

Architecture and Biological Analogies

Finding a generative design process based on biological rules

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Abstract. “The study described in this paper evolves within the larger context of a research aimed at inquiring into analogies between architecture and nature, and more specifically between architecture and biology. Biology is a recursive source of architectural inspiration due to the tight relationship between form and function, the natural balance of forces and the corresponding geometric solutions found in living beings. Roughly, one can classify historical analogies between architecture and biology into two main categories. The first tries to mimic biological forms and the second biological processes.

The specific goal of the described study is to find how new technologies can redefine and support the process of constructing such analogies. It uses as a case study a tower project designed by the architect Manuel Gausa (ACTAR, Barcelona) called Tornado Tower because of its complex shape inspired in the frozen form of a tornado. Due to the geometric irregularities of the tower, Gausa’s team had difficulties in designing it, especially because solving the structural problems required constant redrawing. This paper describes the first part of the study which primary goal was to conceive a parametric program that encoded the overall shape of the Tornado Tower. The idea was to use the program to simplify the drawing process. This required a mathematical study of spirals and helices which are at the conceptual basis of the external structure and shape of the tower. However, the program encodes not only the shape of Gausa’s tower, but also the shapes of other buildings with conceptual similarities. Such class of shapes is very recurrent in nature with different scales and with different utilities. Therefore, one can argue that the program makes a mathematical connection between a given natural class of shapes and architecture. The second part of the study will be devoted to extending the program with a genetic algorithm with the goal of guiding the generation of solutions taking into account their structural fitness. This way, the analogy with genetic procedures will be emphasized by the study of the evolution of forms and its limits of feasibility. In summary, the bionic shape analogy is made by the generation of mimetic natural forms and a genetic process analogy starts with the parametric treatment of shape based on code manipulations. At the end the program will establish an analogy between architecture and biology both terms of form and process. ”

Keywords Genetics; Evolutionary Systems; Parametric Design

Introduction

The first goal of this investigation is to create a program capable of parametrically generating the geometry of a designated building. In order to understand the geometrical solutions to be engendered and write the program, a method of approach based on biological analogies was applied. This building selected is the Tornado Tower, (designed by Manuel Gausa ACTAR Arquitectura, 2001, Barcelona). As inferred by its name, the inspiration for the Tornado Tower came from the frozen shape of a tornado. More than its source of inspiration – a natural phenomenon - this project was chosen because of its shape and its constructive solution. Its irregularity provides a good challenge for encoding, parametrically manipulating and for the application of genetic algorithms.

Manuel Gausa designed two different tornado towers with more or less the same appearance but conceptually different in terms of structure and function. Both cases were difficult to conceive geometrically because of their formal irregularity. The first is a telecommunication antenna: a feasible project where the exterior shape is obtained with a light and permeable structure. He solved the structural design problems with a central concrete column that is responsible for supporting the total weight of the building at the ground level. The second was conceived for the Ground Zero site in New York City. It offered a structural challenge as it is an office building where the exterior shape is coincident with the structure causing wind and gravity difficulties.

From the personal investigation and conclusions taken from conversations with the ACTAR authors and engineers at IST (Instituto Superior Técnico - Lisbon), we realized the Manhattan Tornado Tower should also have had an interior structural column with the vertical communications. The relative position of this column must be such that eventual eccentricities with the mass center of the building are avoided. The wired structure

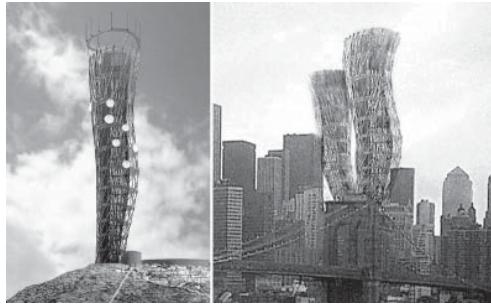


Figure 1. Antenna Tornado Tower and Ground Zero office building Tornado Tower. (Courtesy of Manuel Gausa).

that surrounds the building connects the different floors which allow the building to act physically as a monolith, without any internal torsion. This was one of the main difficulties at the design stage because everything had to be hand-drawn.

Considering the organic development of this building shape, the idea was to create a computer program capable of modeling flexible spiral structural shapes, similar to the ones found in nature, mainly in living organisms.

The context

Architects and designers are usually aware of the advantages of a multidisciplinary approach to the conceptual process. We might say that the crossing between knowledge fields is an inherent characteristic of architecture. The search for unprecedented themes in mechanisms and concepts alien to architecture is common in architectural design. Biology in particular, due to its holistic characteristics as a science, can be related with an immense variety of technical and artistic disciplines.

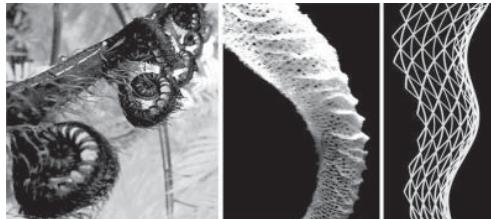


Figure 2. Photos of a plant, a sponge (*Euplectella silica* structure) and a 3D object generated with the program. (Photos of the author)

For designers, the first appeal to biology is usually related with the way living beings integrate harmonically form and function. In each life form, the way nature achieved a perfect balance between internal and actuating external forces can be observed. Another appeal to biology is related to the simplicity of some geometric canons and tools that nature uses to generate an almost infinite number of forms.

It is very common to see life forms represented in architecture. We have all seen buildings with biomorphic allusions to plants, animals or even anthropomorphic allusions. Furthermore, architects and designers like Frank Lloyd Wright have referred to organic architectures not only from the shape but also from the functioning point of view. When shape or procedural analogies with biology have functional applications in architecture, they are referred to as bionic (Jack E. Steele, 1958), bio-architecture (Frei Otto, 1961) or biomimicry (Janine Benyus, 1998). These fields of study are concerned with the study of analogies with living nature to provide tools that solve conceptual and design problems. The restriction of bionic investigations to living beings is frequently discussed. This happens because some of the phenomena that are the basis of living mechanisms share common design solutions with natural inanimate structures. Therefore, this differentiation can never be seen as a real restriction to the investigation.

The present work is part of the author's PhD research at ESARQ-UIC in Barcelona, which evolves within the wider domain of research called bionic architectures, but focuses on genetic analogies in architecture. The intention was to start investigations related to some of the most recent and complex analogies that were created between architecture and living mechanisms. The digital approach, the one that was used in this work, is based on the relation between the biological and technological evolution, showing some of the procedure analogies that relate both programming and genetic codification.

The investigation behind the program

Spirals and helices can be described by the relation between one rotation and one or several directional arrays. To construct the program, it was necessary to study mathematical functions that generate spirals and consequently helices. These functions had been translated into Auto-LISP code in order to generate helical structures based on helices, spirals and ellipses. Also some trigonometric notions were necessary for the introduction of the third dimension and respective variables. The forms generated by the program can be perceived in nature from the micro up to the macro scale. They are usually related to movement and packaging. We can observe the helical movement in a tornado, but also in the relative movement of planets and solar systems inside galaxies. In living beings, these kinds of forms are frequently used to pack things within a minimal space. We can observe it in the double helix of the DNA, in the disposition of some plant seeds or in a vast variety of shells of invertebrate creatures.

Spirals that have a constant growth are known as arithmetic spirals. For example, these can be observed in a spider's web where the dimensions of its body serve as references to produce the spiraled growth around a central point. On the other hand, logarithmic spirals have growth proportions other than 1. They can be found everywhere in nature. Mathematicians and architects give special attention to those logarithmic spirals that have a proportion similar to that of the Fibonacci sequence (0, 1, 1, 2, 3, 5, 8, 13, 21...) because of their applications in mathematics, geometry, biology and music. D'Arcy Thompson, in his most famous book "On growth and form" (1917), qualifies as mystical the idea of a direct relation between the Fibonacci series and life. Although this specific proportion has interesting properties for exploration, the present study never had the intention of pursuing any specific kind of spirals or helices. The



Figure 3. Render of spirals made with the program - a logarithmic spiral, an arithmetic spiral and a spiral made with a low quantity of segments. The number (1) corresponds to the number of turns; (2) distance between turns; (3) Extrusion ray; (4) Number of segments per turn - geometric resolution.

idea was to investigate a variety of spirals that exist in nature with different proportions and utilities.

The program

The program was developed within the CAD II class (Duarte 2005a) of the Architecture Program at the Instituto Superior Técnico (IST) in Lisbon, where learning Auto-LISP and applying it in an architectural context is part of the career discipline for all students. The LISP language began to be developed in 1958 by John McCarthy and is still being used in artificial intelligence applications. At the present time, Auto-LISP is frequently used by architects in order to automate functions inside of AutoCAD and other programs.

At a first stage of their training at IST, architecture students learn coding with the automation of procedures as their main objective. Secondly, they learn how to use Auto-LISP in order to investigate more complex aspects of the creative process, providing thus innovative solutions to the study of forms with parametric manipulations, iterative and recursive programming methods.

To develop the program gradually provides the opportunity to get familiarized with the Auto-Lisp programming. At each stage, a software development logic based on a progressive growth of complexity, maintaining and actualizing at each step the abilities of the program was applied. Gradually, the idea materialized into very flexible software. This means that a wide range of variables were

created and manipulated by a recursive algorithm. The number of code lines was minimized, simplifying and clarifying the mathematical functions.

The way the code was written and the kind of variables that were implemented were in part inspired by D'Arcy Thompson's theories about the way nature achieves morphologic diversity in living beings by the effect of exterior physical forces. The idea was to produce a balance between complexity and diversity based on the relation between rules and variables. Considering a Linnaean classification, the mathematical functions characterize the class of objects that are created and the variables applied to those functions usually characterize the diversity inside the families.

Inside the program

The variety of structures generated by the program was achieved by the inclusion of numerous variables. The parametric control of those variables allows the adjustment of the development's direction, dimension, number of elements, proportions and rhythms involved in the creation of the structure.

As can be seen in the Figure 4, even with small changes in one or two variables at a time, the difference between the results is considerable. To simplify the automation of the process, in most versions of the software, the variables are selected and altered at the beginning of a run of the program. After this first step, there is an intermediate

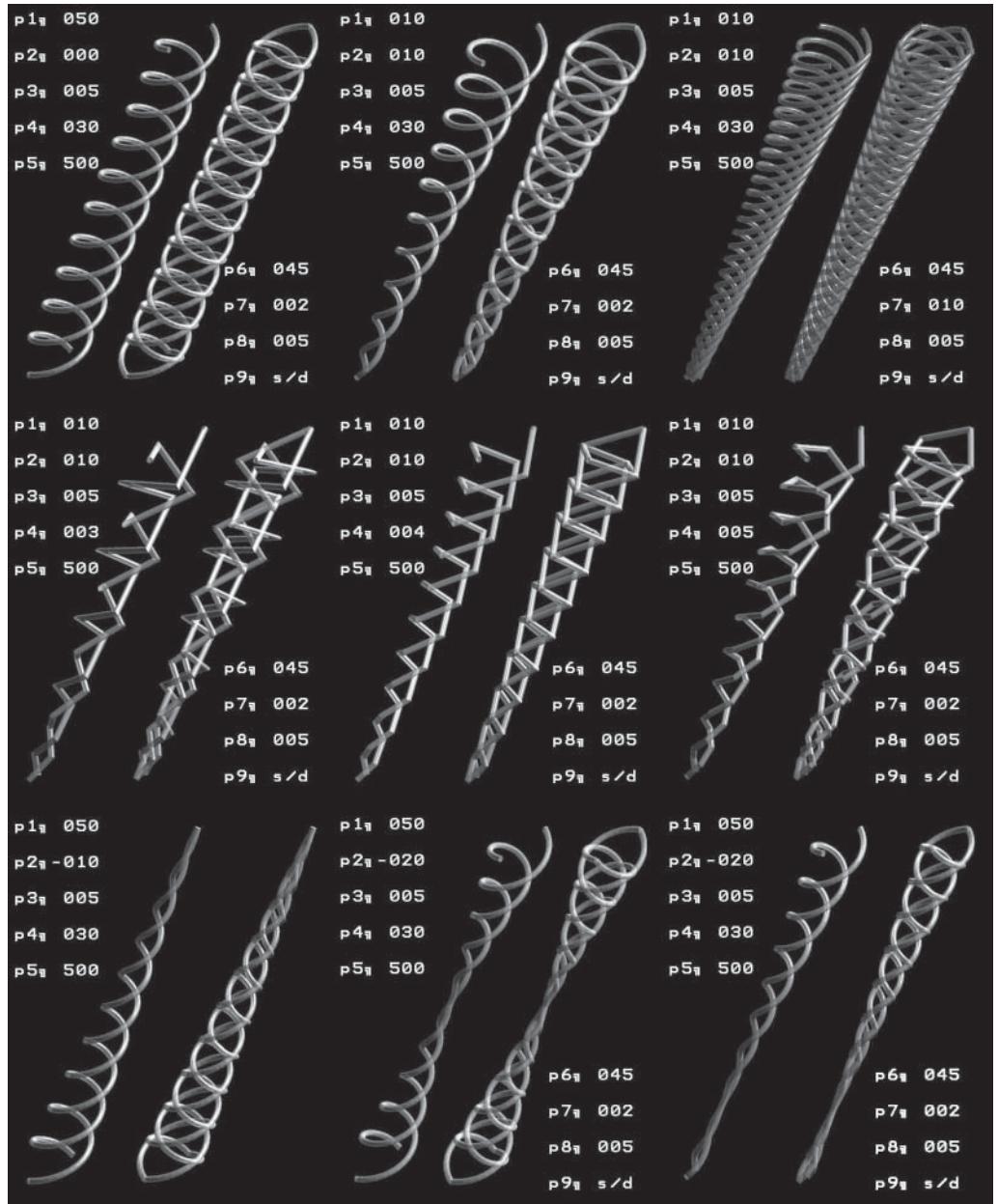


Figure 4. Board with renders of helices made by the program with different variables applied. (1) Initial ray value to the variable; (2) Distance between turns; (3) Number of turns; (4) Number of segments per turn - geometric resolution; (5) Total helices height; (6) Angle with the zz axis; (7) Number of helices; (8) Extrusion ray; (9) Single or double rotation

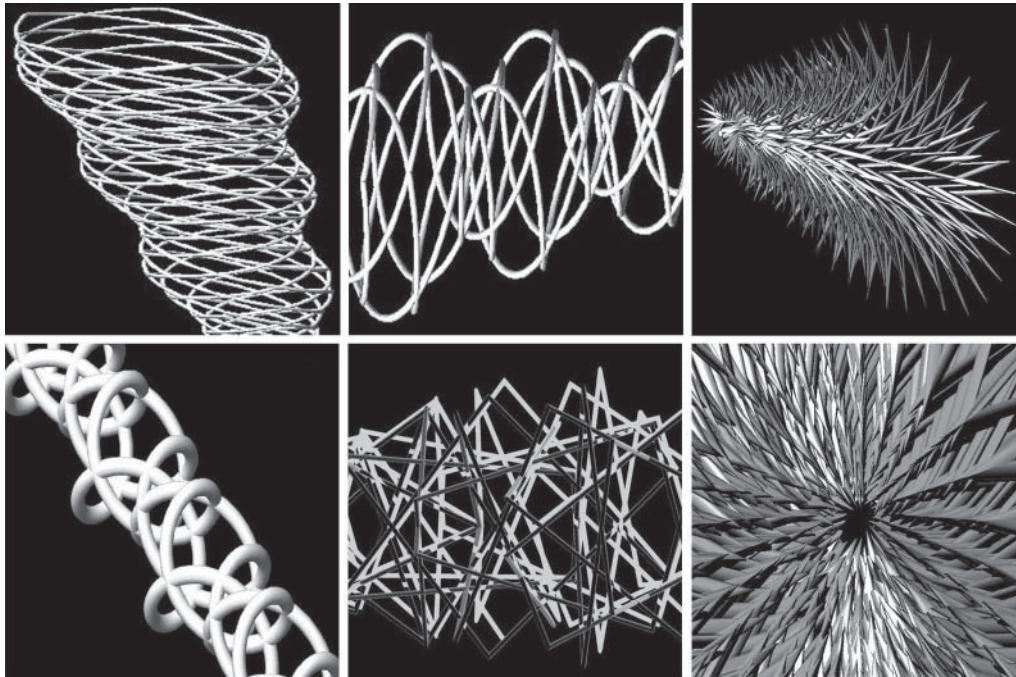


Figure 5. Renders of some meta-applications of the spiral generator program

function inside the code that is responsible for the translation of measures and the calculation of the variables to be applied in the main function. When all the data is ready, this last function generates the helices' reference points, based on processes of repetition, associated with recurrent sub functions, in a system of polar coordinates.

At a second stage, the use of this software was also tried on itself. This means that the main mathematical function that generates the reference points to draw the axis of the helices was used to generate values to some of the variables of a similar mathematical function.

Conclusions

The results obtained fulfill the main objectives put forward by the approach used in this case study. A parametric model of the form was

conceived and can be applied to recreate the case study. Parallel to the case study investigation, a program was created to produce structures based on the combination of geometric equations of helices, spirals and ellipses.

Design is not entirely conceived within the designer's mind. The creative process is based on analogies between the information that surrounds the designer and his thoughts. Sometimes, to conceptualize some kind of intricate forms is not only a question of time and effort but also a question of capacity to create and visualize structures beyond a certain level of complexity. As well as similar parametric programs developed to serve specific interests, it may be advantageous for designers to conceive a class of three dimensional geometries usually difficult to build mentally without a computer. By visualizing almost instantly the results, designers can organize complex conceptual struc-



Figure 6. Render of the Tornado Tower generated by the program.

tures. This means that creativity can be expanded artificially.

As already stated, there was also a large number of forms that have little relation with the case study and other projects belonging to a similar class of shapes. Therefore, they were not analyzed exhaustively. Nevertheless, those forms gave the sensation of being at least as interesting as the main forms that were created. Furthermore, these conceptual similarities do not necessarily include shape similarities.

Some of the forms that were generated revealed close resemblances with other buildings that already exist. This fact provides us with a basis to suspect that many of these buildings have a common conceptual logic that can be mathematically codified. Some of them can even have a totally different shape from each other but they can be generated by the same function. Norman Foster, Toyo Ito, Renzo Piano and Dennis Dollens are just some of the authors that apply similar conceptual structural solutions to their buildings. Those observations can be used to help the study of the architectural conceptual processes in one alterna-

tive way based on the relationship between the inherent logic of the conceptual process - its genetic code - and the exterior influences.

From a bionic perspective, it might be said that the main part of the investigation completed so far was dedicated to create a program capable of simulating and reinventing a variety of spiral and helical compositions that can also be found in nature and applied in architecture. Furthermore, a first step towards a genetic procedure analogy was achieved. We can look upon some classes of forms that were created from the same main code by manipulation of variables and transformation of equation components in order to obtain a vast range of structures. In the next stage of the investigation, the analogy with genetic procedures will be accentuated and focused on the limits of the feasibility of some particular project concepts. Using as a reference previous work on goal-oriented form generation (Monks 1999, Shea 1999, Caldas 2002, Duarte 2005b), the parametric model of the Tornado Tower will be coupled with a genetic algorithm to guide the automatic generation of solutions according to their structural fitness.

These analogies to Darwin's natural selection theory will permit to simulate the evolution of the forms following predetermined objectives. The search of fitness is passed to the computer that will work in a population of designs two-by-two in order to analyze the capability of each generated family of objects to be materialized with a specific purpose. Because of the random and selective effects of the genetic laws application, the evolutionary process of artificial creativity generation can



Figure 7. Photos of some buildings with geometric and mathematical conceptual similarities capable to be generated by the program. (Photos of the author)

produce as much efficient as unexpected results.

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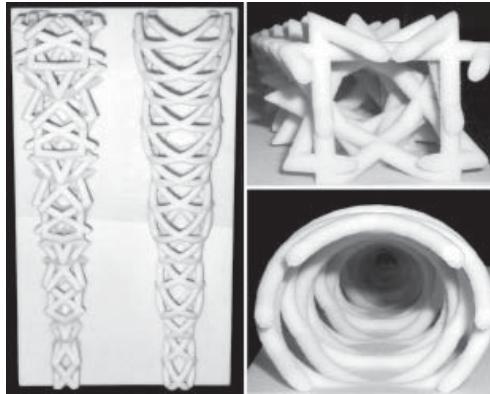


Figure 8. Photos of two irregular models generated by the program and materialized by a rapid laser prototyping machine.