phases: global rules, shape delimitation rules, local rules and spatial rules, each one with its own rules. It must be pointed out further that the elaborate grammar is a parametric grammar. This means that the rules must be interpreted by geometric parameters and not by the dimensional accuracy of their geometry in the graphic description of them.

Shape grammars rules
Global rules - Living structures proliferate in space by growth levels. They are so important in the geometric composition of the shapes that all structural elements are organized by their rules. This suggests that growth levels play an important structural basis role. Thus, it seems important and clear that the first phase of the design process is intended to generate a structural basis where will be referenced all the following phases. Therefore, global rules define the structural basis rules. They control the proportional relationship of the shapes as well the proportional variations between the structural elements which embody the shapes. The rules developed to this phase will only contemplate wave expansion (figure 9).

Shape delimitations rules - These rules are based on the union geometrical characteristics of the living structures growth mechanisms. Their purpose is to generate irregular shapes contour over the structural basis, able to reveal the multi diverse connectivity of the union principles. For this operation a guide mesh of points is introduced over the expansion lev-
Figure 7  
Structural Growth geometrical characteristics. 1) Growth center - Living structures are generated from a center through growth levels. 2) Repetition - The structural composition result from the repetition of elements with spatial exclusivity.

Figure 8  
Connection geometrical characteristics. 1) Union - The connection with the surround require irregular limits with multi-diverse irregularities.
Figure 9
Shape generation design process.
Examples of some grammar rules in each phase.

PHASE 1
GLOBAL RULES

GR1: $(x, y) \rightarrow F_1 \rightarrow n_1$

GR3: $n_i \rightarrow n_i \rightarrow n_{i+1}$

$\frac{m_{i+1}}{m_i + m_i + m_i} = 2/3$

$i \in \mathbb{N}$

$i > 1$

PHASE 2
SHAPE DELIMITATION RULES

SDR1: $F \rightarrow F \rightarrow n_i \rightarrow n_i \rightarrow n_{i+1}$

$\theta = 45^\circ, 60^\circ, 65.5^\circ, 90^\circ, 120^\circ, 135^\circ$

SDR6: $D_{ij} \rightarrow D_{ij} \rightarrow D_{ij+1}$

$D_{ij+1} = (m_i \cdot \text{sen} \theta_i \cdot m_j)$

$i > 2; j > 3; j > i$

$i, j \in \mathbb{N}$

PHASE 3
LOCAL RULES

PHASE 4
SPATIAL RULES

LR1: $F \rightarrow n_1 \rightarrow n_1$

$\text{N}^d \text{de P} = (4 + y)$

$y \in \mathbb{N}$

$y = 1, 2, 3, 4, 5$

LR3: $n_1 \rightarrow n_1 \rightarrow n_1$

RE8: $F \rightarrow b_i \rightarrow F \rightarrow n_i$

$R = (F \cdot \cos \alpha; F \cdot \text{sen} \alpha)$

$i \geq 4; x > 1$

$i, x \in \mathbb{N}$

RE11: $F \rightarrow n_1 \rightarrow F \rightarrow n_1$

$R = (F \cdot \cos \alpha; F \cdot \text{sen} \alpha)$

$i \geq 4; x > 1$

$i, x \in \mathbb{N}$
els rings. These points will be the contour guide reference of shapes. The union of the selected points will be made by concave or convex lines in order to increase the shape connectivity with the environment (figure 9).

Local rules - These rules correspond to the shape materialization stage. It is the stage where the physical structure is generated. These rules will generate the structural shapes of the geometric composition one by one, from the geometrical qualities of the initial shape. To generate these shapes is applied the voronoi diagram concept. To simplify the generation process of structural shapes, this grammar only contemplates the use of polygonal shapes (figure 9).

Spatial Rules - The purpose of these rules is to transfer the two dimensional geometric composition defined in phase 3, to a curved surface in space. Two geometric surfaces are used as the basis for this transfer, the torus and the sphere. Both surfaces share the main structure quality of the geometrical composition, the expansion from a center. Thus, the surfaces centers will be the base reference to transfer the bidimensional composition into space. The concavity of these curved surfaces allows enclose internal space. This particularity gives to these compositions a structural purpose of "shelter", which enables the human occupation (figure 9, 10 and 11).

Validation
The design process proposed, generate shapes whose structural composition reflects the geometrical characteristics identified as crucial to the growth mechanism of living structures. The shape structural elements reveal the same geometric familiarity. All are polygons. These polygons are distributed by the structural composition through an expansive shape (wave). The proportion ratios between them also respect the scale variations of harmonious proportions. The structural composition is generated from a center through growth levels. The composition is struc-
tured through the repetition of familiar geometrical elements with spatial exclusivity qualities. They do not share anything with other shapes or elements. They are clear, simples and irregulars. The resulting spatial exclusivity of the combination of all the elements reveals a vibrant geometrical pattern (roughness). The shapes union with the environment is strong. They contain boundaries with a large diversity of connection with the environment. The result is a strong “friction” between shapes and environment. The result of combining all these features in one structure only, is compact, cohesive and non uniform shapes. So, the geometric design process proposed, respond positively to the challenge of being able to generate a wide range of geometric shapes with the same identity and to the challenge of generate shapes that reveals a geometric pattern more similar to the ones existing in the living structures.

CONCLUSIONS
This investigation shows through a geometrical design process that is become necessary to change the design process for the architecture start to demonstrate simultaneously in the same geometric composition, the geometrical characteristics of living structures identity that Alexander advocates as crucial to the architectural quality in terms of spatial integration of the shapes in the natural surroundings. The
major change is the interpretation of shape generation through a perspective of growth mechanisms. These mechanisms require that the shape generation be always made from the geometric qualities present in the geometric composition before each transformation. This fact shows the crucial role of each element in the geometric composition and in its cohesion. So in ecological terms, what can be deduced from growth mechanisms is that these are crucial in the optimization of structural elements, because its generation requirements only use the necessary elements to its composition, without leftover elements. So, it is important to pass for community that the growth mechanism have an important role in the structure optimization and inform others researches lines which operate in the ecological pattern for this fact. The idea is to see how this information can influence their optimization goals and how their results, may in turn, influence this research. In terms of architecture, the geometrical design process developed reveal that is able, only in geometric essence, to generate space for human activities through a diverse range of shapes that reveal the geometrical characteristics of the living structures identity identified. Right now, the design process only explores the spherical and the torus surface. The idea is to add in the future more complex surfaces which allow exploring different types of architectural spaces. In this stage of the investigation, the models generated through the chosen surfaces give the idea of portable “shelters”, but the generation process cannot be restricted only to that, because these geometric compositions can be influenced by scale. So, this design process suggests that scale can diversify the applications in the architectural field, which shows how versatile it can be for architecture and for all the design in general.

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