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Didactics

Fractal Shape

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Abstract. This present paper deals with the fractal geometry applied in architecture. The generative rules for fractals can be used to develop the students' knowledge about shape grammar. Students use that knowledge to increase their own shape vocabulary in the early stages of architectural design.

Keywords: fractal geometry, shape grammar, architectural design

Introduction

What do fractals have to offer to contemporary architecture? Since Peter Eisenman's 1985 project "Moving Arrows, Eros and other Errors," some architects have continually used fractal geometry as a shape design instrument. Previously, architects included aspects such as fractal recursiveness, to take one example, in an intuitive way. Nowadays some studies have pointed out appropriate models for the potential use of fractals in architecture.

This experiment presented here was carried out with architecture students and attempted to bring fractal geometry to computer-aided architectural design (CAAD). We elaborated a program directed to architecture called "Fractal Shape," concentrating on the generative characteristics of fractals. This content provides an overview of fractal architecture, presents methods for using fractals in the design process, and proposes activities for the early stages of design. Thus, the fractal order is explored through generative exercises that deal with concepts of scale, recursivity, self-similarity and iteration.

The aim of the study is to facilitate comprehension of fractal geometry as a shape grammar, using scale transformations which provide generative rules. When these experiments are applied in the early stages of design, it increases the students' knowledge of shape vocabulary. The student identifies patterns, symmetries and design resources during the transformations of shapes and scales. The idea is to allow them to develop their own shape vocabulary well before they advance to the definition of the design.

We developed a program that relates fractal grammar and architectural design, which we established through pedagogical criteria and brought to the students through on-line virtual learning. The hypertext activities are about the creation of guiding regulatory frames for fractals, and then the transformation of the two-dimensional objects into three-dimensional objects. To do those exercises the students use addition and/or subtraction of elements, shape configuration and grouping and, especially, the extrusion of fractal objects viewed in plan or section. During these procedures the student selects and creates shapes, working on ambiguous models. They then set a proportion and a utility for the object, in a process called scale and function emergence.

The study of a fractal shape grammar is interesting from a pedagogical point of view when it combines the areas of interest of the students involved in this research: contemporary architecture content, the shape grammar exercises and the computer-aided architectural design technology. Students are also interested in learning subjects that are closely related to the reality of contemporary architecture. Finally, for the design professor, we see fractal geometry as one of the available tools which helps instigate students' creativity.

Fractal shape

Fractal geometry arose at the end of the 1970s from the research of Benoît Mandelbrot [1983, 1998]. Despite the creation of architectural works that have fractal concepts, long before the establishment of that theory, it was Peter Eisenman who first used that geometry to justify a project [Eisenman 1988]. The inclusion of fractal geometry in the architecture design grew increasingly popular in many ways in the years that followed. Our study presents a teaching methodology to introduce that content and the results of using fractals as a tool for generative shapes in the early stages of design. We believe that before the students come into contact with the complexity of architectural design, they should handle shapes, creating their own visual vocabulary. So the union of fractals with contemporary architecture as a generative tool is the approach that supports this research.

The authors have developed the course "Creativity and CAAD" which was first offered online to undergraduate architecture students at the Santa Catarina Federal University (UFSC) in the second half of 2008. The course content was made available through a virtual learning object, using hypertext¹ that was produced for the Virtual Learning Environment for Architecture and Design (AVAAD in Portuguese). This environment is developed and maintained by the lab Hiperlab from UFSC and used by students who follow the courses through chapters of hyperbooks.² Pereira [2007] explains that virtual learning environments make content accessible through computers, thus serving as basis for various media that compose the teaching strategies of this research. In this context it is believed that the AVAAD contributes to the teaching of fractal architecture due to its characteristics of providing resources to support diverse teaching-learning processes.

Fractals

Before discussing methodology, we will briefly explain the characteristics of fractals that make its study relevant to architects. Fractal shapes are extremely irregular and discontinuous. According to Mandelbrot [1998], such forms are natural and chaotic, and fractal geometry can be represented by rough, porous or fragmented objects. Fractals are irregular and self-similar, have infinite complexity, are developed through iterations, are dependent on an initial condition, and are common in nature [Lorenz 2002].

We can say that fractal geometric objects are generated by recursive³ processes where an initiator and a generator are iterated⁴ an infinite number of times. Thus a part of a fractal is equal, similar or similar in all. This is possible because these objects are formed by a process of repetition. According Lorenz, a self-similar structure is changed by modifying the structure by the same factor of scale: "the new form can be smaller, larger, rotated and/or reversed, but the shape remains similar" [2002: 10].

The idea behind fractals is the iteration of simple mathematical expressions with a rigid order specified in origin, which produces a very complex and irregular behavior that

seems random [Espanés 2001: 144]. There are several ways to consider fractals in architecture: through its recursive patterns, as generative patterns, as tools of scale perception. Translating the characteristics of fractal geometry in order to apply them in architecture allows the students to create a shape vocabulary. As Barbosa [2002] explains, the use of fractal geometry is important in the classroom because of its connection with various sciences, the dissemination and access to computer technology, the existence of beauty in fractals and the possibility to awaken and develop an aesthetic sense in the student. For Montenegro [1987], to use fractal geometry in didactics is to work with the aesthetic sense, the beauty of shape, the organization or the order as a concept of beauty, and therefore requires the student's intuition. Barbosa and Montenegro both cite the focus on the intuitive and aesthetic appearance of fractals; in architecture we discuss these issues when fractal geometry suggests a generative system of shapes.

This characteristic of fractals to behave as a generative system developing morphologies has been used recently, especially in the creative context. Celani [2003] explains that generative design is a process of generating shapes from rules, and argues that fractal geometry is an example of a generative system with creative attributes. We can say that the potential of fractals in the generation of shapes begins to be exploited in architecture. Espanés believes that the use of fractal geometry "in the creative process contributes to translate the essential idea in architectural form" [2003: 118]. When multiple solutions are listed through a generative process, we open a space for individual creativity.

Fractal architecture

In confirming the existence of architecture with fractal attributes, we can name many projects that intuitively make use of fractal forms, even in periods prior to the creation of the term fractal, such as Hindu temples, Gothic cathedrals and decorative patterns in Africa. Some contemporary architects clearly show inspiration of the fractal in their designs. The fractal architecture defined by Jencks [2002] is diverse in forms; architects work with curves, lines, planes or volumes that refer to fractals. The virtual learning object (hyperbook) developed for our course cites the main buildings of fractal architecture, based on indications provided by Jencks [2002], Baier and Sedrez [2001], Ostwald [2001], Sedrez [2009] and other buildings that have recently used fractals in the composition, for example, pavillions developed by the London AA School students.

Other research projects have looked into the creation of methods to apply fractal geometry in architecture; these can be divided into three types:

1. Conceptual methods, which use fractal geometry and its concepts as a guiding element to its theories (Eisenman [1988]; Salingeros [2005]; Haggard, Cooper and Gyovai [2006]). The conceptual methods provide theoretical solutions that ultimately influence the final form, for example, Haggard, Cooper and Gyovai [2006] used holistic characteristics and endless scales aiming at the creation of sustainable architecture.
2. Geometric-mathematical methods, which use the scheme of counting squares to calculate the fractal dimension (Bovill [1996]; Sala [2000], Lorenz [2002], Capo [2004]) and which use computer calculations for fractal simulation (Çagdas, Ediz and Gözübüyük [2006, 2005]). Mathematical methods are useful for an analysis of existing buildings. But the experiment of Çagdas, Ediz and Gözübüyük [2006] goes further, using a shape generative algorithm based on fractals for the early

stages of design; the architect inserts data of the topography, a fractal dimension and the initial shape; a software then searches a library of architectural shapes and generates alternatives.

3. Geometric-intuitive methods, which use the geometry as inspiration for creative expression (Espanés [2003]; Architectural Association School of Architecture [Hunter 2006]). We selected the geometric-intuitive method of Espanés [2003] as the first pedagogical strategy, because it happens to be the most appropriate for the main object: teaching CAAD with a creative approach from fractals as shape generative system.

The method of Espanés arose from research to develop “geometrical and morphological guidelines for design applying fractal geometry and to determine the creative relations between the ideas contained within this new order and architectural forms” [2003: 13]. Compositional and design activities are contextualized by Espanés, who uses modeling techniques with materials such as wood and paper to demonstrate fractal aspects that might produce architecture. The shape vocabulary of fractals is used to create shapes where the observer/designer decides what aesthetic he/she wants to highlight or achieve.

Espanés makes an analysis of fractal morphology applied to architecture, suggests compositional and design activities without regard for the constructive, functional and scale aspects. Therefore, the conjunction of Espanés’ method with that of Baier and Sedrez [2007] proved to be relevant and was adopted as a second teaching strategy. Based on a mathematical approach to the history of architecture, Baier and Sedrez advance to the use of software for drawing geometric shapes, providing an alternative to the teaching of mathematics aimed at CAAD using software that builds three-dimensional graphics.

According to Baier and Sedrez, “the beautiful and complex shapes of the graphics inspire the development of sketches of architectural shapes, contributing to the architect’s formation” [2007]. In the phase when they come into contact with the mathematical knowledge, the architecture students have little knowledge about architectural program, building technologies and other aspects of architecture. Therefore, there is still a vital creative freedom with regard to the shapes, resulting in proposals based on each student’s empirical knowledge.

When the methods of Espanés and Baier and Sedrez are combined, they bring out another aspect of the fractal architecture, especially because it is studied using CAAD. We have developed other learning strategies that encourage students’ creative thought while learning to use Google SketchUp. Through techniques for creation of shapes, students understand the functions and commands of the software, understand the mathematical relations of the fractal geometry generative system and learn about the creative potential of fractal architecture. The virtual learning environment features synchronous tools and, especially, asynchronous tools for communication: e-mail, links to web sites, forums, document sharing, and databases, all of which are provided by AVAAD simply and affordably.

In keeping with the characteristics of the method of Baier and Sedrez, activities with specific, rigidly defined architectural programs were not imposed on students; we used function emergence as the pedagogical line of thought. The final generated shapes of the suggested fractals were freely adapted to the programs by the student’s creativity. So after a series of geometric, aesthetic and creative decisions, with the final volumetric shape set

the student can choose the appropriate size for that object, adding model dolls or figures⁵ and proposing architectural information through doors/windows, landscaping, furniture and surfaces, finishes, colors.

Structure of the discipline

The course lasted eighteen weeks. In the first two weeks extracurricular activities from the architecture course were developed, aimed at familiarizing the student with the virtual environment – AVAAD. This environment mediated between the processes of teaching and learning. Students were asked to install the CAAD software in use, Google SketchUp. This software is free, and has a language that is easily understood by all students. In a first step we introduced historical and creative aspects of CAAD and the main controls of the software through exercises that explore creativity. This stage of the course was adapted from the master's thesis by Bruno Ribeiro Fernandes [2006] and serves as the introduction to Google SketchUp. The second stage of the course was developed for Maycon Sedrez master's thesis [2009] and is the focus of this article. This presents the historical and mathematical aspects of fractal geometry, the evolution of the applications of fractals in architecture, key projects and methods, and a model with practical activities using fractals as a shape generative tool.

Using Bloom's Taxonomy of Educational Objectives [1972] we have elaborated Learning Objectives for the initial familiarization with fractal geometry and with fractal architecture, as shown in fig. 1.

Fig. 1. Pedagogical strategies map [Sedrez 2009]

These two modules (familiarization with fractal geometry and fractal architecture) form the content of Fractal Shape and were taught at a distance through AVAAD. Based on the fractal objects drawn in the first stage seen in plan or section, the students are guided to the creation of three-dimensional objects. At this moment, doing the composition activities, they already have knowledge about the recursive behavior of fractals and how it generates shapes. They also know about contemporary fractal architecture and how architects incorporate these iterative patterns. Finally the design activities are proposed as follows.

Fig. 2. Design by Luciano Santana Portella [Sedrez 2009]

Fig. 3. Design by Luiz Henrique Fernandes [Sedrez 2009]

Regulatory outline. The student must assemble a combination of vertical and horizontal elements whose arrangement is governed by the floor plan using the fractal “L” as base. The choices of the type of object, the dimensions and materials are at the discretion of the student, who can compose the elements randomly, following a numerical pattern, or symmetrically. Luciano created a composition for a playground, observing the appropriate scale (fig. 2). The regulatory outline defines a complex volume that is apparently irregular. This type of order is useful as experimentation and as a resource for the architectural design.

Horizontal extruded section. The objective is to extrude parts or the whole of the subdivided plans of any fractal. The distribution can follow rules of symmetry or proportion, calling on students’ sense of composition and scale. The student Luiz preferred to use Sierpinski triangles to model an office building with sixteen floors (fig. 3). This activity asks students to work with aesthetic appearance through colors, elements and styles. Students understand how to work with unusual angles on Google SketchUp. The horizontal extruded section leads to the understanding of how an architectural composition can be developed with the addition or subtraction of elements through a complex order.

Two-dimensional fractal modules. We use the Hilbert curve, which can be rotated, inverted and mirrored to allow further configurations. The section of the fractal must be transformed into a volume, then copied several times. The modules are extruded and juxtaposed through the aggregation of elements. Students regulate the composition, creating a rhythm of elements. Some indications of architecture are also required for the definition of scale, for example, the addition of human figures and stairs, windows, landscaping, and so forth. Leticia proposed a residential building with twin units (fig. 4).

Fig. 4. Design by Leticia Longo Triches [Sedrez 2009]

Vertical extruded section. From a replicated linear fractal, we build up different objects, and then put them together and re-adapt them. Students start with abstract manipulation moving towards architectural forms. They can use a Hilbert curve or another object designed earlier and make the extrusion of the object into three parts, representing sections. The definition of the scale should be improved, moving increasingly closer to that of an architectonic design model. The student Patricia created a multifunctional building for parties and meetings (fig. 5).

Fig. 5. Design by Patricia Ramos [Sedrez 2009]

Fig. 6. Design by Fernando Carneiro Pires [Sedrez 2009]

Scale superposition. The Koch curve and Sierpinski triangle are exemplified for this activity. A fractal that is re-scaled and superposed several times creates in its intersections buildings, squares and a territory. The student is asked to multiply the object at three different scales, superposing them. This activity aims to extend the student's attention to the issue of urban scale and how buildings can be placed in context. Fernando created a set of buildings on the edge of a lake or reservoir, in this activity, most studies showed only volumetric intentions (fig. 6).

Conclusion

This paper aims to provide architecture students with tools for manipulating shapes, before deepening their knowledge of architectural design. At this stage students can explore morphologies with greater freedom. The "Fractal Shape" hyperbook activities used the concepts of function and scale emergence [Baier and Sedrez 2007; Mayer and Turkienicz 2008]. We felt that students received the content and the methods in a positive way. We have noted that the forms produced starting from the same basic fractal objects were completely different for each student. These issues were also reported by students in the comments of activities.

The students developed their knowledge of the software and complex shapes, improving their visual vocabulary. Students were taught useful shortcuts and commands in the design process of fractals that can be used in any other project. Decisions regarding the use of Google SketchUp to generate shapes and select the scales were intuitive, that is, made naturally without requiring much effort. Proposals reflected the harmony and symmetry that are characteristic of fractals, but because these were initial compositions, students did not have to completely resolve issues such as combination of colors and materials or aspects of the architectural program.

We highlight students' perception of fractal geometry as a regulatory framework that facilitates creative composition. There is therefore a diversity of fractal architecture and it can be incorporated into any project level. This feature is supported by a study prepared by the AA School [Hunter 2006], whose students, guided by teachers from different areas, developed and built a small pavilion.

The good level of content understanding and creative results highlighted the personal approach of each student. The digital models produced were not detailed, and this is a step that is intended for the development of the course. The next step will be a discussion and evaluation of the proposal to teach fractals in architecture.

We perceived the necessity of more time for design activities. Another issue that can also be addressed is the complete elaboration of one activity, where the student must present a more detailed design for a real site. This research showed that the most important quality of fractal geometry for architecture lies in its generative system of shapes.

All activities can include other fractal objects and especially improve the use of nonlinear fractals. For this we need to advance research on available computer programs that do a reading of fractal objects with a high number of iterations. We intend to continue to create activities with fractals as architectural shapes. In order to continue this research, we want to create a set of composition activities for architecture students to develop before going into the technical aspects of architecture design.

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Notes

1. “Hypertext” is the group of nodes linked by connections; the nodes can be words, pictures, graphics, sounds, documents [Filatro 2004].
2. “Hyperbook” is the grouping of hypertext in units (or subunits) that allows linear and random navigation.
3. “Recursive” is the procedure used to generate a fractal, the successive application of the same routine.
4. An “iteration” occurs each time a fractal is fed with a self-similar shape through a recursive process.
5. In Brazil we call a small models, doll or figure *calunga*, representations of the human figure.

References

- BAIER, Tânia and Maycon R. SEDREZ. 2001. Geometria fractal e arquitetura contemporânea – Kisho Kurokawa. In: *Salão de Iniciação Científica 13*. Porto Alegre: UFRGS.
- . 2007. Uso de gráficos de funções matemáticas, construídos com recurso computacional, na elaboração de projetos arquitetônicos: uma proposta pedagógica. In: *Congresso Nacional de Matemática Aplicada e Computacional*, Florianópolis: SBMAC.
- BARBOSA, Rui M. 2002. *Descobrimo a geometria fractal para sala de aula*. Autêntica: Belo Horizonte.
- BEHRENS, Marilda Aparecida. 2006. *Paradigma da complexidade: metodologia de projetos, contratos didáticos e portfólios*. Petrópolis: Vozes.
- BLOOM, Benjamin Samuel. 1972. *Taxionomia de objetivos educacionais. Vol. 1 Domínio Cognitivo*. Porto Alegre: Globo.
- BOVILL, Carl. 1996. *Fractal Geometry in Architecture and Design*. Boston: Birkhäuser.
- ÇAGDAS, Gulen, Gaye GÖZÜBÜYÜK and Özgür EDİZ. 2006. Fractal based design model for different architectural languages. Pp. 280-286 in *GameSetandMatch II*. International Conference on Computer Games, Advanced Geometries and Digital Technologies, Delft University of Technology, Delft, Netherlands, 29 March – 1 April 2006. K. Oosterhuis, L. Feireiss, eds. Rotterdam: episode publishers.
- . 2005. Fractal based generative design for harmony between old and new. Pp. 150-159 in *GA 2005*, Proceedings of the 8th International Conference on Generative Art, Generative Art 2005, Milan, Politecnico di Milano.
<http://www.generativeart.com/on/cic/papers2005/14.GayeG%F6z%FCb%FCy%FCk.htm>.
Last accessed 13 June 2011.
- CAPO, Daniele. 2004. The Fractal Nature of the Architectural Orders. *Nexus Network Journal* 6, 1: 30-40.
- CELANI, Maria Gabriela. 2003. *CAD criativo: exercícios para desenvolver a criatividade de arquitetos na era digital*. São Paulo: Campus.
- EISENMAN, Peter. 1988. Eisenmanesie. *Architecture + Urbanism*, Extra ed. (August 1988): 70.
- ESPANÉS, Inés Moisset de. 2003. *Fractales y formas arquitectónicas*. Córdoba: I+P División Editorial.
- . 2001. El desafio de los fractales. *Summa+* 51 (outubro e novembro 2001): 144.
- FERNANDES, Bruno Ribeiro. 2006. Estratégias pedagógicas de uso de técnicas de computação gráfica como instrumento de apoio ao processo criativo de projeto de arquitetura. Master’s thesis, Programa de Pós-graduação em Arquitetura, Universidade Federal de Santa Catarina, Florianópolis.
- FILATRO, Andrea. 2004. *Design instrucional contextualizado: educação e tecnologia*. São Paulo: Ed. SENAC.
- HAGGARD, Kenneth, Polly COOPER and Christine GYOVAI. 2006. *Fractal Architecture: Design for Sustainability*. North Charleston: BookSurge Publishing.

- HUNTER, Will. 2006. On the Cutting Room Floor. *Building Design* (23 June 2006). <http://www.bdonline.co.uk/story.asp?sectioncode=453&storycode=3069350>. Last accessed 13 June 2011.
- JENCKS, Charles. 2002. *The New Paradigm in Architecture: The Language of Post-Modernism*. New Haven: Yale University Press.
- LORENZ, Wolfgang E. 2002. Fractals and fractal architecture. Master's thesis, Vienna University of Technology.
- MANDELBROT, Benoit B. 1983. *The Fractal Geometry of Nature*. New York: W. H. Freeman.
- . 1998. *Objetos fractais: forma, acaso e dimensão seguido de panorama da linguagem fractal*. 2 ed. Lisbon: Gradiva, 1998 (Portuguese trans. of *Les objects fractals*).
- MAYER, Rosirene and Benamy TURKIENICZ. 2008. The cognitive studio: exercises in design learning. In: Third International Conference on Design Computing and Cognition DCC08. Atlanta: DCC08.
- MONTENEGRO, Gildo A. 1987. *A invenção do projeto: a criatividade aplicada em desenho industrial, arquitetura, comunicação visual*. São Paulo: E. Blucher.
- OSTWALD, Michael J. 2001. "Fractal Architecture": Late Twentieth-Century Connections Between Architecture and Fractal Geometry. *Nexus Network Journal* 3, 1 (Winter 2001): 73-83.
- PEREIRA, Alice Cybis, ed. 2007. *Ambientes virtuais de aprendizagem em diferentes contextos*. Rio de Janeiro: Ciência Moderna.
- SALA, Nicoletta. 2000. Fractal Models in Architecture: A Case of Study. Pp. 18-23 in *Proceeding of the International Conference on "Mathematics for Living,"* Jordan, November 2000. <http://math.unipa.it/~grim/Jsalaworkshop.PDF> Last accessed 13 June 2011.
- SALINGAROS, Nikos A. 2005. *Principles of Urban Structure*. Amsterdam: Techne Press.
- SEDREZ, Maycon R. 2009. Forma fractal no ensino de projeto arquitetônico assistido por computador. Master's thesis, Programa de Pós-graduação em Arquitetura e Urbanismo, Universidade Federal de Santa Catarina, Florianópolis.

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