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RESEARCH ARTICLE

Biomimetic Geometry Approach to Generative Design

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Abstract

This paper provides an initial exploration of natural forms streamed into geometric patterns, providing a basis for further research that may find use in generative architectural design. The development of interest in geometric forms encountered in nature, and their implementation in design solutions, is expanding with the help of modern computer technology that has enabled the use of generative models. The biomimetic approach sets new standards in generative design. Through the form of the flower, which was singled out as an example, all the qualities derived from these connections, and the primarily aesthetic impression based on harmony and perfect proportions of elements, following the stability, strength and power of this form, can be clearly observed.

Within the research, the study was based on the geometry of the flower species Ramonda nathaliae P. et P., an endemic species with restricted distribution in Serbia, by using parametric modelling methods and experimental designs displayed on the DVD (duplicate along curve) and the use of Voronoi diagrams.

Keywords

biomimetic, geometry, generative design, flower form

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1 Introduction

Design occurs as the result of many different influences, needs, environmental conditions and the personal affirmation of the creator. However, if the inspiration for the design came from nature, it is significant to point out and understand the importance of such solutions, because they lead to the evolution of the biomimetic concept. Nature offers an almost inexhaustible source of inspiration and solutions, and biomimetics is a rich design tool that interprets the natural processes and forms, transferring them to the artificial creations (Gruber, 2011). The biomimetic approach does not separate fixed entities like form, function, structure and material, but unites, defining them as a semi-organic composition. By copying natural models, applying geometric principles and biological knowledge, it is possible to produce spatial structures that are stratified, variable, and connected.

From the perspective of biomimetics and geometric approaches to contemporary architectural design, the range of innovative ideas has expanded and the boundaries of technical possibilities have been transformed (Ranđelović, 2012). What until recently seemed unreal, and was impossible to implement, has become a reality thanks to computer technologies in which are implemented research results and process models. Generative design solutions based on fundamental algorithmic forms were obtained by applying analytic geometry. The variety of geometric shapes that could be achieved by this method represents an initial step towards the formation of more complex objects.

The process, where the basic patterns are modified and used for new creations, is reminiscent of the traditional Japanese craft of paper folding – origami. This carries three important elements: a set of truths - a set designed to understand the basic geometric principles; a set of life - a traditional set for introducing the very skills, and a set of beauty - meant to instil creativity and energy in spirit; thus, a desire to create beauty through play (Cueva, 2013), experimenting with bending forms to infinity, which brings the uncertainty of the result. These principles carry a universal message that is completely identified with the role of the designer, who transforming their creative energy in the experiment, interprets all parameters specified by nature into the design; a source that offers multiple opportunities as an outcome of the process.

2 Computer technology in design

Generative design based on parametric models uses algorithmic patterns that rely on geometric relations (Teofilović, 2011). Thanks to these models and with the help of modern computer programs, it is possible to simulate the transformation characteristics and analyse their variations and outcomes. In this way, it is possible to test large scale structures and their reactions to different materials and constructions, as it is extremely important to find an appropriate design configuration before building these structures (Fig. 1 & 2).

Fig. 1 Changsha Meixihu International Culture and Art Centre in Changsha, China by Zaha Hadid Architects

Design programs used for animation like 3ds Max, Softimage, Maya, Cinema 4D, Blender, Rhinoceros and similar, are useful because they possess the tools that enable the transformation within the given time-frame. These tools could be models that arise from the parametric information specified by the designer (Jović, 2012). At the same time, BIM (Building Information Modelling) software connects the relations between segments of the model; it can create alternative solutions with the help of tools that define the time frame, and capture every frame during the period of model change and its evolution (Dounas, 2009).

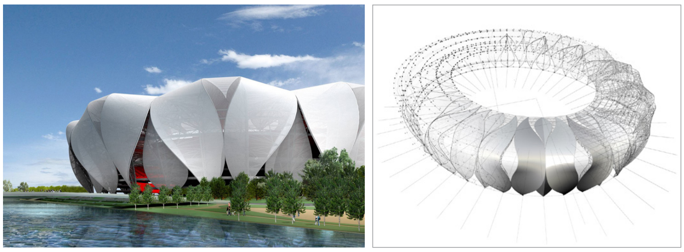

Fig. 2 Bloom-Shaped Olympic Sports Centre Stadium in Hangzou, China

In the process of modelling, Rhinoceros software is often used. With the help of the basic software, and its plug-in Grasshopper (Fig. 2.), it is possible to create, control and change the model. Grasshopper controls the model in real time, through the transformation of the basic forms of changing parameters such as shape, size, height or situations simulating mechanical influences on the model (Milošević et al., 2014). Another option is to divide the model into several components that can be specifically modified. Due to the introduction of parametric modelling, with the help of animation software, it is possible to generate and manipulate many structures and explore complex geometric forms and natural patterns.

3 Flower form

All natural forms, which are the elements and structures in the proportional relationship, could be called beautiful. For these reasons, particularly outstanding is the form of the flower, which exudes both harmony and elegance; consequently, it is often used as inspiration in architectural design (Shambina et al., 2012) (Fig. 3).

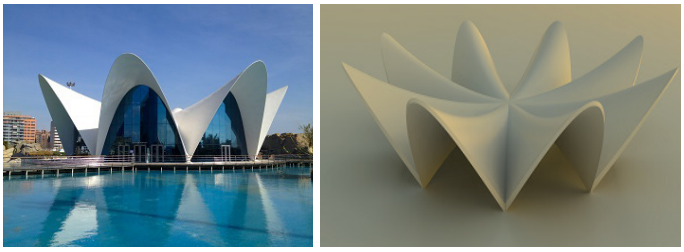

Fig. 3 L'Oceanogràfic - museum complex in Valencia, Spain by Felix Candela (1958) (object recalls the flower form)

Examples of contemporary architectural structures, whose basic form is inspired by the morphological structure of the flower, are established on minimal geometric shapes that build complex structures. This is possible thanks to the correlation between their elements that invisibly merge the structural differences; this being one of the basic characteristics of generative design. Possibilities for the implementation of biomimetic principles in architectural design, based on geometrical principles, provide an opportunity for the development of various generic models based on parameters that originate from nature, and whose configuration is adapted to the requirements of spatial constructions.

Examples of architectural structures in the shape of a flower, whose form was inspired by a natural origin, are shown in Figs. 4, 5, 7, 8, 9 & 10.

The form of the flower bud carries a symbolic message that can be transferred to the object itself (Fig. 4).

Fig. 4 Baha'i House of Worship (Temple of Light) in Santiago, Chile by Siamak Hariri (reminiscent of a flower bud)

The stages through which the plant during flowering, the opening and closing of the petals, and the use of this principle in architectural design brings a „smart"- dynamic facade solution (Fig. 5).

Fig. 5 Flower Shaped Venezuela Pavilion Expo 2000 in Hanover, Germany by Fruto Vivas - inspired by an orchid flower

Many solutions have been inspired by the lotus flower (Fig. 6). Within its shape, there is the form of floating flowers, often interpreted in some futuristic solutions (Fig. 7, 8, 9 & 10).

Fig. 6 Lotus flower (*Nelumbo nucifera G.*)

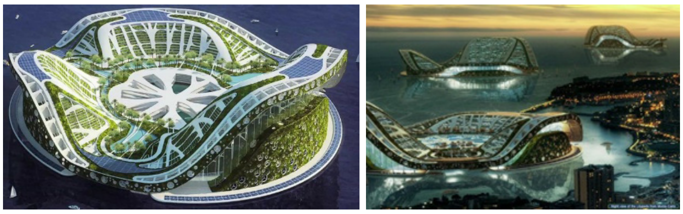

Fig. 7 Lilypad by Vincent Callebaut

Fig. 8 The Lotus Building in Wujin, China by Studio 505 (2013)

Fig. 9 Art Science Museum in Singapore, Singapore by Moshe Safdie (2011)

Fig. 10 Lotus Temple in New Delhi, India by Fariborz Shaba (1986)

4 Materials and Method

4.1 *Ramonda nathaliae* Pančić et Petrović

The species used for the example is *Ramonda nathaliae* P. et P., (Fig. 11) which is endemic to Serbia and Macedonia. *Ramonda nathaliae* P. et P. was discovered by famous botanists Josif Pančić and Dr Sava Petrović, and named in honour to the Serbian Queen, Natalija Obrenović. This species is characterised by poikilohydry - the ability to survive harsh conditions through a resting phase until favourable conditions allow it to „come to life"; because of this, it is known as the "Phoenix Flower".

Fig. 11 *Ramonda nathaliae* P. et P.

The flower is composed of lobular, 4-5 articulated calyx leaves and 4 crown leaves with pistil and 4-5 stamens. Symmetry is actinomorphic (poly symmetrical).

The form is simple, consistent and elegant, and therefore suitable as an example for research into the development of generative forms, based on the structure obtained through the evolutionary processes of form exploration.

4.2 Voronoi diagram

So that it could be used in a subsequent design process, the flower form of *Ramonda nathaliae* P. et P. is transformed into the geometric pattern. In this process, a Voronoi diagram (Voronoi Georgi, (1868-1908), Russian mathematician) was used.

A Voronoi diagram is a graphical representation of objects or points, in which their mutual distances form a geometric pattern. If the level points are arranged in rows, the Voronoi diagram allocates areas closest to the specific point, but if it comes to a group of objects or spatial entities, the plane is divided on the basis of points which alone confer the closest spatial unit. In case a point whose spatial unit is not uniform, the Voronoi diagram will be formed accordingly of points that are on the same distance of two or more spatial units (Jović et al., 2011).

4.3 Delaunay triangulation

A Delaunay triangulation is a set of points represented by a set of edges that meet the requirement of „empty circle": for every edge that can draw a circle that contains the endpoints of these edges and no other point (Jović et al., 2011). The possibility of a line connecting two vertices of a Voronoi diagram, provided that the edge between two Voronoi polygons is shared, is marked as a dual structure of a Voronoi diagram – In this process, a Delaunay (described) circle is used).

4.4 Voronoi diagram concept

The construction of a Voronoi diagram is based on five steps:

Labelling starting points – marking the points that are characteristic of a particular form, vertices of a triangular mesh

Delaunay triangulation – the closest neighbouring dots merge into a line segment, in a way that the staples do not intersect

Determination of half of the line-determination of the half edges of the Delaunay triangulation

Construction of the normal on site halving and determine their point of intersection – on each half of every line of a Delaunay triangulation, precise construction of these normal, that merge into a single point, represents the centre of the circumscribed circle of the triangle.

The formation of Voronoi diagram cells within which are „given" points to the shortest distance from the edges of the polygon Voronoi diagram – drawing lines per normal of Voronoi diagrams to obtain closed fields with vertices that are centres of circle described triangles of a Delaunay triangulation.

5 Results

Based on petal veins of the *Ramonda nathaliae* P. et P. flower, characteristic starting points were set up as a basis for future patterns obtained with the help of a Voronoi diagram. The schedule of veins is transformed into a pattern whose structure corresponds to one petal of the flower. To form a flower, a schedule of petals could be placed in a square base with a characteristic overlapping (Fig. 12). This overlap can be represented by duplicating petals along a curve, corresponding to the number of petals in nature, in this case four times (Teofilović et al., 2013).

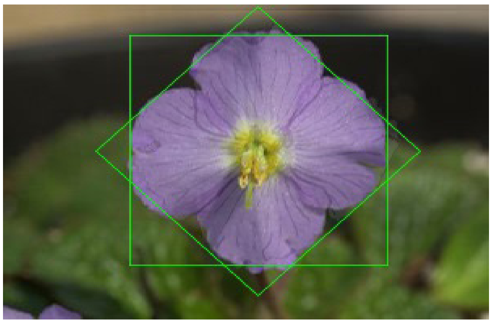

Fig. 12 *Ramonda nathaliae* P. et P., contour of flower

The derived model is the result of the application of digital technologies for the 3D modelling program Rhinoceros and its plug-in Grasshopper, which, with the help of geometric relations, generates a model form the outcome of which depends entirely on the parameters provided by the shape of the flower of *Ramonda nathaliae* P. & P.

To get the shape closer to the organic form in this paper, the cells of the Voronoi diagram are filleted.

The resulting pattern is covered by petals in a lobular shape (Fig. 13).

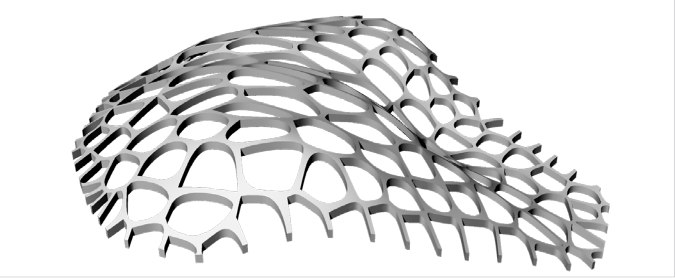

Fig. 13 Flower petal constructed with a Voronoi diagram

The flower is constructed by setting a series of petals, arrayed along the curve and set on an angle, so that petals are characteristically switched, representing identically the overlapping in nature. (Fig. 14).

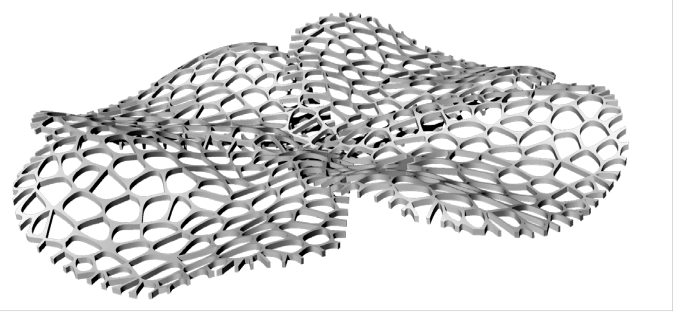

Fig. 14 Constructed flower

Creating more complex structures could be achieved with elements composed in different arrangements to achieve more intricate forms. (Fig. 15).

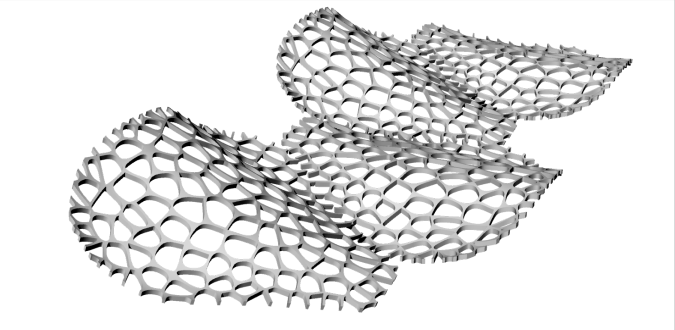

Fig. 15 Structure obtained by different arrangements

6 Conclusion

Inspiration based on the structural and functional principles of natural systems provide realisable solutions. Design that represents the link between engineering and natural solutions provides a constant interaction between the object and the environment. The different reactions to the changes that this environment creates and the relative outcomes can predict the form of the object based on the principles of generative design.

The flower, as a plant organ, is part of a system that varies greatly in structure and function. However, the form of the flower has been singled out as a visually attractive structure that has served as an inspiration to many different architectural objects.

With the example of *Ramonda nathaliae* P. et P., the geometric structure of the flower is derived as the starting form to be used for further implementation into the generative design. The obtained pattern could be further manipulated, together with the current application of computer programs for 3D modelling. Based on the initial form, it is possible to establish a distinctive arrangement of repeating elements or use tessellation to build complex structure models.

The basis of the derived pattern could find applications in smaller scale structures such as elements of interior design suitable for 3D printing, and exterior elements such as fountains, pergolas, or paving styles. For the structure of more complex objects, it is necessary to continue the research. The interesting characteristics of the species *Ramonda nathaliae* P. et P. that are differentiated by its poikilohydric nature can lead to the development of solutions that rely on these principles, and whose structure is more complex, where design involves more than just copying the visual patterns. The idea that the concept of „Phoenix flower", transferred and portrayed in the future, could be explored by further research enabling the correlation of structural elements and their functions. These, in turn, would contribute to improved implementation of the design in spatial solutions.

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