

SPIROSPACES IN ARCHITECTURAL DESIGN

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Abstract: The proposal of this paper is to present "Spirospace" and their utility in Architectural Design, exploring their relation with other geometrical disciplines such as knot theory, tiling and patterns generation. A spirospace is a geometrical entity generated from the spatial interpretation of a "Spirolateral", a well known bidimensional entity. A computer program to generate spirospaces configurations is presented and demonstrated with several examples. This is complemented with the exposition of the mathematical framework that supports closed spirospaces generation.

1. Introduction

The essential matter of this paper is the creative use of geometry in architectural design, in particular, the feasibility of using a set of complex geometrical entities, based on spirospaces, as creative triggers to empower inventiveness.

Although it is not always an explicit fact for the designer, there is an intrinsic order underlying architectural objects that maps to mathematical models. Furthermore, mathematical models can be abstracted into typological models or paradigms.

From this perspective, we can consider architectural objects as particular instances of typological models. Furthermore, we can use design procedures that uses some kind of deductive process to go from typological models to architectural ideas. This is an example of what, in academic communities, is called "to go from the form to the purpose". One way to accomplish this is by using a mechanism called creative triggers.

From a general perspective, a creative trigger is anything that is capable to inspire design ideas: an object, an image, a sensation, etc. In particular in this work, we postulate the potential of spirospaces as a powerful creative trigger for architectural design.

In order to provide even a higher degree of formal richness, we propose to combine spirospaces with other well known geometrical entities, such as knots, fractals, and patterns generation. This opens an astonishing explosion of geometrical combinations.

Due its complexity, the generation and manipulation of these graphical entities would not be practical without computers power. Therefore, for this specific purpose, we develop an application based on the general idea explained above. Demonstrative examples are exposed at the end of this paper.

2. The Design Process

The design process is a subset of an overall process intended to accomplish the materialization of a new building. It is carried out by an AEC enterprise.

It can be analyzed from the perspective of the product, the process, and the particular context where it takes place.

2.1. THE PRODUCT

The output of the design process is a technical and constructive definition of a building, in the form of a graphic representation. This representation, explicitly or implicitly, carries the definition of all architectural objects' attributes.

We consider the architectural object as a system composed by qualified spaces and masses. To our purpose, it can be analyzed from the dimensions of form, function and structure, each one defined as follows.

The form considers the architectural object from the human perceptual perspective. It comprises the architecture significant codes: aesthetics, symbolism, emotiveness, etc.

The function considers the architectural object from the perspective of purpose. It regards the elements of an architectural system from a utilitarian view referring them to the activities that they shelter.

The structure considers the architectural object from the organizational perspective. It is defined by the physical relationship between system's elements.

We will return to these dimensions later, when we explain the logical mechanisms involved in using creative triggers.

2.2. THE PROCESS

We are not intended to postulate a design method. Instead, we will point out some considerations about the design process inspired on the work of Dr. J. Samaja (2003).

We understand the design process as a rational, dialectic and epigenetic process. The designer operates on a system of ideas, called the object model, which is the subject of a re-configuration movement from the abstract to the concrete.

The object model intercedes between the architectural object and the designer, or from other perspective, between architectural theory and praxis. The logical mechanism used by the human rationality to traverse this way is the pair: induction/deduction. Deduction is used to go from theory to praxis (from the general to the particular), and induction is used to go from the praxis to the theory (from particular to general).

This explanation must be completed with the introduction of the couple: analogy/abduction, which comprises the fundamental logical mechanisms for creativeness. They are the tools that allow human to propose creative, and sometimes really complex, solutions extrapolated from existing regularities from other order or dimension.

Analogy and abduction are complementary logical operations. Abductions allow us to identify, from design requirements, typological organizations, which are capable, as a preliminary hypothesis, to be used as a solution for the design problem. Analogy, on the other hand, allows us to extrapolate some characteristic from the well known organization, usually identified by the abduction, to the design problem under consideration.

We must point out that only the pair induction/deduction is recognized by formal logic due its apodictic value. Even thou, not formally recognized, analogy and abduction are key operation for creativeness.

The construction of the object model begins with an initial comprehension of the whole situation that involves the design request. This is called "modeler pre-comprehension process" and implies to perform a simplification of the variables related to the design problem through the derivation of a first and fundamental creative analogy. On this paper we will focus our attention on this phase.

2.3. THE CONTEXT

By the context we understand all circumstances that round the design process. We will include ideas, values and other designer beliefs, that pre-exist before the design process.

In this point we include all tools and assets that the designers possess to accomplish her/his work.

3. Spirospace

A Spirospace (Barrionuevo, 2003) is a tridimensional geometrical entity characterized by its formal configuration, which in the general case, resembles a spiral. It is inspired on a bidimensional geometrical entity called Spirolateral (Odds, 1973).

The main value of spirospaces for architectural design resides on its spatial potentiality. It is easy to verify from a simple observation of a spirospace, like the one shown on the Figure 1, its strong analogy with architectural forms.

Other valuable attribute is its capacity to generate complex forms without loosing its apparent simplicity. This allows us postulate its use as a support frame for other geometrical entities, as we will explain later.



Figure 1. Typical spirospaces.

3.1. BACKGROUNDS

A first formal definition of spirolaterals was given by F. Odds (1973). The name spirolaterls derives from the words, "lateral" for sides, and spiro for hairsprings, since the first spirolateral was made up from "square hairsprings" (see Figure 2).

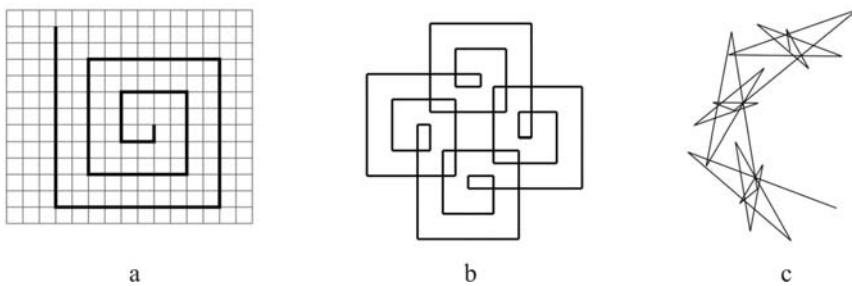


Figure 2. a) square spirolateral, b) closed spirolateral, c) open spirolateral.

Krawczyk (2001a, b) enriched the formal domain of spirolaterals, proposing the use of curves for its generation, and he developed the first computer program to automate their generation (see Figure 3).

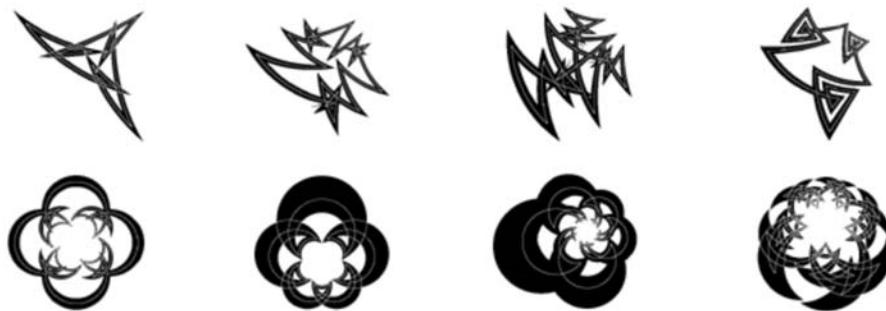


Figure 3. Curved spirolaterals. (Krawczyk, 2001a, b)

Barriidue and Borsetti (2001) extended the spirolateral definition to the three-dimensional space, introducing the concept of "Spirospace". They developed a computer program to draw closed spiroraterals and they outlined the possibility to carry out rotations in three-dimensional space to generate more complex configurations.

Krawczyk (2002) proposed spirolaterals space interpretations by means of the "sculpture" concept. He developed three methods: by embossment, doing a simple extrusion from a bidimensional figure; by assembling, combining several positive extrusions all together; and by construction, introducing vertical supports at the rotation junctions of each segment, module, or segment (see Figure 4).

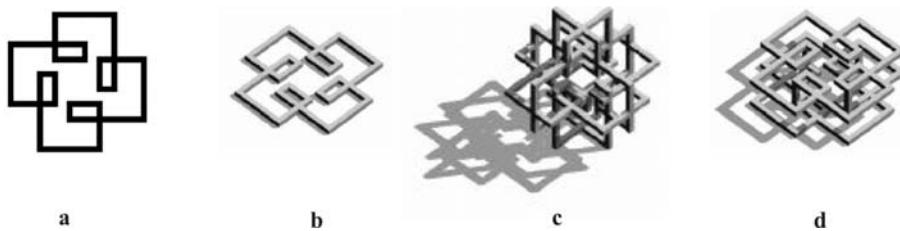


Figure 4. Krawczyk spirolateral interpretation of a by means of the sculpture concept.
a) spirolateral, b) embossment, c) assembling, d) construction. (Krawczyk, 2002)

3.2. SPIROSPACES COMPONENTS

To project a bidimensional object to the tridimensional space implies to add new levels of complexity. Therefore, some distinctions between spirolaterals and a spirospaces are required.

A spirolateral is conformed by a series of "segments" combined together according to a set of directional and dimensional rules. Segments conforms "modules" that rotate at a different angle than elements (see Figure 5).

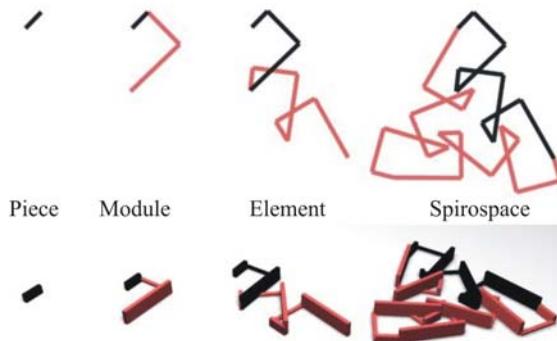


Figure 5. Spirospace components.

On the other side, a spirospace is made up of tridimensional units, grouped by "packages" of variable complexity. A first package is compound by a set of "Pieces", somehow equivalent to spirolaterals segments. A second package is the "Module", conformed by consecutive pieces of variable length. A third package defines an "Element", which groups modules together. The integration of elements can continue indefinitely, generating even more complex elements.

3.3. SPIROSPACES PARAMETERS

In this work we will present only those parameters tightly related with spirospaces' appearance.

These parameters are directly related with the components that define a spirospace, which are: pieces, joints and spaces. Parameters that operate on the "pieces" are:

- (a) Shape Parameter: defines the geometry of spirospaces' pieces (see Figure 6).

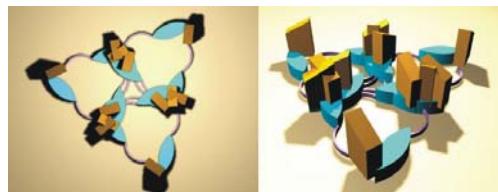


Figure 6. Spirospace shape parameter.

- (b) Dimension Parameter: defines the size of spirospaces' pieces (see Figure 7).

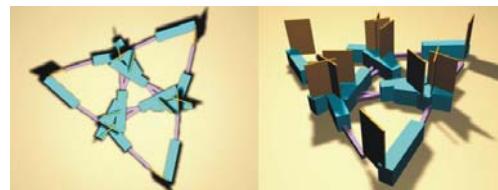


Figure 7. Spirospace dimension parameter.

- (c) Orientation Parameter: controls the rotation angle for each piece that composes a spirospace. The angle variation is only possible along the longitudinal axis of each piece (see Figure 8).

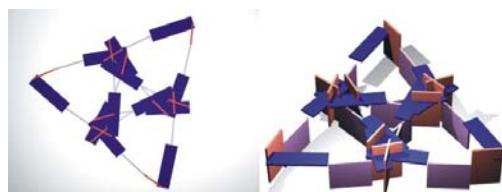


Figure 8. Spirospace orientation parameter.

(d) Materiality Parameter: refers to the appearance of spirospaces' pieces (see Figure 9).

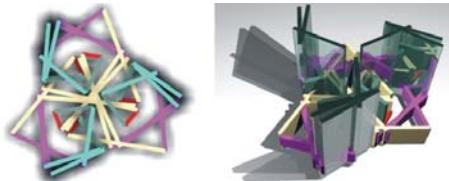


Figure 9. Spirospace materiality parameter.

(e) Joints Parameter: joints parameters are classified based on the relative positions of concurrent pieces. Considering plan and elevation relative positions, we propose the distinction between "Meetings" (plan), and "Encounters" (elevations).

"Meetings" parameter expresses all possible combinations of joints between two consecutive pieces. Figure 10 exemplifies this.



Figure 10. "Meetings" types.

Considering all pieces centered upon their longitudinal axis, the parameters of possible "encounters" between two pieces are as shown in Figure 11.

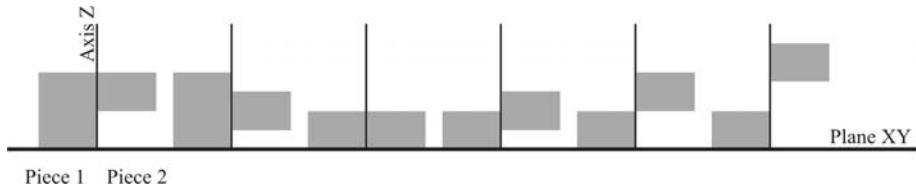


Figure 11. Possible "encounters".

Spirospace spatiality varies with the type of junction. Figure 12 shows the same spirospace with different junctions.



Figure 12. Spirospace junctions.

Spirospace spatial parameters are defined by its component pieces. In this point, we will apply a comprehensive concept for “space” and we will not make the traditional distinction between hollow or non hollow.

We define "Objectual space" as the space comprised by the pieces. On the other hand, we defined the "Interstitial space" as the space comprised among pieces. The composition of both spaces generates a "Mixed space".

The dimension of the objectual space is defined by the dimension of the piece, while the dimension of the interstitial space is variable in height, depending on the design intention (see Figure 13).

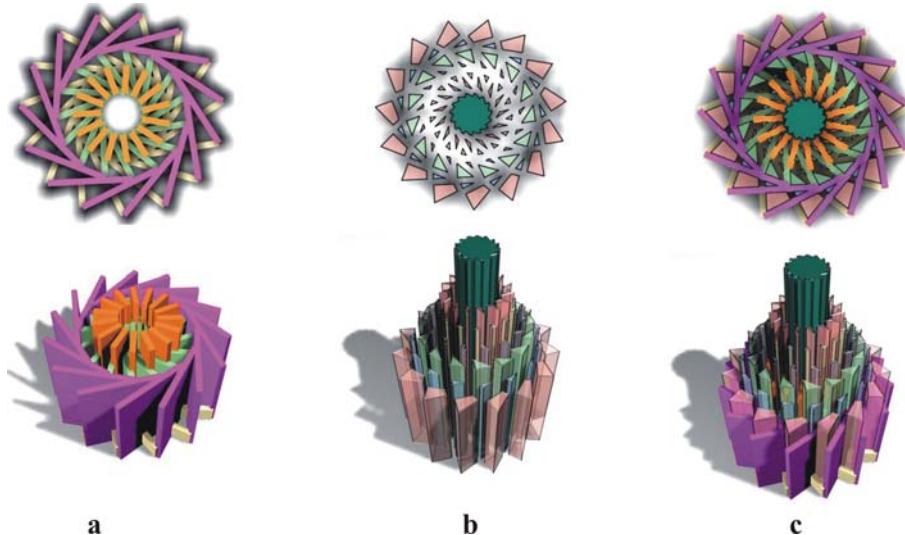


Figure 13. The same spirospace interpreted from different space definitions. a)- Objectual space b)- Interstitial space with established heights c)- Mixed space.

3.4. SPIROSPACES PROPERTIES

The properties of the Spirospaces can be considered according to three aspects: closing property, cycles property and compactness property.

3.4.1 Closing property

Spirospaces admit the closing property, which means that it is possible to generate open or closed spirospaces. If the initial point of their first component (segment or piece) does not match the final point of the last component, we say that the spirospace is open (see Figure 14). If it does match we say that it is closed (see Figure 15).

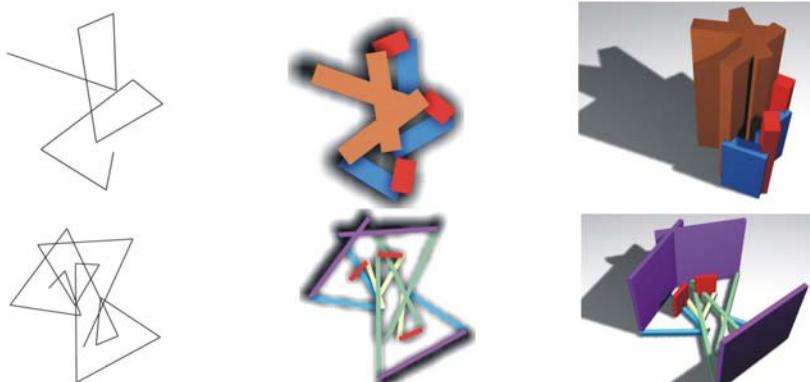


Figure 14. Open spirospaces.

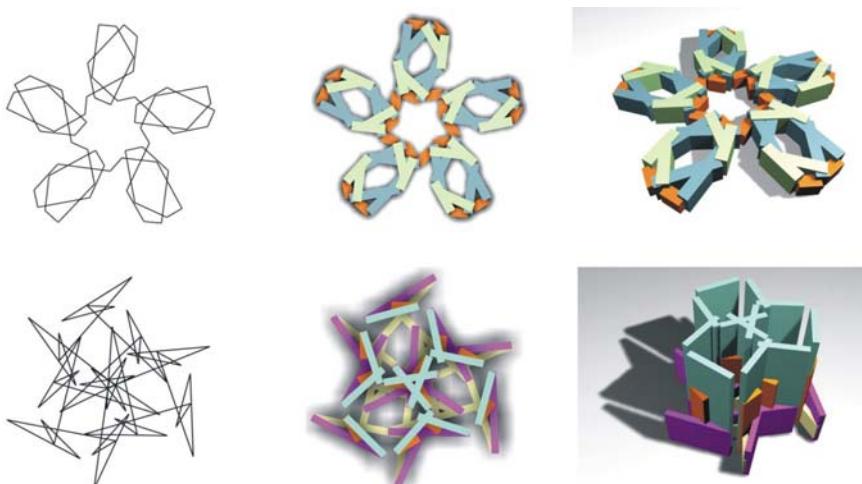


Figure 15. Closed spirospaces.

In both cases, components may accumulate turns, that is to say, it is possible to add cycles. This fact takes to the following property.

3.4.2. Cyclical Property

Closed spirospaces may have a variable number of cycles. A procedure to control this property, that establishes a relation between the number of elements "N" and cycles "C", is described below (see Figure 16).

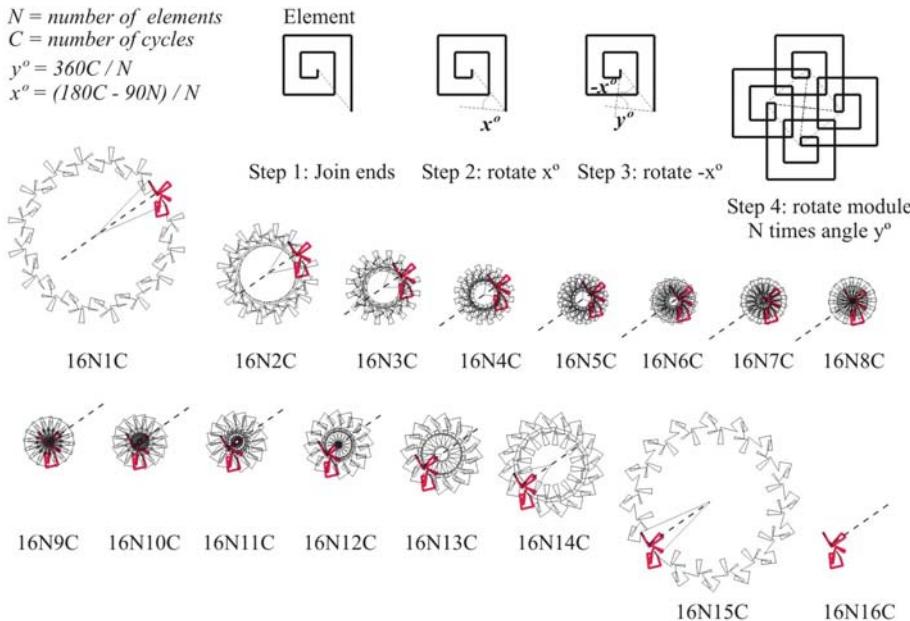


Figure 16. Procedure to generate closed spirospaces.

The procedure to generate closed spirospaces can be summarized as follows:

- Draw an element of the spirospace.
- Establish the quantity of elements N and the number of cycles C .
- Calculate the angle of rotation of the element using the formula:
 $y^\circ = 360 C / N$
- Trace a segment among the extreme points of the element.
- Calculate the angle of rotation of the traced segment with the formula:
 $x^\circ = (180 C - 90 N) / N$
- Rotate twice the traced segment, with center in each one of the ends.
- In the intersection between both rotated segments, establish the center of rotation of the element.
- Rotate N times the element by an angle y° .

3.4.3. Compactness Property

A spirospace contains both: objectual space and interstitial space. This property quantifies the relation between them. When the quantity of interstitial space is bigger than the quantity of objectual space it is said that the spirospace is "porous", Figure 17. In the opposite case it is said that the spirospace is "compact", Figure 18.

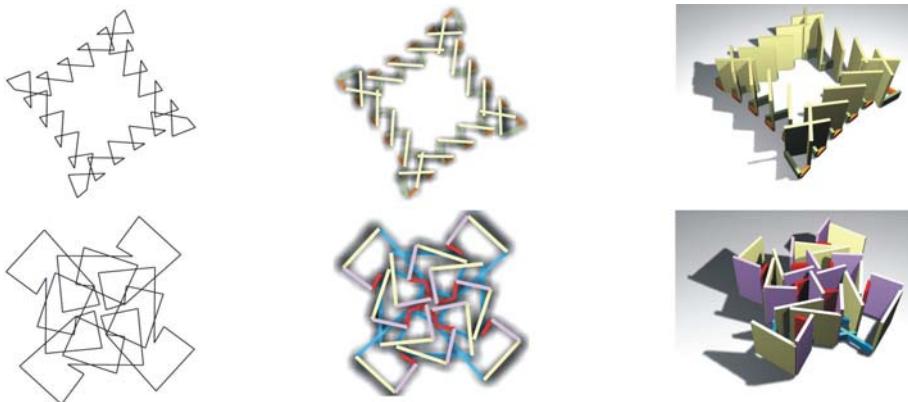


Figure 17. Porous Spirospace.

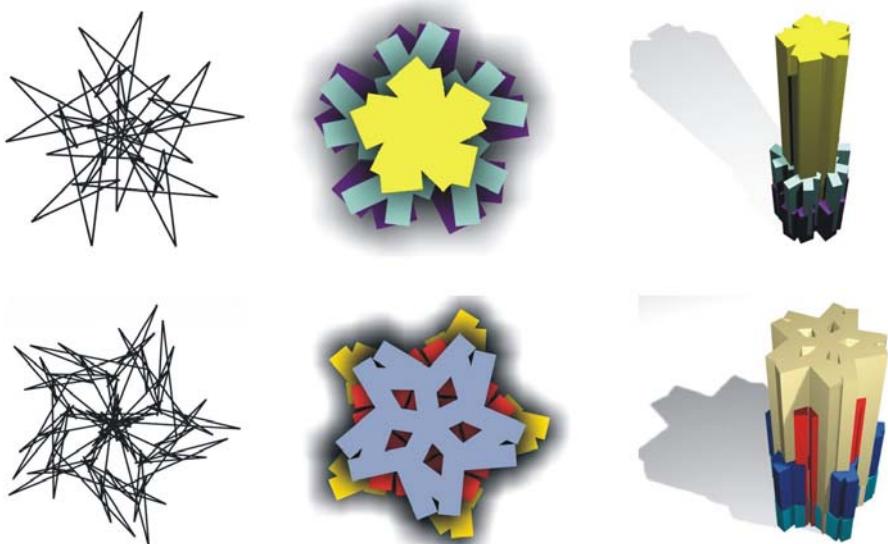


Figure 18. Compact Spirospace.

4. Spirospace and other Geometric Entities

The purpose of this work contemplates the possibility of empower architectural utility of the spirospaces exploring its relationship with other geometric disciplines such as knots theory, fractals theory, tessellations theory and generation of patterns theory.

Modern computer graphics has emphasized the fact that mathematics is a visual art, in which objects perception and visualization has primordial importance: certain mathematical forms constitute inspiring ideas for the generation of artistic or architectural forms. One could say that the key word that unifies art and mathematics is *visualizing* and, in fact, *visualizing relationships*.

Creativity consists on visualizing from a new conceptual point of view. To look is a kind of action. To see is another. To look means to make an effort to see. It can take a lot of time and effort looking until one is able to see the set of relationships that intervene in form generation, satisfying different aspects like it happens in Architecture.

These "visualized forms" can have different significance and behavior according to the branch of geometry from which is used (Euclidean, topological, projective, fractal, hyperbolic, etc.). These different branches of geometry are usually identified by means of classes of entities, concepts or theories that characterize them. For example, topological geometry is identified easily with anything elastically deformable, which means that it can suffer transformations in its physical appearance without changing the relative position among its component points. A sphere and a cube are equivalent because, to obtain one starting from the other, it is only necessary a continuous deformation (it is demonstrated modeling with the hands some clay).

4.1. KNOTS THEORY

To define the theory of knots and nooses, we will say that it is a branch of mathematics that is in charge of studying the topological behavior of linear entities that configure forms in three-dimensional space.

A lineal entity is truly a knot when it has its extremes tied up in an immersive manner, that is to say, it should not have ends. It is a closed three-dimensional lineal curve and tied in itself, also well-known as topological knot, Figure 19 a. On the other hand, it is defined as a noose a piece of lineal curve tied up with open ends, Figure 19 c.

Those knots that are built starting from lineal pieces are denominated geometrical knots, Figure 19 b, conforming a polygonal path in three-dimensional space. These knots are also called tame knots or docile knots because it is possible to modify them twisting their axis to will. When two or more topological knots are tied up together we got a lariat, Figure 19 d.

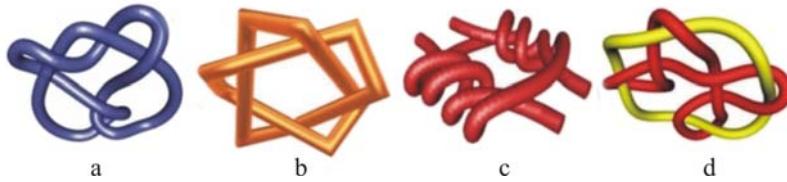


Figure 19. a) Topological knot b) geometric knot c) noose d) lariat.

Establishing analogies between these concepts contributed by the Theory of knots and spirospaces, we will say that a rope with certain degree of mess can be topologically transformed into a *closed spiro* or into an *open spiro*. If it is a *knot* (closed and tied curve) it is a *closed spiro*. If it is a *noose* (with open ends) it is equivalent to an *open spiro*. The Figure 20 shows a spirospace inspired by a knot.

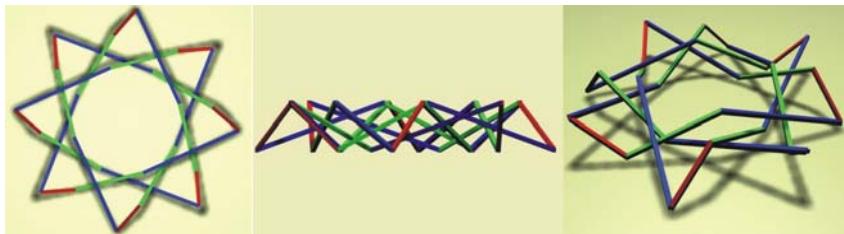


Figure 20. Closed spirospace inspired by a knot.

Knots are usually presented by means of diagrams or two-dimensional outlines that indicate where the knot crosses itself. The simplest knots that are really knotted are the trefoil knot and the double knot (figure eight knot). The Figure 21 shows two versions of the orthogonal projection of the trefoil knot and a double knot. The minimum number of crossings is of three in the case of the trefoil and of four in the case of the figure eight knot.

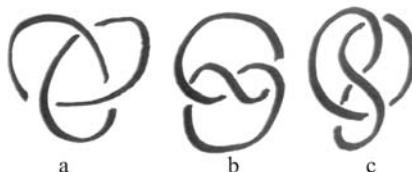


Figure 21. (a, b) Two versions of a trefoil knot, (c) Double knot.

Knots are useful mathematical forms for the generation of ideas with architectural ends, particularly when they are associated to "spirospaces". Being completely three-dimensional, not having front neither back, they favor creative freedom. Spirospaces associated with the theory of knots allows the development of designer imagination in spite of the restrictions imposed by the architecture (for instance, the necessity of a support plane).

A spirospace conceptualized as a knot, contains a great quantity of interpretations, depending on the multiplicity of points of view from where it is observed as an architectural object.

4.2. FRACTALS THEORY

Fractals theory, was introduced by Benoit Mandelbrot (1975) at the 70s. Their most relevant characteristics, from the perspective of this work, are:

- (a) Irregularity (ruggedness, roughness).
- (b) Self-similarity (shape similarity in different scales: the parts resemble the whole).
- (c) Infinitely complex (seemingly chaotic, but it is described with simple algorithms).
- (d) Recursivity (starting from a shape that operates as initiator, it is developed by means of the iteration of rules that act as generator).
- (e) Initial conditions (their development depends on the initial conditions, that is to say, of the initiator and generator).
- (f) Organic (it is common in nature).

When working with spirospaces it is possible to incorporate several of these characteristics, particularly if they are generated by means of iterated function systems (IFS) or by means of Lindenmayer systems (L-systems). The shape of the initiator is established, then the same element is reproduced recursively, changing its scale and modifying its shape by transformation rules. Figure 22 shows an example of a fractalized spirolateral (the first three steps) whose extrapolation to the space admits varied designs.

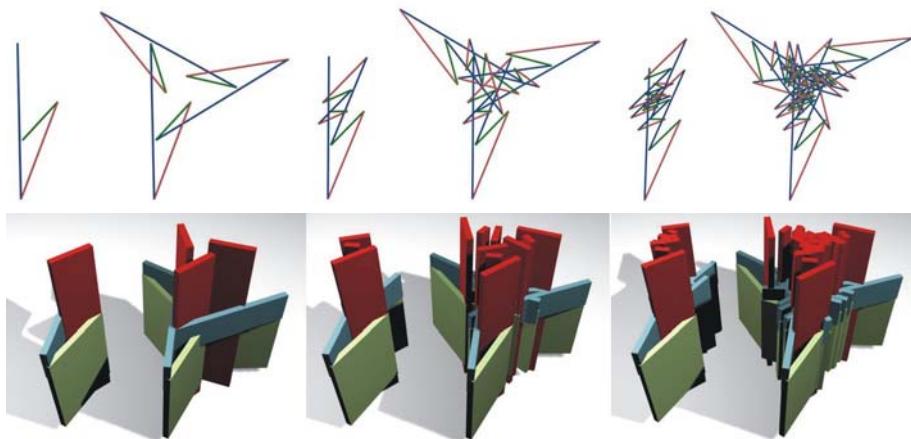


Figure 22. Three first steps of a fractalized spirospace.

4.3. PATTERNS THEORY

In the art or in the Nature a pattern is sustained by three characteristics: (1) a cell or unitary element (2) the repetition of that cell (3) a system of organization of the repeating parts. Spirolaterals in the plane as well as spirospaces in 3D fulfill these three characteristics, what allows us to conclude that all spirospace constitutes a repetition pattern.

5. The Computer Program

The authors of this paper have developed a computer program that produces spirospaces from a set of parameters and operators related to architectural principles of shape handling.

5.1. DESIGN OF SPIROSPACE OPERATORS

In order to generate and manipulate spirospaces with our computer program, a set of operators has been defined.

- (a) Generation operators create entities considering the following parameters: Shape, Position, Dimension, and Orientation.
- (b) Transformation operators work either on a specific spirospace component, or on a set of those components, depending on the nexus that exists among them. Some of these operators are: Translation, Size, and Rotation. They modify one or more shape parameters, for example the element position. These operators allow to gradually tuning the result.

(c) Edition operators administer the appearance of spirospaces. One of them is "visibility", which allows to show or to hide entities that compose a spirospace. Edition operators are: Color, Transparency, and Visibility.

It is possible to implement operators to manipulate other more valuable architectural parameters. For example: proportion, scale operators, compactness operators, etc.

5.2. BRIEF DESCRIPTION OF THE APPLICATION PROGRAM

The program for spirospaces generation has been implemented under the AutoCAD 2002 system, making use of the integrated development environment (IDE) Visual C++ 6 and the applications programming interface (API) ObjectARX 2000. The Figure 23 shows a dialog box for aleatory spirospaces generation.

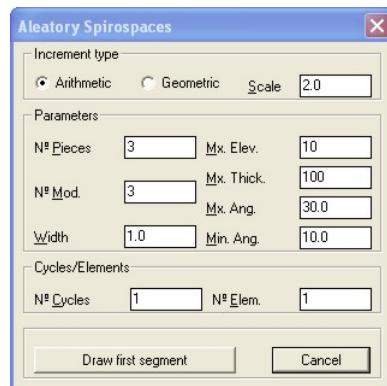


Figure 23. Dialog box for aleatory spirospaces generation.

Two modes of Spirospace generation were considered: with results completely predetermined by the user, and another with the incorporation of a stochastic component. For the first case, the factor to consider was the predictability. The result obtained depends directly on the values entered by the user. In the second case one kept in mind the surprise factor, the unexpected thing. The use of the system is adapted to the mode of bank of tests, to define the architecture of the group in the early stage of the design.

6. Creative Analogy

Essentially, we propose to use the processing power of modern computers to manipulate complex geometrical organizations. These organizations become a useful source of inspiration for the modeling process, specially the

conceptual pre-comprehension step which, as we saw, is the entry point to the design process.

This creative phase of the process, challenges the designer capability to settle analogies against entities of other orders, and is heavily conditioned by his/her vital and professional experience.

The analogy process implies to relate two organizations, two totalities, and to translate some characteristics from one to the other. As we stated, we propose spirospaces as the analogy source, and the design idea as the target. Now the question is, what do we get from spirospaces that can be translated into architectural ideas? To answer this question we will analyze the way we perceive spirospaces.

6.1. THE ANALOGY SOURCE

Even thou a spirospace can be a very intricate entity, it is always perceived with a strong sense of unity, provided by its generation rules. For this reason, we postulate that the characteristics related to the wholeness sense of spirospaces are valuable on three basic features: geometry, space, and syntax organization.

(a) Geometry: it refers to the morphological characteristics of a spirospace. The spirospaces arrangements usually have a remarkable formal personality, obtained from their generation rules, which means that this aspect has a powerful analogy potentiality.

(b) Space: it refers to the space generated by spirospaces. It implies the observer interpretation to consider either objectual or interstitial spaces configurations, mentioned before.

(c) Syntax: it refers to the conceptual organization of a spirospace. It implies a high degree of abstraction from direct observation. It is the form structure of the spirospace.

6.2. THE ANALOGY TARGET

Starting from a conceptual definition it is possible to associate some features of the object used as a creative trigger, establishing a relation by analogy. Creative analogy is accomplished by translating some characteristic from the paradigmatic entity used as a creative trigger to some characteristic of the architectural ideas. As we stated, we consider as relevant architectural features, the form, function and structure, and indeed, these are the target for the creative analogy. This means that we can use the geometry of a spirospace to inspire architectural morphological configurations.

We can use spirospaces to interpret some functional architectural schemes; those related to a central system with peripheral rotational subsystems, or to use the syntax organization of a spirospace to inspire the layout of the same kind of architectural ideas.

The function of the digital tool is to provide a manipulation interface by means of a geometrical operator set for complex geometric entities (spirospaces) in a way to favor these analogies.

The following table expresses all possible analogies between a spirospace and an architectural object. See Table 1.

Table 1: possible analogies between a spirospace and an architectural object

Spirospace	Analogy	Architectural object
Geometry	Resembles morphological configurations	Form
Space	Resembles required spaces	Function
Syntax	Resembles organization structures	Structure

6.3. EXAMPLES

(a) Spirospace's geometry to architectural idea's form analogy. Spirospace element configuration inspires interior architectural solutions (see Figure 24).

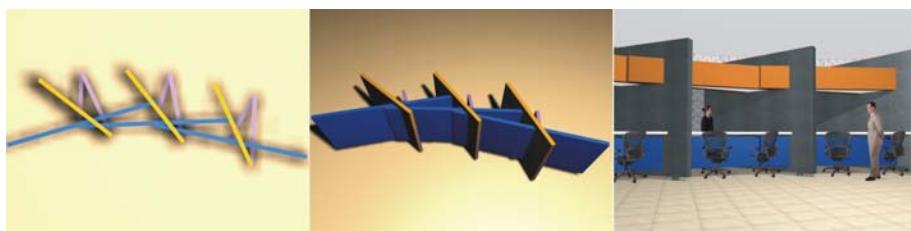


Figure 24. Architectural interpretation of an interior space (R. Borsetti)

(b) Spirospace's syntax to architectural layout analogy (see Figure 25).



Figure 25. Architectural layout from a spirospace interpretation (R. Borsetti).

(c) Spirospace's space to architectural function analogy (see Figure 26).

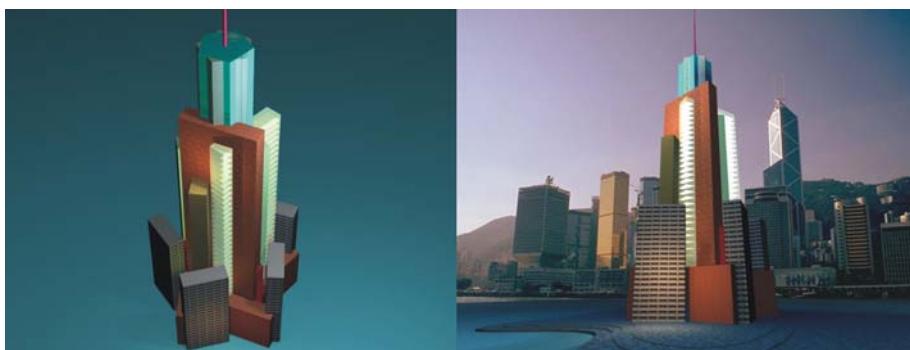


Figure 26. Architectural interpretation of a skyscraper.

7. Conclusions

The greatest challenge when using spirospaces as creative triggers for architectural design is to find out a procedure to obtain valuable architectural inspiration.

It is not enough just to generate geometry. It is required to define an interaction interface that provides the designer with an inference mechanism to translate spirospace potentiality into architectural ideas.

We hope the procedure stated on this paper will contribute to the development of a new generation of design tools, and, even thou it is possible to state some practical objections to it, we believe that this is the way to follow.

To conclude, this work embrace the idea that it is possible to enrich architecture creativeness by exploring the use of logical-mathematical operations, such as symmetry, combinatory analysis, recursion and parameterization, and that computer can be used not only as a representation media but also as a programmable tool for creative design.

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