

Towards Morphogenetic Control of Nonstandard Geometries for Designers

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Abstract

The present paper discusses a novel computational design strategy for approximating architectural freeform geometry with discrete planar elements by using morphogenetic patterns. The investigation we report on is part of an ongoing research project [1], which is focused on the design of flat ornamental tessellations by using computational geometry for the discretization of nonstandard double curved forms. The significance of our approach lies in the fact that it allows the designer to progressively embrace the constructive constraints and their aesthetic potential already in the design stage and to follow them through to actual fabrication.

Introduction

The digital age has brought the possibility to build surfaces of complex geometry in 3D CAD tools very easily [2]. But as soon as one tries to turn such forms into built construction many constraints arise. Cost-effectiveness of both fabrication and assembling processes has a huge impact on whether the shapes of a digital design can be preserved in the physical construction. Despite the widespread computational tools and programming skills we, as designers, often find ourselves struggling with the process of conceiving straightforward strategies for designing computational architectural geometry [3] that is also efficiently buildable. Typically there is a disconnect - both in terms of software used as well as people in charge - between the design of freeform geometries and the conception of the construction method which then makes these free forms buildable [4]. When the designer is done with the shape, the geometry and

construction specialists take over. The fruitful process of trying to bring a shape and a structure into the best possible accordance cannot happen in this division of labor. The purpose of our work is to change this. We propose a new way how nonstandard architecture can be built material- and cost-efficiently by approximating complex curved shapes with flat panels, while allowing the designer to control this discretization. In this paper we will focus on how the various practical constraints, arising from the discretization, can already be considered at the design stage. Thus opening up a way to develop ornamental discretization patterns based on morphogenetic processes. As will be explained in more detail in section 3, what we refer to, as morphogenesis, is an iterative process that develops a formal solution by gradual negotiations between a designer's aesthetic preferences and optimization algorithms, which respect geometric and construction-related constraints.

The concepts and approaches presented in the following sections should be seen as preliminary results of an ongoing research effort that will run for thirty months. We are still in the process of completing part of our computational and geometrical algorithms. This project has successfully grouped expertise from different backgrounds: geometry, computer science, architecture, scripting and design. These sciences are certainly leading the future of design thinking. In our case this intersection has opened up versatile and different opportunities for a major and more integrated collaboration. Effectively we have found ourselves with different aims and issues that have progressively redefined and consequently improved our research project. As a consequence the foundation of this approach, based on CAAD technologies, is to generate an integrated advance within the computational geometry design as a field for exploration, experimentation and moreover for problem solving major constructability issues, which lie on the core of design thinking.

In the following sections we will discuss the fundamental question on how to crack the complexities enclosed in the mathematical form finding, the geometrical issues and the physical constraints of a randomly generated design.

1.0 Computational geometry and the architectural design field

Computation has generated, for us as designers, a new way of conceiving, creating and building physical objects [5]. New cognitive processes give rise to new problems. In our case these problems arise out of the study of new forms namely freeform design. Computational geometry focuses on the study of algorithms for problem solving geometrical situations, which

arise out of the advent of modelling software [6] that was mainly designed for computer animation, automotive industry and aircraft technologies.

In the architectural design field, computation has opened up the possibility to design a wide range of complex geometrical forms, which during the last two decades have famously been used by prominent architectural companies such as Gehry Technologies, Foster and Partners, M Fuksas D, NOX Arch, ONL, EMBT, Greg Lynn Form and Zaha Hadid (to name just a few).

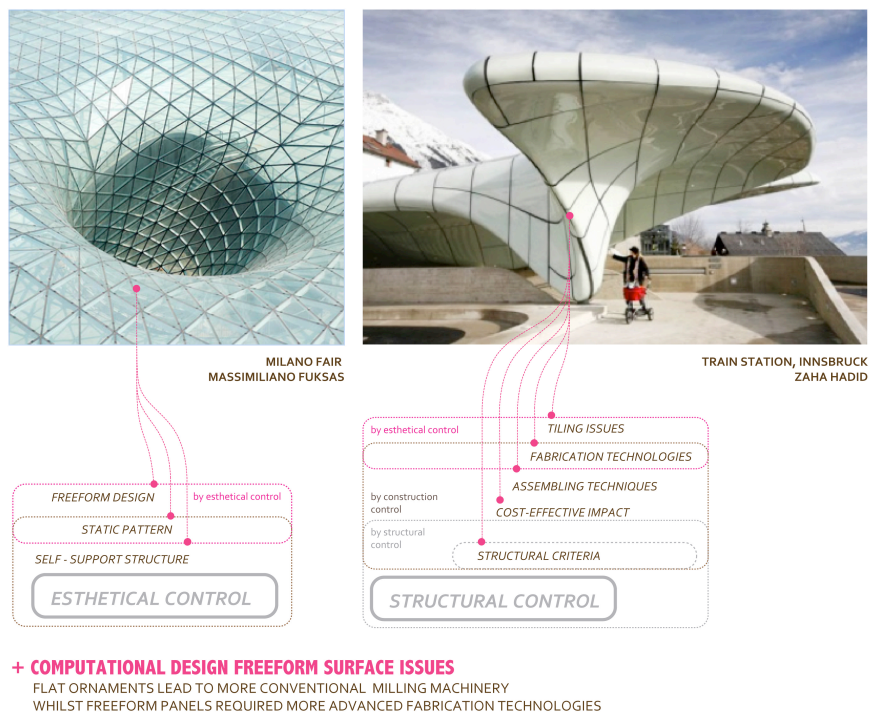


Fig. 1 Left Milan fair building by M Fuksas D, where the surface was panellized by using triangular flat panels. Right: Funicular station structure by Zaha Hadid where the surface was enveloped by using quad curved panels. Both approaches' main issues are discussed in the introduction.

In most of the complex forms represented in the physical buildings designed by these renowned architects, the fabrication processes, assembling techniques or the material strategies were not considered during the design stage, but instead were solved by specialists after the 3D form was already defined [7]. This is mostly due to the lack of appropriate

software. Current 3D modelling packages do not provide any feedback about the constraints of structures and fabrication techniques during the design process. Faced with this limitation there are different attitudes towards construction that designers may take. For example, in the Milan Fair by Massimiliano Fuksas [Figure 1, top left] the freeform surface was discretized into flat triangular panels as it involves strong curvatures. This is a straightforward strategy: any surface can be discretized into triangular panels easily. But it is already a compromise if one tries to optimize the shape by using quadrilateral panels. Furthermore, the approach does not allow the designer to control the variation of the size according to structural loadings. Consequently the Fuksas project is not a self-supporting structure, but a skin depending on a secondary structure based on columns. An alternative approach is that of Zaha Hadid, in her Innsbruck funicular railway station, which is a freeform building composed of individual curved surface elements, assembled along rather visible and somewhat oddly distributed seams. As these seams point out, even with this approach, which is cost-intensive, but can theoretically be used for any shape, the tiling remains an issue [7, Figure 1, top right]. Both projects offer standard and coherent answers to the problem at hand, but they do not move beyond the separation of form and structure, which is typical of many contemporary digital design projects. Here our approach becomes significant as it employs a series of computational and geometrical design strategies for reconsidering, solving and integrating most of these fundamental issues that the aforementioned examples avoid with their respective post-rationalized constructive solutions.

2.0 Computational geometry: a core issue, towards evolutionary morphogenetic geometrical patterns

Panelling a 3D object is a simple task for single or double transitional surfaces. However it becomes a difficult task when the surfaces are generated in a more random manner and contain strong changes in the curvature they describe. In recent investigations we have explored strong curvatures based on both positive Gaussian surfaces and negative Gaussian surfaces. In most cases, the techniques based on the tangent plane components or the “U-V” values of a surface could solve transitional double curvature surfaces without significant deviations of the desired design. However as soon as one combines, in a random manner, zero positive and negative Gaussian surfaces the control of the pattern and the approximation of the desired design become hard tasks to solve [9, 11, 12,

13, 14, 15]. At the present time, no one in the international research community working on these issues seems to have a generally applicable solution for these types of surfaces, which underlines the complex nature of the problem. The reason is very simple, the problem at hand interrelates a cross-multidisciplinary effort. While recently advances have been made in the interdisciplinary field of architectural geometry [11], this remains a challenge.

Another major issue here is that of applying a given 2D pattern on a freeform surface in order to preserve the desired pattern. Preserving the “mapped” [18] 3D pattern during its conversion into flat panels, while keeping these panels as close as possible to the given freeform surface, is a complex optimization problem, with different parameters that interrelate in intricate ways.

During the last decade, this latter problem has brought major collaborations in order to find out different possibilities for optimizing freeform surfaces out of flat panel tessellations [9, 12, 13, 14, 15, 19, 20]. However, these strategies have been focused on the optimization for approximating the given design. Instead, we propose to do it the other way round. Based on controlling the aesthetical behaviour of a topological tessellation we propose a process of semi-automatic negotiations that eventually results in a satisfactory approximation of both, the desired pattern and the freeform design [Figure 2].

The computational algorithms described in the present paper are meant to support designers in creating original work that negotiates between the constraints of esthetical ornaments, morphogenetic design and self-supporting structures.

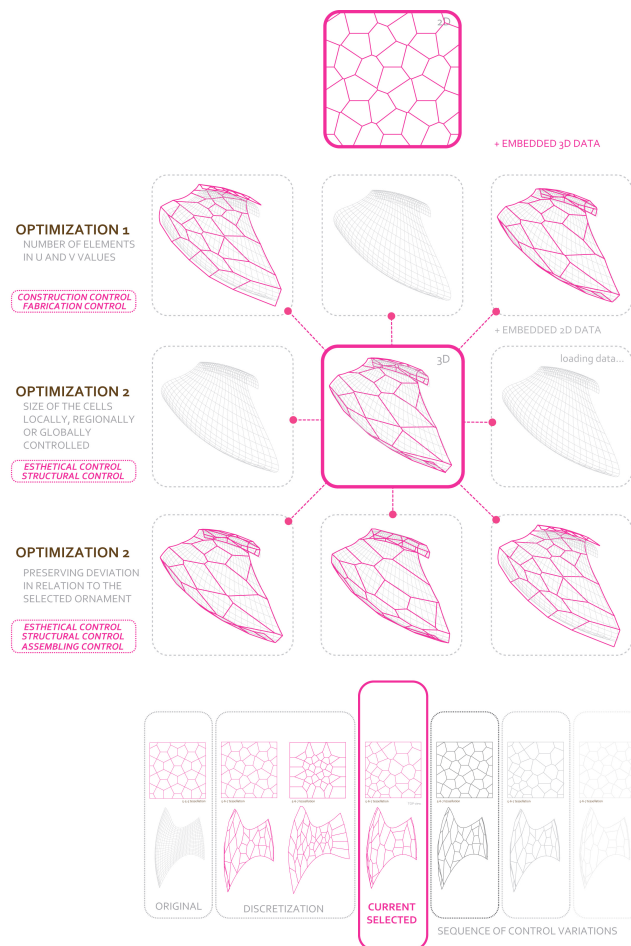


diagram showcases the possibilities for the user to select between different data optimization for enhancing the architectural design approach

INTERFACE: DEVIATION SURFACE CONTROL

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Fig. 2 A glimpse ahead: figure two shows the framework of the overall platform (work in process) and its possibilities for integrating fundamental architectural and engineering issues in the first place of a design process.

3.0 Morphogenetic computational [21] geometry [22]

In biology morphogenesis refers to the process that causes an organism to develop its shape. In the present approach morphogenetic will refer to the process that controls the organization and spatial distribution of flat panels in order to create freeform surfaces. Morphogenetic computational geometry is applied in order to compute digital algorithms for self-adaptation and responsiveness to the contextual freeform generations. The fundamental meaning of the morphogenetic approach here lies on the processes for evolving digitally the topology of the individual cells and their interrelations with the global form. Eventually this computational strategy crack the complex logics that computational geometry hides into a more simple control of the spatial components' distribution that creates the overall structure of a nonstandard design.

3.1 Morphogenetic strategies

Parametric, associative and evolutionary design meet here in order to create an overall network system capable of generating multi-levels of design potential processes.

Through a collection of points on a determined surface, a parametric design system, similar to a constrained generated procedure [23], is formed with the intention of breeding a transitional design of the tessellation's individual components. Then, the central component has the possibility to change the relationship with the other components [Figure 3]. The outputs of these central components are inputs to others. These inputs and their encoded functions determine both the shape and type of the tessellation and the matching of the tiling for eventually producing the flat ornaments. The overall network system is capable of encoding a great variety of possible behaviours and allows the designer to interactively influence its outcome.

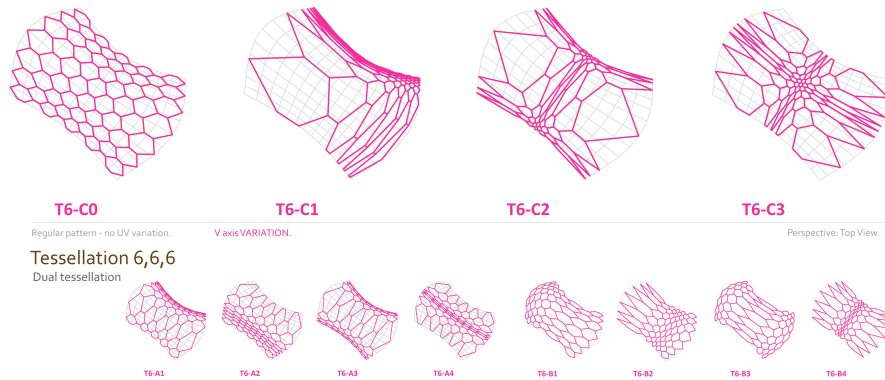


Fig. 3 The figure shows different permutations of a hexagon tessellation aimed by the control of individual or the whole system of parametric cells.

3.2 Parametric design

In terms of parametric design, our morphogenetic system is capable of modifying the shapes of a given design surface, altering its dimensions or modifying the whole topology of the surface [24] by controlling very simple parameters of the overall system [Figure 4].

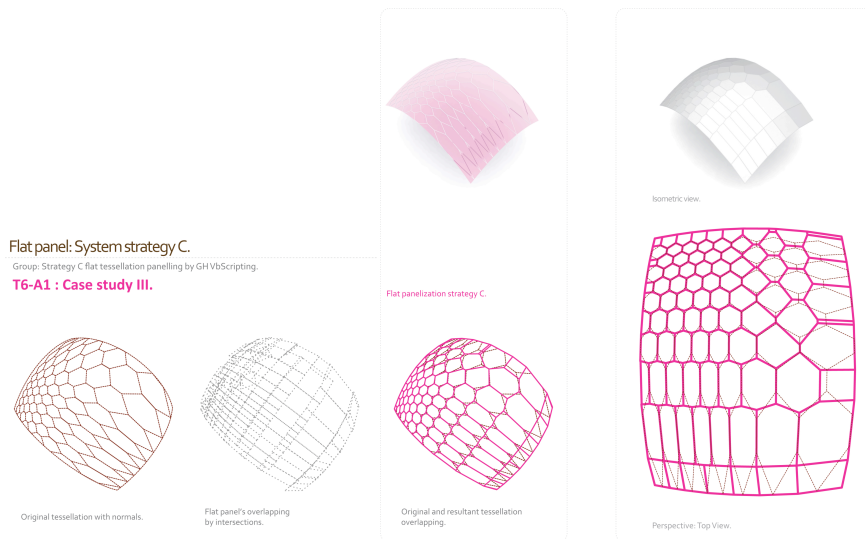


Fig. 4 From bottom left to right side, the image shows the process for getting the flat panels where both parametric and associative design intersects in order to create an overall network system.

3.3 Associative design

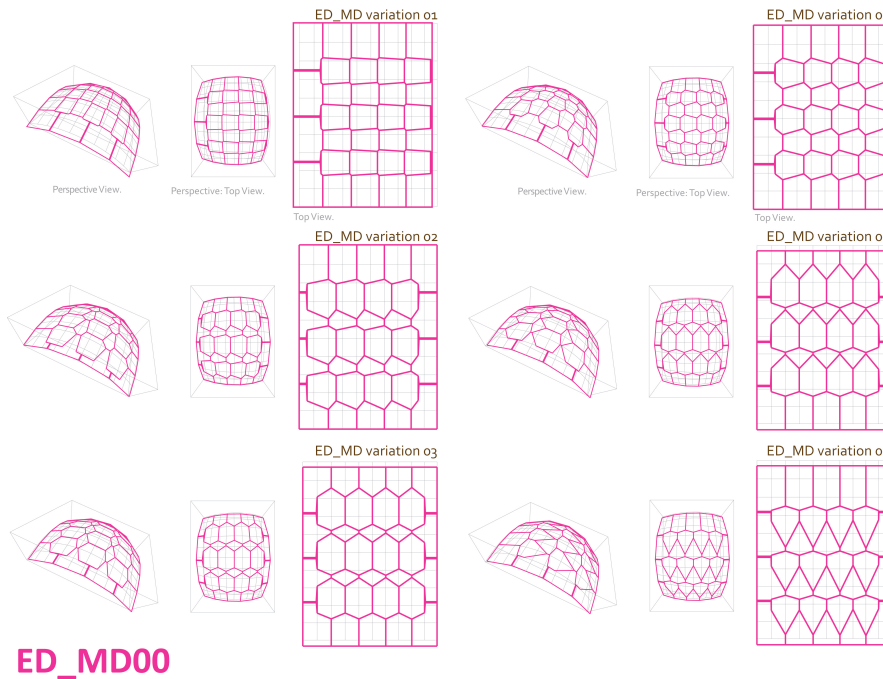
Regarding the associative design strategy, which remains in this case an embedded property from the parametric design, focuses on re-calculating both, the given pattern and the deviation of the given surface. In some of the cases the designer could aim both, the minimum deviation of the approximated surface and the output pattern visually similar to the given tessellation to compute [25]. Thus the individual components could be considered as part of a whole series of components and then these individual components could be controlled by the overall system or, the other way round it is also possible to get the individual components manipulating the overall system [Figure 5].



Fig. 5 Figure four shows a non-homogeneous pattern resulting from the iteration between the desired pattern with the combination of both, positive and negative Gaussian curvatures. The output of the ornamental surface, shown in the image, is already enveloped out of flat panels.

3.4 Evolutionary design and the morphogenetic system

The evolutionary or morphogenetic system will allow the designer to control the shapes of the tessellations or patterns that could, in the first level, change the topology [24] of the main structure. This first level unfolds into two potential strategies: the very first one lies in the number of elements that enclose a whole cell, e.g. the possibility to change from a single square, i.e. four elements of a cell, to pentagons, hexagons, heptagons or a mixed combination. The second unfolded potential is focused on controlling the inside area of a cell i.e. we could generate an infinite series of combinations out of one single pattern, by changing the angles, the scale of one or more elements of the topological structure of a cell or the whole cell itself [Figure 6].



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Esthetical differentiations by morphogenetic design strategies.
Note that variation has been aimed with the use of only hexagon tessellations.

Fig. 6 By controlling one or more cells of the whole system the designer may generate esthetical differentiations on the overall surface. The image showcases the importance of the esthetical results aimed by modifying very simple rules of the whole system. The system, in this case, evolves creating different permutations of one individual tessellation (hexagon).

The second major transformation lies in the fact that the designer could move towards the control of one individual cell or a region of cells in the series of already flat panel components [Figure 7]. This second transformation also unfolds itself into a series of possibilities, which are described as follows: a) the designer's potential to change the scale of one of the components or a region of components or different isolated components; b) the designer's potential to change the position of one of the components, a region of components or different individual components; and c) the designer's potential to change the shape of one of the components, a region of components or different individual components [Figure 7].

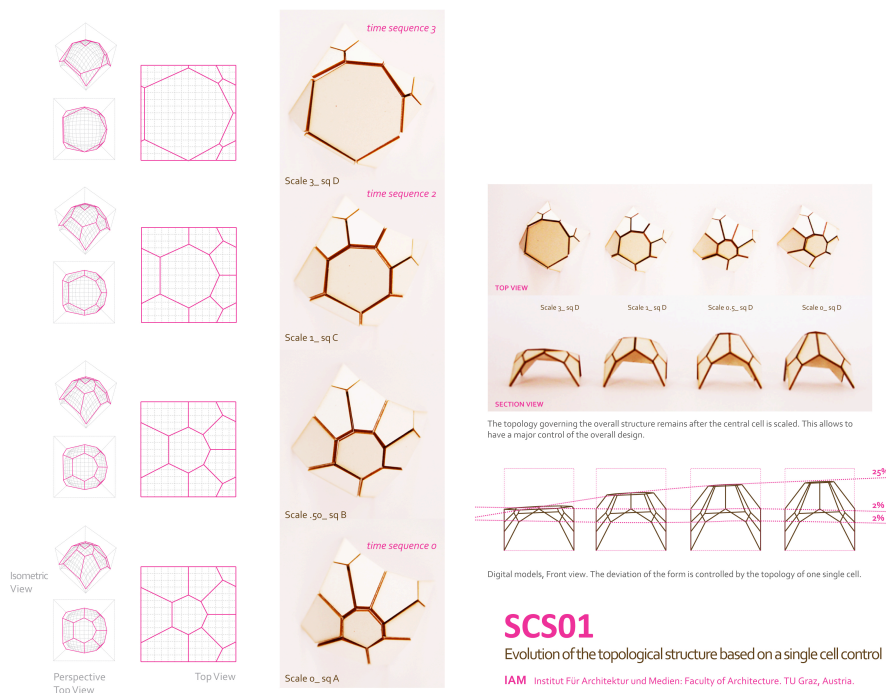


Fig. 7 Explains the dynamic interrelationships between cells. By modifying the angles or the scale of one or more cells, the designer could generate a complete different pattern and thus get to control the aesthetics of the output building [26].

The third potential is then to move towards an evolutionary design on a given surface by applying morphogenetic tessellations. In other words the designer may modify the variation of patterns and tiling throughout a given surface. For instance a given surface could be designed starting on

one of its boundaries with a hexagon tessellation [27] and then, for instance, change to pentagon tessellation in the middle of the surface in order to adapt to the surface complexity's curvature and eventually ending with a square, octagon, heptagon or coming back to the hexagon tessellation.

By doing the latter the designer is expected to have the opportunity to negotiate, decide and compare between different solutions of the aesthetical tessellations introduced here [Figure 8, Figure 2]. Certainly this reports on an ongoing research project. Consequently there are still different issues to be solved and moreover paths to be explored. However with this report we intend to open up a new discussion for integrating constructive and geometrical issues that should be turned into keys elements within the design stage.

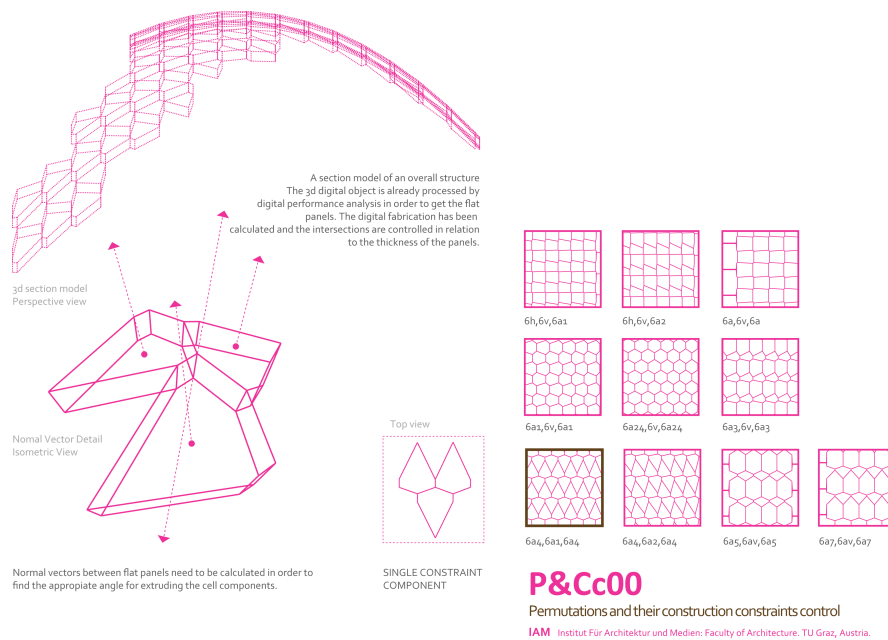


Fig. 8 This figure demonstrates how by interacting between the type of ornament and the organization of the single components one may control both the sketch of the given surface and the desired thickness of the physical material that may have a variation throughout the surface.

Further discussions

In the introduction we discussed how computational techniques have opened up the possibility for building very complex geometrical designs. The complexity is a characteristic that has been explored by human beings along history. However this complexity becomes a hard task to solve when the physical materials, structural technologies and assembling techniques have to meet in order to approximate a desired design.

These latter aspects are fundamental issues for architectural design and engineering construction fields, which during the last decades have been tremendously transformed from sequential and standard constructions to very complex, non-periodic and variable constructions. There is a hunger for nonstandard, chaotic and complex geometrical designs that has been fed by computational software. Since the very last decade and during the following years we will continue experiencing buildings that deal with this kind of complexities. However the lack of integration between the two major fields in building construction, architectural design and engineering technologies still remains a fundamental problem. The major issue relies all the way through design education. There is a major gap in education systems and this is not only related to the design or engineering fields.

The software proposed here, for instance, is intended to solve a number of the fundamental issues that contemporary designers have to deal with when designing nonstandard geometries. However the designer, or the user, still needs to be trained in different backgrounds in order to get to know the major advances that computation is rapidly generating. The lack of “new” knowledge is a core problem that computational technologies have brought along. There is a fundamental need for a revolutionary change in education systems that may solve this major gap.

Coming back to the lack or invisible integration of both fields, architectural design and engineering construction, the issue here is that the physical constraints in building construction have not been explored or integrated during the design stage. This is not a new issue but certainly computational technologies have enormously increased the size of the gap. Currently, this problem is being faced in one or two different ways. In the first case we are seeing computer scientist, engineers, mathematicians or geometers dealing with the optimization of the desired designs. Consequently, a few consultant offices have emerged in order to deal with these issues, but this does not solve the intrinsic nature of the problem.

Regarding the practice and teaching of CAAD technologies, the fundamental importance of our approach emerges when solving the aforementioned issue right on the design stage whilst the core of the solution lies on the integration of fundamental geometrical and physical constraints. Even though the project presented here is on one the one hand still on process, on the other, we are mainly introducing the possibilities of controlling the aesthetics of it. The overall scope is to meet the possibilities that digital design offers with the building constraints along with the current fabrication technologies in order to solve major geometrical issues that may also meet esthetical negotiations.

The fundamental pursuing of this approach is that CAAD technologies enhance the integration of allied disciplines in order to highlight creativity as the core meaning for finding the logics that will form the future environment for more flexible and embedded designs.

Acknowledgments

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24. Topology here means the number of elements and the way these are connected to each other in order to generate a whole structure.

25. It is important to note that in most of the cases the overall network system could certainly meet the minimum deviation of the given surface if needed. However due to geometrical circumstances in some cases the visual deviation of the given tessellation remains an open problem.
26. The given surface or pattern may be altered depending on the new esthetical component's organization.
27. This may be aimed due to an esthetical design requirement or by following geometrical properties of the given surface. These two potentials are intended for the designer to open up a new series of possibilities to explore creativeness and intuition.