Expanding of the Limits of Forms in Architecture through the Use of Parametric Methods and Algorithms

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1. ABSTRACT

The debate of new aesthetical approaches to form in architecture is permanent and one of the key topics of theoretical and applicative studies. The content in architecture is strongly interrelated to language and form, as the basic expressive and communicative tools.

This paper demonstrates the role of the technological improvement and of the implementation of new applied mathematical concepts, in determining the components of language and obviously those of form generation.

This understanding is reached through a historical analysis of the evolution of the modeling techniques and their impact on the limits of form and its conception methodology.

The main object of the analysis is to evaluate the influence of parametric modeling in the form conception and generation process. The experiment consists in comparing a variety of three-dimensional models, generated by means of classical methods and different advanced Computer Aided Design applications which utilize primitive geometry or parametrical modeling and algorithms.

The outcome confirms on one hand the absolute quantitative advantage of the alternatives generated through Computer Aided methods and on the other hand the fact that parametric modeling and algorithms can generate aesthetically pleasant and unusual three-dimensional results. These tools are already capable of reshaping architect's aesthetical convictions and they are certainly promoters of a new methodological approach to design that most probably will affect radically the future visual quality of the built environment.

2. FORM IN ARCHITECTURE

The theoretical considerations concerning architecture cannot be fully comprehensive without discussing about form. This is a multidimensional debate on which form should be considered associated to several parameters which influence it and not as an isolated concept.

The understanding of form concerns an overlapping relationship of geometrical (aesthetical) and perceptive (psychological) concepts.

Nowadays the grammar of the communication language with architecture is mainly a formal issue. Form is the first perceptive element that leads to the understanding of the architectural organism. From this point of view form becomes the key communication tool of the content of space. This means that the role of form should not be seen as container of the whole, but as an inner characteristic of the being of space.

"Architectural form is the point of contact between mass and space..." Bacon, Edmund: The Design of Cities. 1974

Form in architecture certainly cannot be separated from the process of form generation and conception. The form generation in architecture is conditioned as an interdependent relationship between two parameters; the aesthetical and technological ones, so it can be defined as a process that balances the intangible feature with the materializing aspect.

The design process has become more complex through time and its evolution has naturally affected the form generation. When the architect was a master builder, his creations were built in real time and the preliminary process of exploring the form was almost inexistent. At that time the form was entirely dependent on the materials being used and on technology. The limited building capacities were forcing a primitive approach to form.

The transformation of the master builder in today's architect is associated with the development of the preliminary modeling phase in the design process. The evolution of this phase starts from the classical two dimensional drawings, as a part of Euclidian geometry, and continues with today's virtual models conceived

via advanced geometric systems. The form generation is also conditioned by the preliminary modeling process. This is the reason why knowing and understanding the limits of form is to explore its means and possibilities of expression.

3. EVOLUTION OF FORM'S REPRESENTATIVE TOOLS AND THEIR IMPACT ON FORM GENERATION

As mentioned above, there is an interrelation between form generation process and its representing methods (Fig. 1). The representative tools are key factors in determining the language of form and its generation process. These factors are dependent on the development of the digital technology and naturally on the evolution of mathematical concepts.

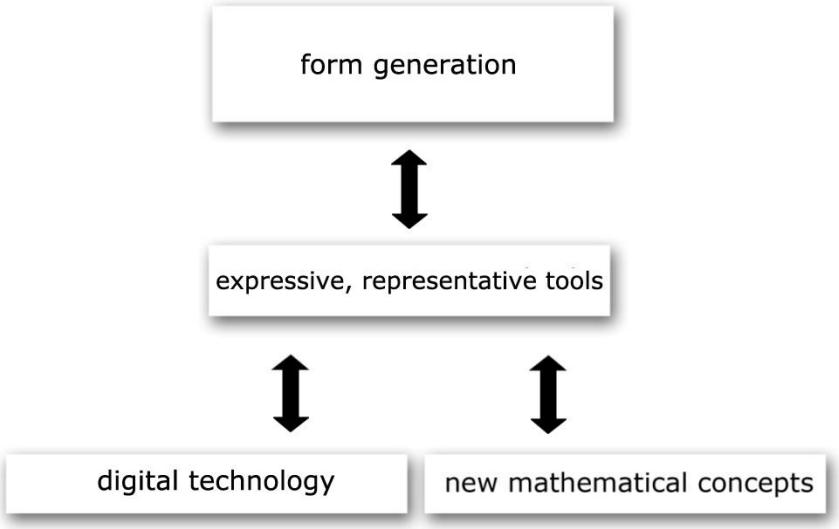

Fig. 1: Relationship between form generation, representative methods, and influencing parameters

3.1 New mathematical apparatus and renovation of geometrical concepts

Traditionally, the Euclidian geometry has characterized the basic expressive and modeling methodology of form and the key element of the graphic representation have been the orthogonal drawings.

"We human beings seem fascinated by the fact that we see in straight lines." Unwin, Simon: Analyzing Architecture.1996

It is very hard for us to search for the limits of form and form generation beyond Euclidian geometry as long as we don't recognize any other system of understanding nature.

How will the situation vary when our knowledge on the complex nature of the physical space will change? The exploration of new mathematical methods is renovating the spatial geometrical concepts and as a consequence the formal approach in architecture. What happened to the formal expressive tools since Lobachevsky confirmed that two parallel lines can be intersected and since the existence of the topological dimension different from the fractal one has been accepted?

The impact of these new concepts in the form generation process has been strongly aided by the implementation of digital technology. Lacking this technological development these mathematical concepts would remain just theoretical and impossible to be transformed into applicative tools that assist the expansion of our formal vocabulary.

3.2 Digital methods in the design process

During the last two decades, the modern society has been facing radical developments of the computer science that have transformed it in the so called Information Oriented Society. The implementation of the digital technologies, almost in all the processes of our everyday life has caused a great change in our convictions influencing also the ones on the research about the nature of the future habitat.

The first experimental attempt of involvement of the digital tools in the design process is dating the year 1967 and it has caused sceptic reactions about their role and influence.

Later on, during 1980 - 1990, the rapid implementation of CAD applications has been transformed in an absolute supporting tool in both 2D and 3D modeling. The operation of CAD applications were still based on the Cartesian system, serving as assisting operational tools that still didn't introduce an essential difference to the classical modeling tools due to their logic of digitalization of the drawing pencil and paper.

The advantages in the precision of the model and its editing possibilities are obvious comparing to the classical methods, but still there is no significant influence in the process of approaching the form. Analyzing the three dimensional form generation principles in these CAD applications we can mention the following main groups:

a) Generation of a 3D shape by extruding a 2D profile (F1) along a vector (u) creating an "α" angle with the profile plan.

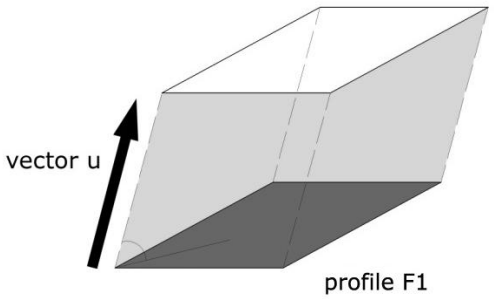

Fig. 2: Extrusion along a vector

b) Generation of a 3D shape by revolving a 2D profile (F1) around an axis of rotation.

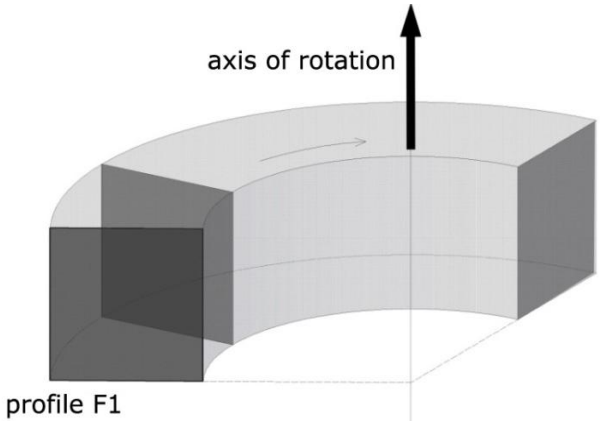

Fig. 3: Revolving around an axis

c) Generation of a 3D shape by sweeping (with or without rotation) a 2D profile (F1) along a 3D path.

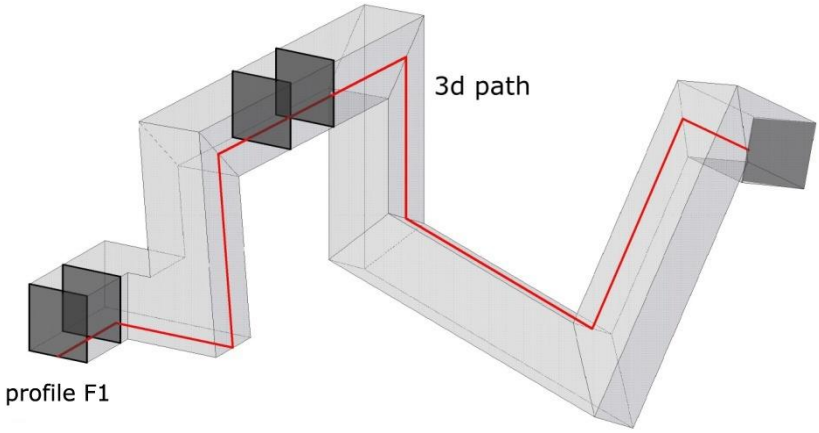

Fig. 4: Sweeping along a 3D path

d) Generation of a 3D shape in freeform modeling by creating and editing surfaces.

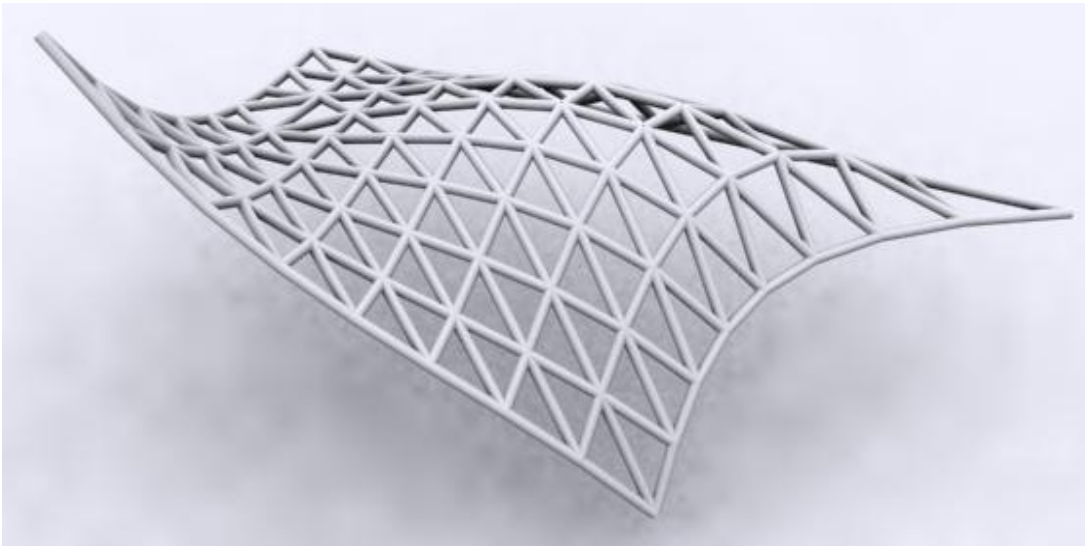

Fig. 5: Freeform modeling

Still form in architecture is generated by primary elements as point, line, plane and the correlation linking them. Up to this moment the role of these basic CAD methods is still distant from the generation of the metaphor of form in architecture and the language is still laconic.

4. THE PARAMETRIC DESIGN AND THE GENERATIVE ALGORITHMS AS ALTERNATIVE DIGITAL METHODS

The modeling scheme of the parametric design, which has been developed during the past 15 years, is not referring simply to the primary geometric elements and their spatial transformations but it has a more complex layout:

input	=> f(x) =>	output

Fig. 6: Basic principle of form generation in parametric design

The principles of parametric modeling merge within the algorithms, data such as integer, double, string, Boolean with geometric primitives as point, curve and surface. As a consequence the form generation process gets parameterized.

"The use of parametric space is a very powerful concept as it allows one to specify geometric dependencies in proportional terms that are not depending on absolute distances and magnitudes.": Fundamental concepts for parametric design. With Grasshopper

The generation of form is achieved through programming and the process parameterizes and calculates the influence on the form of all the conditioning elements. This complex process of calculations materializes the inputted parameters in architectural form.

"Contemporary avant-garde architecture is addressing the demand for an increased level of articulated complexity by means of retooling its methods on the basis of parametric design systems." Schoumacher, Patrik: Parametricist Manifesto at 11th Architecture Biennale. Venice, 2008

At the moment the digital tools are getting transformed from supporting elements of the preliminary representation of the built form, in form conceiving tools. This is not anymore a sequential path that implies firstly the conception and then the modeling of form, but there is coherence between both of the processes. As it can be understood, the form generation process is a parametric data interpretation that gets transformed in space.

"Today, form is in any case no longer created from the fund of beautiful forms and given to an object. Instead form is invented, produced, generated in a computer, evolved, transformed" ARCH+ 159,160: FORMFINDING, BIOMORPHIC TILL TECHNO-FORM. 2002.

4.1 Influence in the design process of algorithms and parametric modeling

The implementation of advanced parametric methods has introduced the evolution of the role of virtual models from supporting tools to suggestive tools and form generators. The implementation of these methods has improved form generation, from a process focused mainly in an aesthetical means, in a much more complex one that reacts to the imputed parameters which are not always physical.

The classical scheme of the approach to form in architecture is changing. The scheme below (Fig. 9) represents a linear process combined with repeated actions, where the designer decides to stop the process in a certain moment by presuming that the formal criteria are met and the other parameters are fulfilled in optimum amount. The moment of interruption of the process is intuitive and always lives apart possible alternatives.

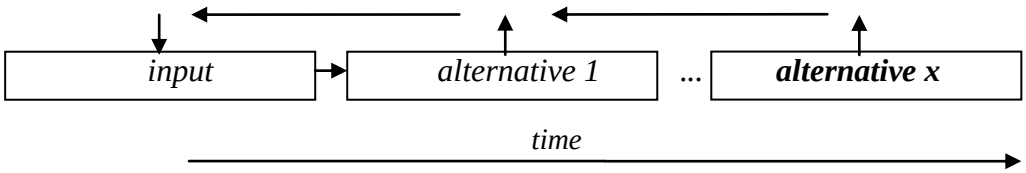

Fig 9: The classical design process.
The alternative research cycles are repeated x times until the designer decides to stop. The evaluation of multiple alternatives consumes time.

In the parametric process (Fig. 10) the moment of interruption comes as a result of the fulfillment of all the possible combinations of the inputted parameters, or by the limits of the processing tools. It means that the real challenge is to define the right inputs for the specific case. For sure there is an absolute numeric advantage of the results comparing to the classical design method.

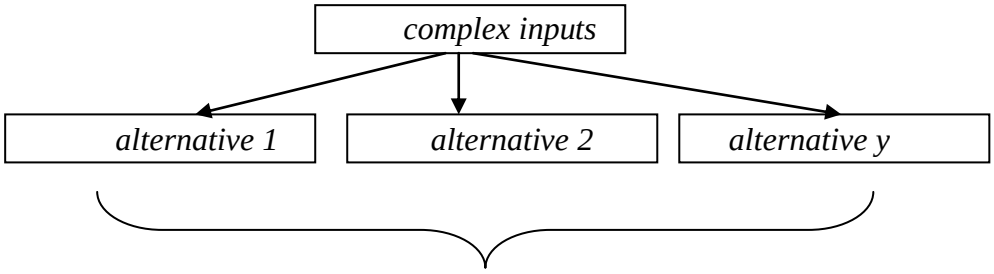

Fig 10: The parametric design process.
All the several alternatives are generated at the same time. The number of alternatives is greater than in the classical process (x << y)

As shown in the above schemes, in the parametric process the quantitative aspect is clearly predominant. Another main advantage of these methods is the aesthetical aspect, because of the tendency of generating topological, fluid and unusual shapes which are almost impossible to be generated with classical CAD methods.

4.2 Evaluation of the influence of modeling software in the form generation process

Experiment:

The aim of the experiment is to evaluate the results in form generation achieved by the use of basic CAD methods and parametric modeling. The exercise consists in modeling a 3D partition through the multiplication of a geometric module. The exercise is repeated in several Auto CAD users and the results are compared to a result achieved by a Rhino user. The results are generated during CAAD courses in the MSc in Architecture programme, in the Department of Architecture and Urban Planning in the Polytechnic University of Tirana.

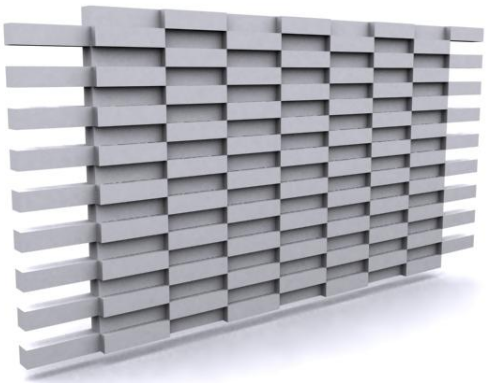

Fig 11: CAD User 1

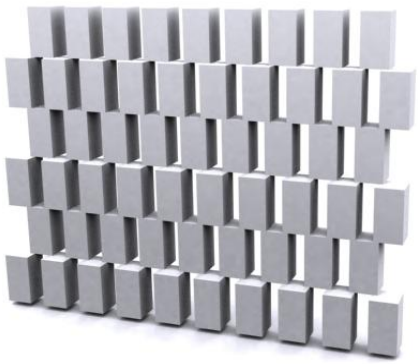

Fig 12: CAD User 2

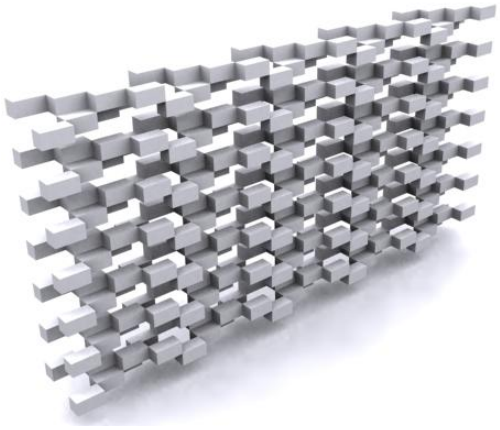

Fig 13: CAD User 3

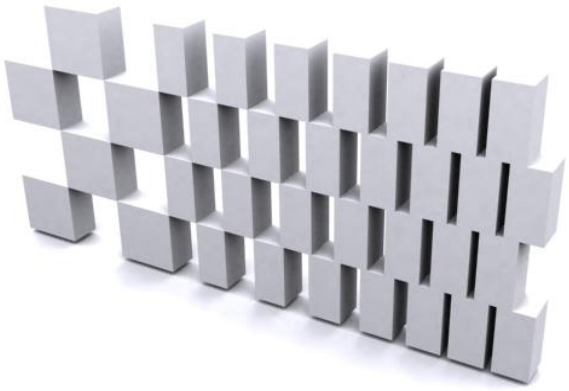

Fig 14: CAD User 4

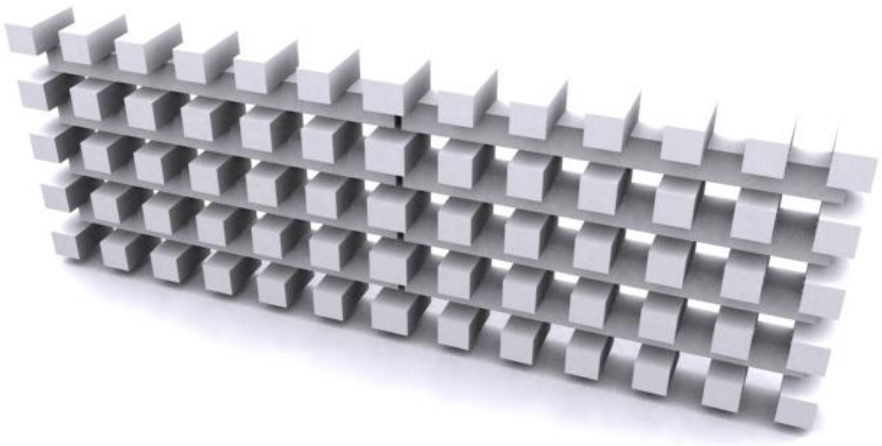

Fig 15: CAD User 5

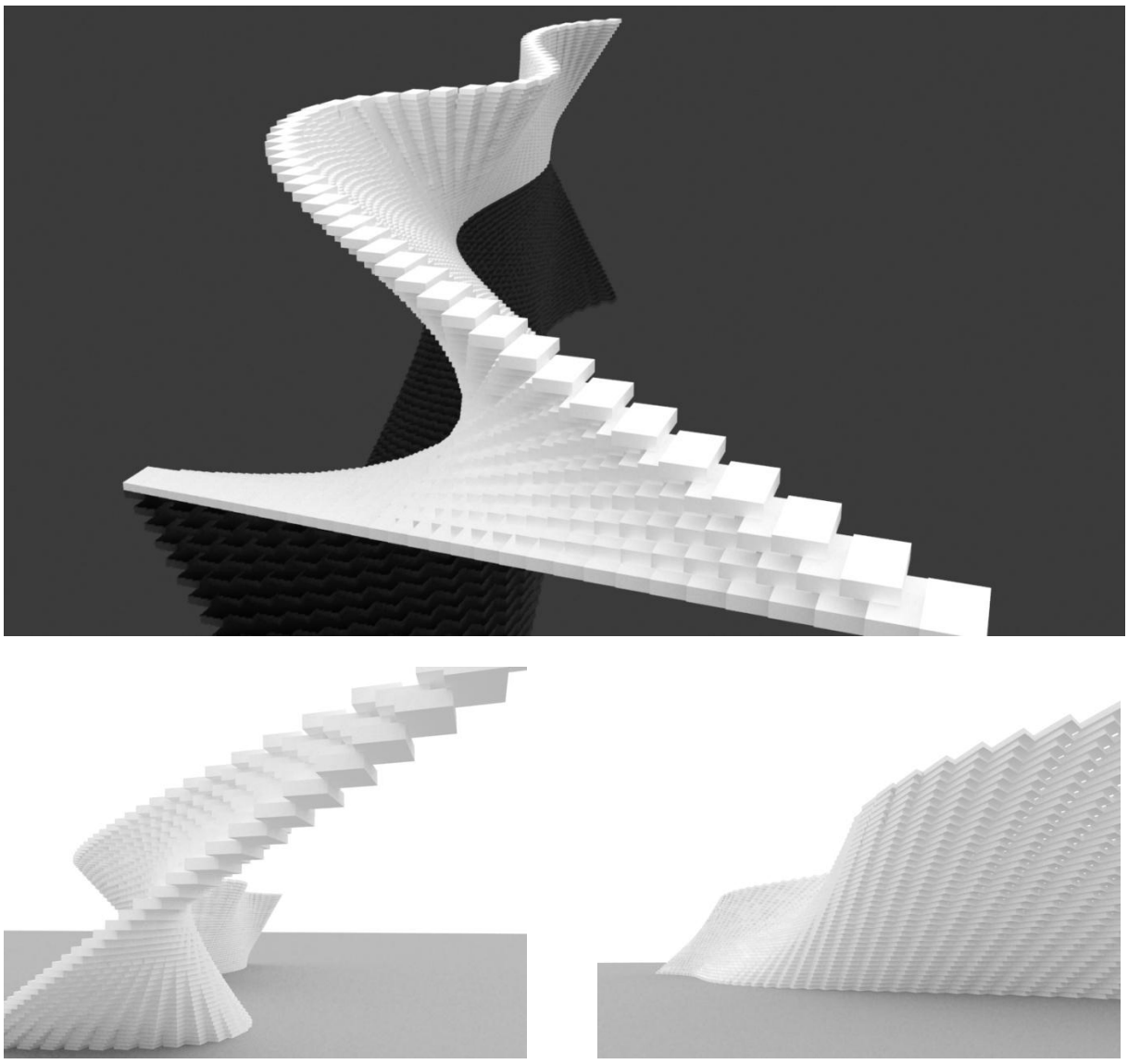

Fig 16: Parametric Method User

The results achieved show that beyond the individual creation capacities, the models generated in Auto CAD have a tendency to create modular patterns which are repeated or alternated. The effort of the CAD user is focused in mechanical actions such as multiplication of the module, displacement and rotation.

In the second case, generated in Rhino, the result is noticeably different and much more complex. The outcome model has generated a topological and fluid spatial context. The intuition that the form deriving

from a cube should be orthogonal in this case is not anymore a conditioning framework or a barrier to overcome.

4.3 When mathematics meet digital technology to generate metaphors. Case studies.

As mentioned above, the physical space is quite complex. This fact has been theorized during the last century. Disciplines as geometrical topology, fractal geometry and the theory of chaos have implemented a revolution in the understanding of form and space. The greatest revolution is introduced by topology which explores the form as a "process" and not a finite condition. In fact the research on the reversible mathematical functions or homeomorphisms has proposed an interesting metaphoric formal concept: the fluidity of form. This principle at a glance seems to be abstract but it is materialized in several examples through the implementation of the parametric methods and generative algorithms.

"In topology any continuous change which can be continuously undone is allowed." Bruner, Robert: What is topology. A short answer

An interesting proposal is that of the BMW pavilion designed by Franken Architekten (Fig. 7). The formal composition is conceived as a fluid and topological shape that materializes the Doppler Effect principle. The form generation through an intangible physical phenomenon defines the metaphor in this proposal. The flow of form between the several sections is not linear and furthermore the section is changing in a controlled transformation during its multiplication. The generation process is achieved through the use of Dynaform which is uses NURBS based surfaces and offers a very high calculation power. The outcome is the effect of fluidity and dynamism that creates an interpretation of form achieved as a result of physical distortions.

Fig. 7: BMW pavilion 2001. Formal concept developed by Dynaform.

A similar innovation in the understanding of space is brought by the fractal theory that also articulates the complex nature of objects. The essence consists in the fact that there is no absolute planar surface or an absolute straight line. The Euclidian agreement clearly classifies the objects in one, two or three dimensional, but in fact, the objects have characteristics that can be both planar and three dimensional. These characteristics are represented by the fractal dimension which is a mathematic expression that indicates the space filling capacity of a pattern.

As long as we cannot only talk about lines and planes, the form generation through software, based on vector transformation, seems impossible. At the moment the digital algorithms are the only tool. A fractal can be an algorithm where the inputs are: the pattern and the number of repetitions.

Many contemporary architects have proposed formal solutions referring to fractal geometry. The results are really impressive. In just one decade these modeling tools have developed enough to avoid the "classical" modeling methods and have presented a real revolution. The inputs that can generate form in architecture have an incredible expansion.

MVRDV is one of the design practices that has proposed various interesting formal solutions based on fractal geometry. These proposals that often are described as self-growing seem quite natural and organic. In the Cloud Towers project (Fig. 8) the form is generated through an algorithm that enables the recursive repetition of the pattern and produces a pixelated structure that bridges the two vertical towers. The recursive division in smaller similar elements of the cubic module produces a complex layout that creates a metaphor of the natural growth of a bioorganism.

Fig. 8: MVRDV Architects. Cloud towers

5. VERS UNE... PARAMETRICISM?!

"It is the elegance of ordered difficulty and the sense of continuous differentiation that relates to natural systems". Schoumacher, Patrik: Parametricist Manifesto at 11th Architecture Biennale. Venice, 2008

The reference to nature reminds us what le Corbusier proclaimed about the language of form in modern architecture, where the straight line and the right angle are methods through which man conquers nature. The house, the street, the town should be ordered. The actual contradiction in the vision of le Corbusier is not about the need of order, but in the restricted concept that the order is strongly related to Cartesian geometry.

Understanding the complexity of nature has become a reference source in the conception of the built environment. Several theoretical approaches, from those dealing strictly with form to those dealing with sustainable development, have been formulated on the above argument.

This formal virtuosity is a response towards the complex character of the physical space.

The interpretation of form as a complex entity associated to nature implies that consolidated compositional notions assume a different gravity.

When we talk about pattern we are not any more limited to ornamental use. The parametric design has not only transformed the pattern in a modeling element of the building skin, but the pattern it is currently becoming a space generator.

Already is understood that the debate is not reduced simply to the terms of form. The complexity of the process represents a wider meaning.

"Digital architectures are profoundly changing the process of design and construction. By integrating design, analysis, manufacture and assembly of buildings around digital technologies, architects, engineers, and builders have the opportunity to reinvent the role of master-builder and reintegrate the currently separate disciplines of architecture, engineering and construction into a relatively seamless digital collaborative enterprise, thus bridging the "gap" between designing and producing that opened up when designers began to make drawings."Kolarevic, Branko: Designing and Manufacturing Architecture in the Digital Age. 2001

Many research fields can be potentially explored in order to respond to the new challenges in the structural design process supporting the evolution of form in architecture.

Will the CAD and CAM relation be applied to architectural buildings as it already has succeeded in industrial design by overcoming the design-production barrier?

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