Periodica Polytechnica
Architecture

47(1), pp. 8-13, 2016
DOI: 10.3311/PPar.9891

RESEARCH ARTICLE

Architectural Design through the Geometrical Principles of Biological Growth

Ricardo Massena Gago[1*]

Received 14 August 2016; accepted 18 September 2016

Abstract
This research is in the field of biological design; more specifically it deals with the decoding of geometrical patterns of ecological shape and their transfer to architectural design. The transfer of these qualities is made through the construction of a geometric design tool, based on biological organization principles (growth). The morphologic pattern is decoded using two distinct drawing tools: shape grammars and Voronoi diagrams. The design tool allows the separation of biologic design from its ecologic references (biological structures), by generating a wide range of human structures with their morphological identity. The tool aims at reaching a morphological coherence between biological and human structures by introducing in human design certain qualities of biological morphology, such as evolutionary balance, integration ability in the environment, structural fluidity and structural multifunctionality.

Keywords
bio-design, generative design, architecture, ecological shape, parametric design

[1] Faculty of Architecture / CIAUD
University of Lisbon, Portugal

[*] Corresponding author, e-mail: umassena@gmail.com

1 Introduction

In recent years, human design of biologic purpose has been experimenting generative design processes distinct from those currently used in the field. These focus on multifunctionality principles (Oxman, 2010; Menges, 2012). Its purpose is to approximate human design to the generative pattern of biologic structures and understand how their processes increase their morphological qualities. This design perspective is imposing changes, not only in how humankind interprets its ecological referential but also in the human design process itself. This approach intrinsically corresponds to an ecological ethics change (Reed, 2007). The design processes are trying to evaluate the integration of human structures in the environment using coherence instead of opposition. According to Craig Loehle (2004), reaching such ecological coherence requires the development of knowledge in six different levels of complexity: space, time, structure, behaviour, process and geometry. Given this characterization and the aim of this research in generating human structures through morphologic coherence with biologic structures, its contribution to biologic design will be made at a geometrical level. Consequently, for that purpose, the following questions have been put forward: How can architectural shape reach the morphological quality of biological structures? How to transfer these qualities to architectural structures? To answer these questions, the following goals were defined: 1) identify a set of geometrical characteristics of the morphologic pattern of biologic structures. 2) develop a design tool, able to generate structures of architectural character with two purposes: on one hand, to be able to implement these qualities simultaneously in structures and by formal diversity, and on the other, to reveal structural organization principles by elements dependency in order to potentiate the shape integration with the environment. To reach these goals, the research focuses on three distinct themes: 1) identification of design processes potentiated with biological qualities; 2) interpretation of biologic geometry approaches and 3) identification of design tools that allow the reproduction of natural patterns.

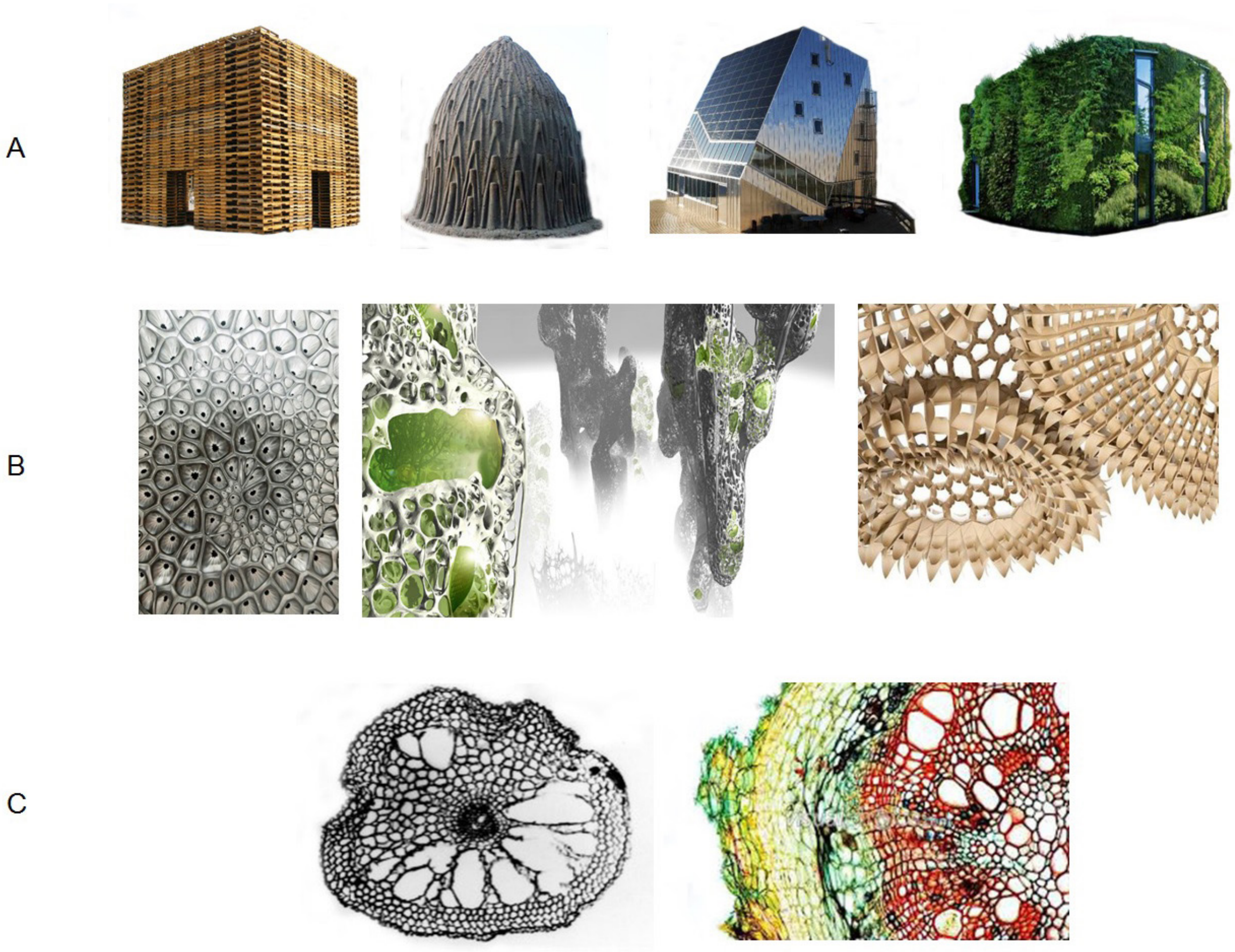

Fig. 1 Morphological comparison of structures with biological connotation. (A) – Conventional biological design strategies. (B) – Shape generation by interpretation of design processes inherent to structural characteristics of biological structures. (C) – Geometric identity of biological structures.

2 Background

The interpretation and decoding of the biological design process through a geometrical perspective aims at giving to human design the capability of generating shapes by formal coherence. In this way, human design can be freed from its biological references and continue to generate shape by morphologic differentiation, but with its geometrical qualities. In this context, the research in digital morphogenetic field are highlighted (Oxman, 2010; Menges, 2012). The digital morphogenetic is a design process whose generative base is structured by algorithms. These are introduced into a computational process to generate shapes that provide maximum optimization of material resources, accounting for functional, environmental and material constraints. It is an approach that aims to counteract the hegemony of shape beforehand thought, through a strategy without spatial pre-conception, but with fixed morphological qualities. However, this process does not encompass the variables of adaptability and growth. Even so, the morphological configuration revealed by their solutions, turn out to be more similar to biological structures, than the ones developed by current ecological design strategies (Fig. 1). What can be inferred from this? That life leaves a kind of bio-signature in structures where it is itself manifested. Moreover, what kind of geometry characterizes it?

Biologic geometry has been studied by at least three types of approach (growth, identity and diversity). In the growth approach, the work of Christopher Alexander and D'arcy Thompson stands out. Alexander (2001) focuses his attention on the identification of geometrical characteristics associated with the growth mechanisms because the author considers that ecological identity is inseparable from the process that generates it. In turn, Thompson (1992) focuses on the study of the proportional relationships of biological structures during the growth and evolutive process. In the identity approach, the work of Maggie Macnab (2011) should be highlighted. The author interprets biological identity as a quality that results from the addition of a set of geometric characteristics. Finally, in the diversity approach, the work of John Blackwood (2012) and Peter Pearce (1978) stands out. Blackwood focuses on the study of symmetry and Pearce on the study of the morphological character of biologic structures.

Through a correlation analysis of author's characteristics, it is possible to verify that the ones defined by Alexander's growth approach have the peculiarity of containing all others (Fig. 2).

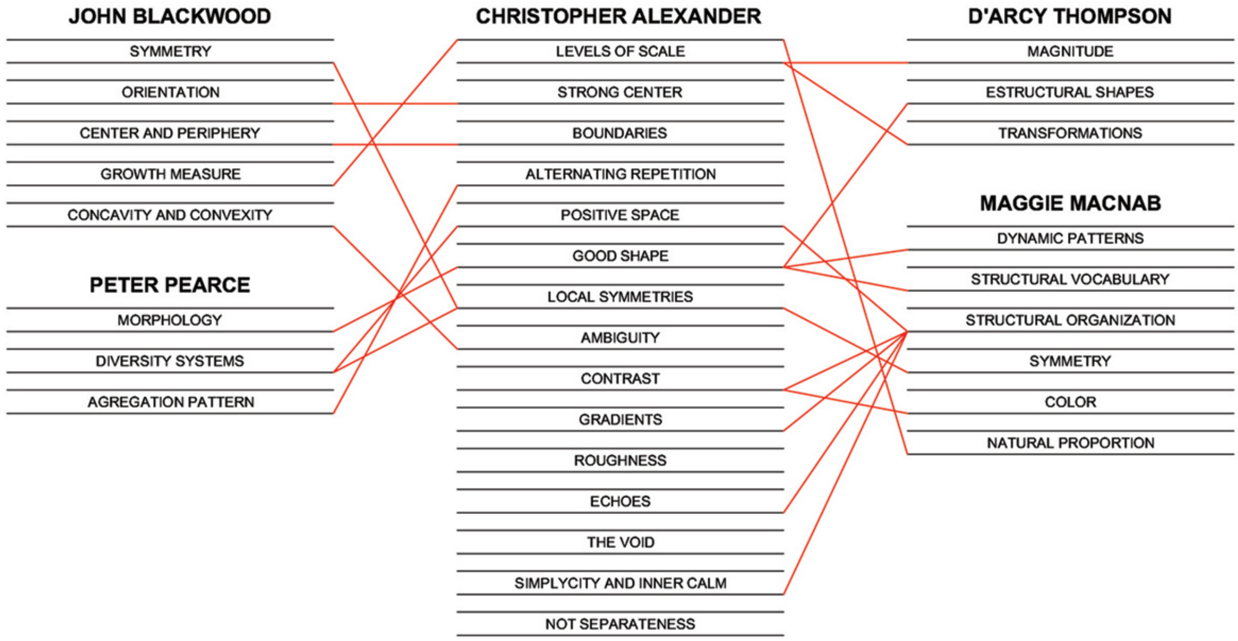

Fig. 2 Correlation between author's geometric characteristics.

This suggests that growth already includes principles of identity and diversity. Given that the growth approach is the most comprehensive in ecological shape characterization, it seems logical, that to proceed, one needs to understand how its process is characterized and what kind of characteristics define it.

3 Growth geometrical pattern

The growth process can be characterized as one which begins with something that expands and never ceases to be an integral part of the surroundings. Therefore, it contains three inseparable parameters: origin, expansion and connection. Which are the geometric characteristics associated with each of these parameters?

Origin is the source of information that gives "body" to a structure. It defines the morphological character and the structural cohesion. So, the characteristics required are the definition of a geometrical vocabulary and the definition of proportional ratios. Both are discussed under the theme of allometry (Fig. 3). Expansion focuses on how origin reproduction is achieved and its propagation in space. It requires as characteristics the repetition and the centre. These are addressed under the theme of structural expansion (Fig. 3). Finally, connection focuses on how biologic structures work, their ability to fit into the surroundings. The geometrical characteristic associated with it is the union and is discussed under the theme of spatial integration (Fig. 3).

How can each of these themes be described? Regarding allometry, biologic structures are composed by two types of shapes: structural shapes that materialize the compositions, and expansive shapes that control the distribution of structural shapes. However, their distribution is not random. They establish proportional relationships between them, by using magnitude values present in accordance with the golden ratio (Fig. 3). As to structural expansion, biological structures expand through expansion levels referenced in a centre. These impose the creation of force fields in its favour. This expansion is made by a repetition of structural elements with a geometrical particularity, namely spatial exclusivity. This quality requires the presence of three characteristics: 1) contrast (elements are easily identifiable and delineable); 2) simplicity (elements are distributed by adjacency and never by intersection) and 3) local symmetries (elements have an irregular perimeter). When all these characteristics exist simultaneously, they create a roughness effect (Fig. 3). In relation to spatial integration, the boundaries of the biological structures are characterized by irregularity and diversified connections (use of convex and concave shapes) (Fig. 3).

To grasp the degree of divergence of these characteristics in architectural morphology, their existence in architectural structures was analysed in this research. The analysis showed that these qualities are not strange to architecture. However, they are not simultaneously present in its structures. This suggests that the human design process does not provide the means to do so, i.e., the morphological divergence between biological and human structures arises from a design problem (Fig. 3).

4 Design process – drawing tool

How can these growth characteristics of biological pattern be transferred to architectural design? Using two generative design tools: shape grammars and Voronoi diagrams. Voronoi diagrams (Okabe et al., 2008) are used in design to reproduce natural textures. Their common pattern reveals some of the growth characteristics identified (geometric vocabulary, repetition and union). However, when disposed through a centroidal organization, it reveals in most cases, the presence of all of them. Nevertheless, this type of organization is not intrinsic

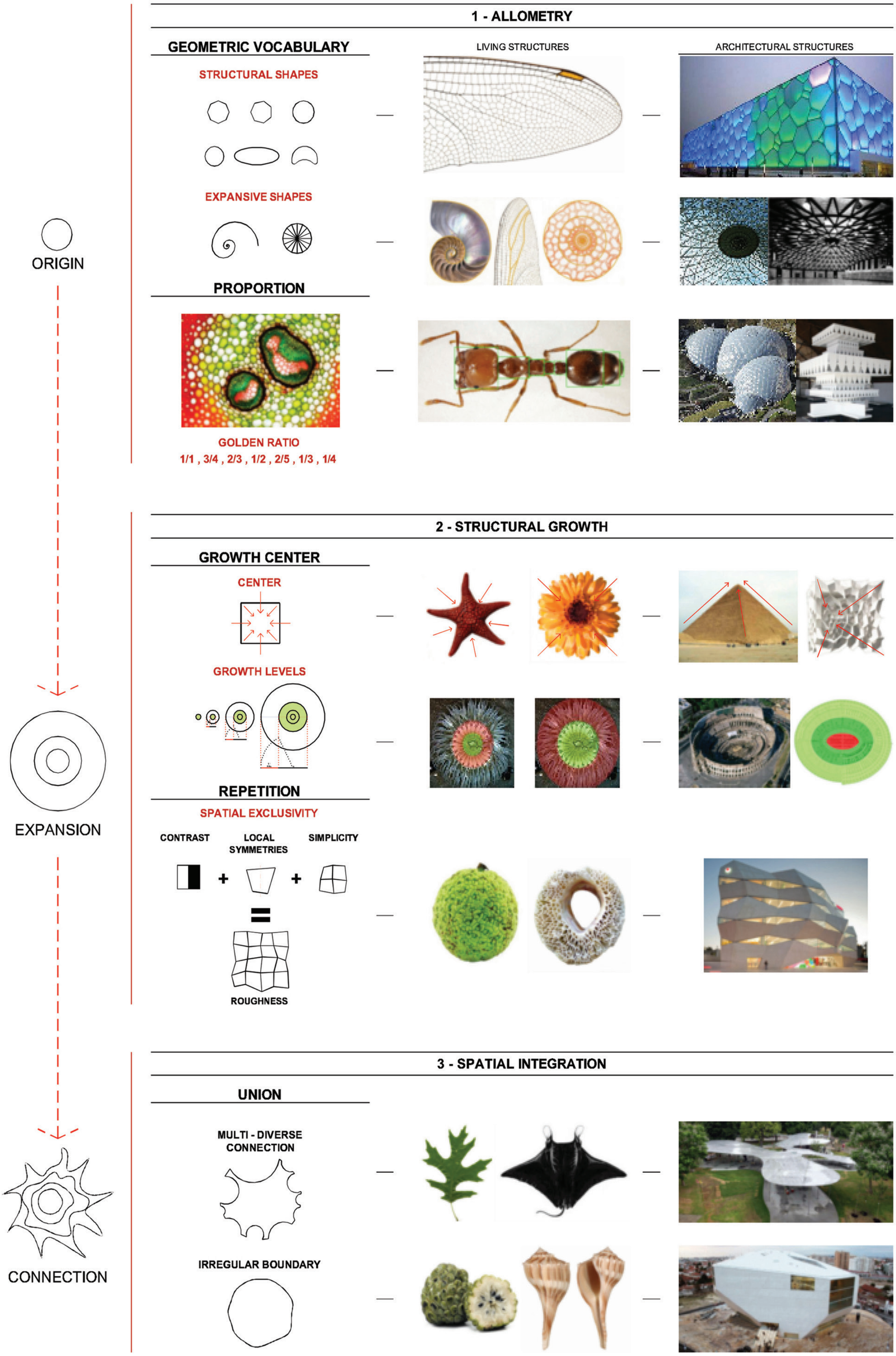

Fig. 3 The geometric patterns of biological growth and its presence in architectural structures.

to the system. It is precisely with the intention to generate this order that the design process uses shape grammars. Shape grammars (Stiny, 1980) differ from Voronoi diagrams by operating through a process of successive transformations of shapes using rules described with geometric and algebraic languages. As the tool allows the generation of elements through others, it can be used to control expansion, morphological character and shape proportions. Thus, shape grammars are defined as the main tool of the design process. The implementation of the growth characteristics in human design requires the development of a grammar with four distinct phases, each one with its own rules. In the first phase, where global rules operate, the structural organization type (expansive shapes) is defined. This also requires the definition of levels and sublevels of expansion to control proportional relationships of the main shape and between elements. In the second phase, shape delimitation rules introduce the union principles in the grammar. Its goal is the generation of shapes on the structural basis defined in the first phase. These have to reveal diverse connections by defining contours referenced in points located in the expansion levels. The contours are defined by concave and convex lines. The third phase, where local rules operate, corresponds to the materialization stage (structural shapes). The physical structure, where all previous decisions stay displayed, is defined. For this purpose, the concept of Voronoi diagram is applied. Finally, in a fourth and final phase, spatial rules transfer the compositions onto a curved surface, (torus or sphere). The concavity of the surfaces allows delimiting an internal space, leading to a "shelter" structural purpose, which allows human activity (Fig. 4).

Although the structures generated by the tool have been referenced in morphological characteristics of biological structures, it is necessary to verify whether they can be understood as such. Pourjafar (2011) developed a characterization work of biological quality in architecture in morphological terms.

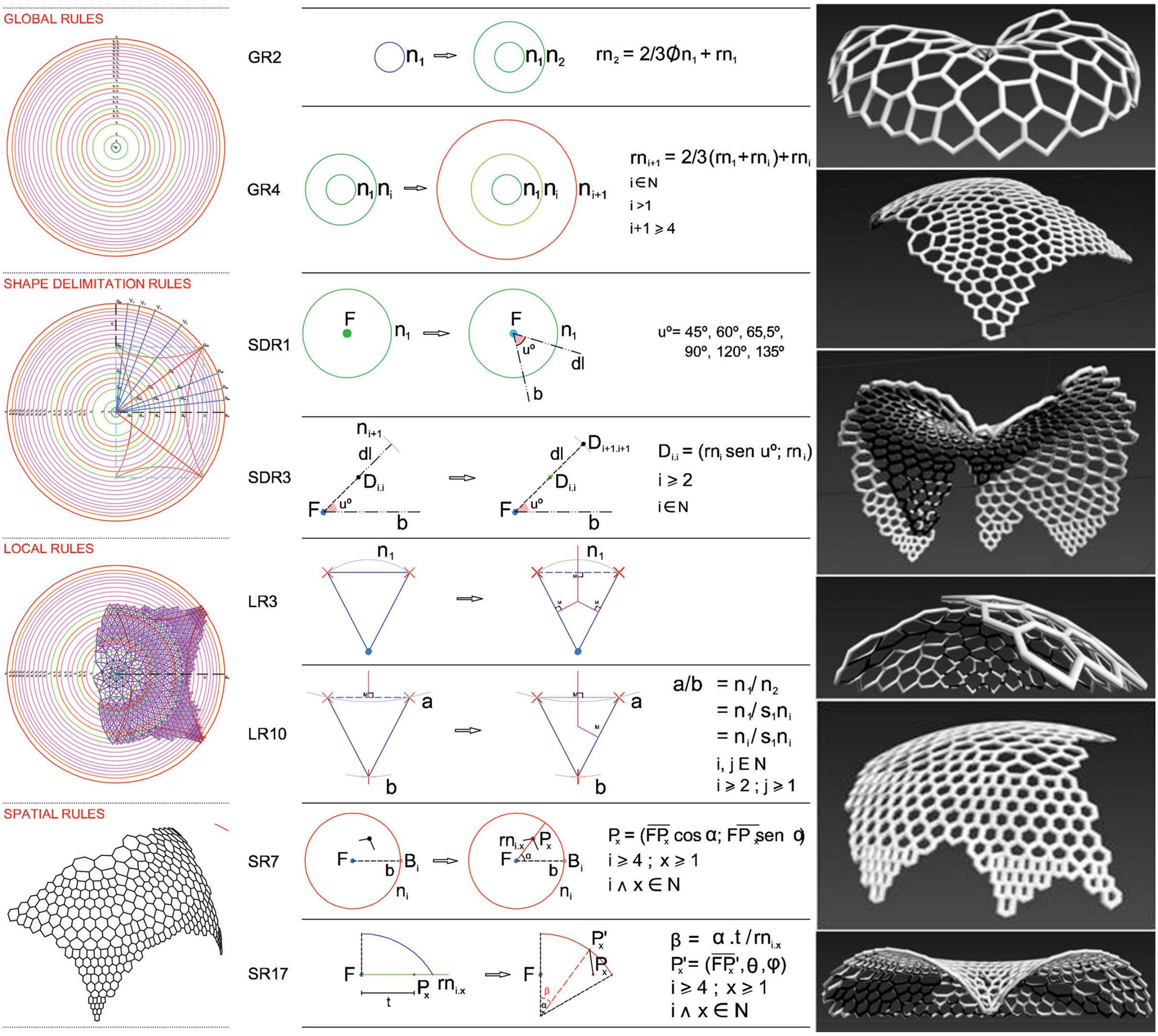

Fig. 4 Generation phases (left). Rules examples (middle). Examples of models generated with the grammar (right).

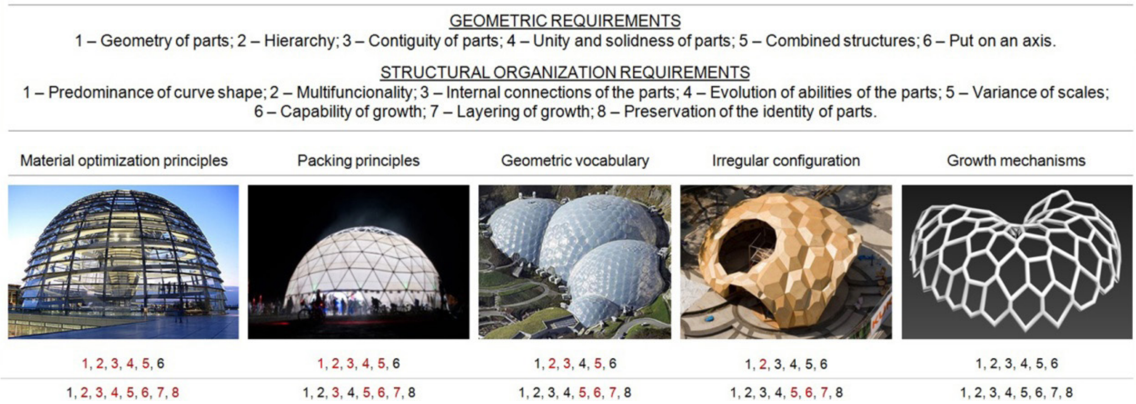

Fig. 5 Introduction influence of geometrical characteristics of biologic origin at a structural elements level.

More specifically, in a geometric and structural organization level (Fig. 5). The structures generated by the tool developed in this research (shape grammar) achieve the author's requirements. However, to grasp the contribution that growth had in its emergence, it was necessary to analyse how other approaches of biological intentionality respond to these biological requirements. The chosen approaches have been selected by the amount of geometrical information of biological origin instilled in the compositions. The analysis revealed that the higher the number of geometric qualities implemented in structures, higher the number of requirements obtained. This analytical cadence (Fig. 5) has shown that growth contribution in human design of biological purpose is made at a structural organization level.

5 Conclusions

Some geometrical characteristics of the defined biological pattern have already been implemented in other research lines (biomimetics and digital morphogenetic). However, in these researches, the implementation of the characteristics is made in structural elements at a geometric configuration level. The implementation of a design process based on growth not only imposes these qualities in structural elements, but it also stands out by giving them a structural organization. So, the contribution of the growth variable to the human design process takes place at two different levels: 1) at the organization level of geometric characteristics and 2) at the geometric qualities level that emerge from its presence. The main organizational requirements that are imposed are a generator centre, orientation, expansion levels and elements distribution. The dependence that the geometric characteristics hold from the growth process is demonstrated by the emergence of other geometric qualities resulting from their joint operation, such as evolutionary balance, structural simplicity, structural fluidity and internal connection to the environment.

As for shape grammars, their introduction provides biological design a flexible tool for anyone who is interested in developing structures with these qualities. It also allows the release of biological design from their referenced shapes, and the generation of shape diversity with the same geometric identity occurs in biologic structures. In the field of architecture, the tool allows the architect/designer to experience a kind of spatial design in a biological perspective, taking into account the simplicity by multifunctionality. This means that elements are not separated by functions. The geometrical and structural configurations are identical. This quality can be used as a reference in the design of self-supporting architectural solutions and their exponentiation in terms of material and structural optimization.

Although the tool fulfils the defined goals, there is the intention to continue to potentiate it with other qualities that encourage an evolutionary approach to biologic structures morphology, and to complement it with a fabrication process.

References

Alexander, C. (2001) *The nature of order: An essay on the art of building and nature of the universe, book 1 – The phenomenon of life*. The center for environmental structure, California.

Blackwood, J. (2012) *Geometry in nature; Exploring the morphology of the natural world through projective geometry*. Floris Books, Edinburgh.

Loehle, C. (2004) Challenges of ecological complexity. *Ecological complexity*. 1(1), pp. 3-6. DOI: 10.1016/j.ecocom.2003.09.001

Macnab, M. (2011) *Design by nature: Using universal forms and principles in design*. New Readers, Berkely.

Menges, A. (2011) *Material computation: Higher integration in morphogenetic design*. John Wiley & Sons, London.

Okabe, A., Boots, B., Sugihara, K., Chiu, S. N., Kendall, D. G. (2008) *Spatial Tessellations: Concepts and Applications of Voronoi Diagrams, Second Edition*. John Wiley & Sons, New Jersey. DOI: 10.1002/9780470317013

Oxman, N. (2010) *Material-based design computation*. MIT, Massachusetts.

Pearce, P. (1978). *Structure in nature is a strategy for design*. The MIT Press, Cambridge.

Pourjafar, M. R., Mahmoudinejad, H., Ahadian, O. (2011) *Design with nature in bio-architecture with emphasis on the hidden rules of natural organisms.* International Journal of Applied Science and Technology. 1(4), pp. 74-83.

Reed, B. (2007) Shifting from sustainability to regeneration. *BuildingResearch & Information*. 35(6), pp. 674-680. DOI: 10.1080/09613210701475753

Stiny, G. (1980) Introduction to Shape and Shape Grammars. *Environment and Planning B: Planning and Design*. 7(3), pp. 343-351. DOI: 10.1068/b070343

Thompson, D'Arcy Wentworth (1992) *On growth and form: the complete revised edition*. Dover publications.