Proceedings of the International Symposium on Algorithmic Design for Architecture and Urban Design,
ALGODE TOKYO 2011
March 14-16, 2011, Tokyo, Japan

Algorithmic Processes and Evolutionary Architectural Design for Nonstandard Geometries.

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Abstract

The present paper reports an ongoing investigation about *morphogenetic patterns*. It discusses latent potentials for controlling esthetical planar ornaments where algorithmic design processes play an important role in enhancing architectural design. Through the use of dynamic user-control and evolutionary processes, the algorithms introduced in this paper, embed freeform design out of planar components. This investigation is intended to extend the synthesis that computational geometry algorithms imply for the key stages of design knowledge. In order to optimize an intended design towards the fabrication strategy and the construction techniques, an early digital architectural design should integrate the following concepts: building shape, intended design, rational material and structural systems, digital fabrication methods and construction criteria [1,2].

The present paper focuses on explaining, through a series of ornamental experiments and related theory, the algorithmic potentialities and the user-criteria for empowering esthetical results. Overall, the aim of the project is to integrate the fore mentioned concepts in order to enhance design thinking. As a consequence the foundation of this approach is to generate fundamental advances for computational geometry design as a field for exploration, experimentation and moreover for problem-solving digital and building issues, which lie at the core of design thinking. [3]

Keywords: dynamic user-control, free-form design, planar ornaments, computational design geometry and design thinking

1 Introduction

Computation has completely changed the way that an intended design is processed into building construction. Conceiving, creating and building a design project has been changed from design thinking followed by structural engineering into a more collaborative environment.

Architecture is in the process of revolutionary transformation [4]. In architectural design a formal concept is first conceived by the architect and subsequently structured and materialised in collaboration with the engineer. For instance, during the last two decades, Cecil Balmond and Matsuro Sasaki's collaborations with prominent architects have clearly showcased the revolutionary changes that architectural design is breeding [3]. However, these revolutionary changes have also revealed major issues within architectural design processes and structural engineering methods.

The traditional designation of the interaction between the architect and the engineer has frequently been one of post-rationalisation [4]. This demonstrates the necessity for a more advanced collaborative environment between engineers and architects concerning early design stages, which will eventually have an effect in both design practice and design education.

Current 3D modelling packages do not give any feedback about the constraints of material, structures or fabrication methods during the design process [3]. This highlights the necessity for a cross-multidisciplinary software design platform. This software requires specialized knowledge in order to extend the flexibility of digital construction to physical construction, causing the intersecting of computational design geometry, fabrication techniques and construction technologies.

Today, parametric software and scripting techniques allow designers to digitally build responsive systems. However, a parametric strategy is often focused on solving a particular situation within construction, fabrication or material constraints. Usually this is the reason why most of the algorithms used up to now have been applied only to one project and then discarded [2]. The reason as explained by F. Scheurer is because at least one of the factors described in the algorithms, changes from project to project.

In the present paper, a series of computational algorithms are presented. The algorithms are not intended to close discussion on the fore mentioned issues. They are generated as a consequence of these issues, but provide an opportunity to integrate user-controlled, esthetical strategies, which enclose specialized knowledge for embedding non-standard constructions into the design stages.

2 Computation: Algorithmic design processes

Until the mid-1990s the software used by designers was mainly focused on the interaction of repetitive elements where regular and orthogonal concepts were the standard methods for designing an architectural building. The advent of computational tools gave designers the possibility to build complex forms. New cognitive processes give raise to new problems. In our case these problems arise out of the study of new forms namely freeform design [3,5].

Algorithmic design processes have played an important role within the mathematical and more recently the computational field. Algorithms have helped mathematicians and designers to find out automatic sequences for enhancing research in science. As a consequence industry evolves; when Industry evolves, construction plays a major role, giving rise to new developments that eventually make designers to come up with new and more challenging

ideas.
The approach presented in the present paper is that of constructing a series of algorithms with the aim of processing evolutionary strategies for transforming esthetical criteria into different and diverse classes of freeform permutations. These permutations approximate the curvature of the shape of a given surface. The presented investigations focused on solving from single and double curved surfaces to hyperbolic and parabolic surfaces. In all cases the examples introduced here are based on positive Gauss surfaces and on convex tilings.

3 Algorithmic strategies

One major issue within the computational geometry design is that of tessellating either partially or entirely a given freeform surface out of planar self-structural components. The overall task becomes progressively complex and demanding to solve as it involves a major cross-multidisciplinary task. Many researchers have been engaged in finding out different solutions and ways of fitting flat ornaments and their mixed permutations in order to approximate mainly a plane [7,8] and more recently curved surfaces [9,10,11,12,13,14,15]. While recently advances have been made in the interdisciplinary field of architectural geometry, this remains a challenge.

3.1 Performative algorithms 1.0 and 2.0: tiling issue

The algorithms presented here solve three core issues of the main problem. The very first one solves partially the tiling issue in order to fit a 3D pattern into a freeform surface. Our research is focused in finding a flexible solution, which allows the designer to interactively change between different tessellations that eventually will end up out of morphogenetic patterns. The tiling's morphologies shown in Figure 1 are constructions evolving from pentagon to heptagon permutations with a specific focused on pentagon's permutations and its possibilities for interactively varying it.

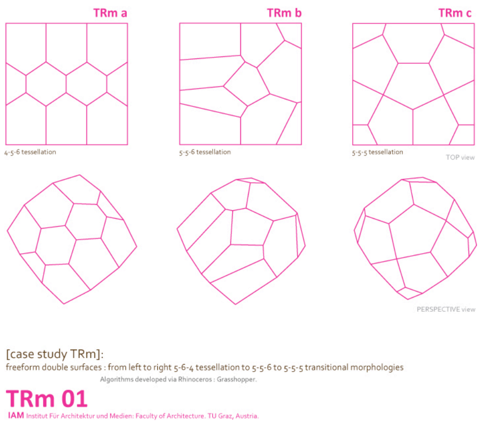

Fig. 1: From left to right the images shows transitional tessellation 'states in order to aim the well-known Cairo tessellation.

3.2 Performative algorithms 1.0 and 2.0: mapping and ornamental issue

Preserving the mapped 3D pattern during its conversion into flat panels while keeping these panels as close as possible to the given free-form surface is a complex optimization problem with different parameters that interrelate in intricate ways. The solution proposed here, for this second issue, is based on controlling the behaviour of esthetical tessellations aimed by applying semi-automatic negotiations that eventually result in a satisfactory approximation of both, the given pattern and the freeform design.

Among many other issues, the third solution is based on the pattern problem. In order to find out an appropriate negotiation between the given pattern and the final ornament exposed on the output flat components the relationship between components plays the most important role of all.

Actually most of the rules that control the overall system are based on very simple ones. For instance figure two demonstrates that by varying the relationships of the rule that enclose the behaviour of the pattern, the designer could aim very distinct and interesting results.

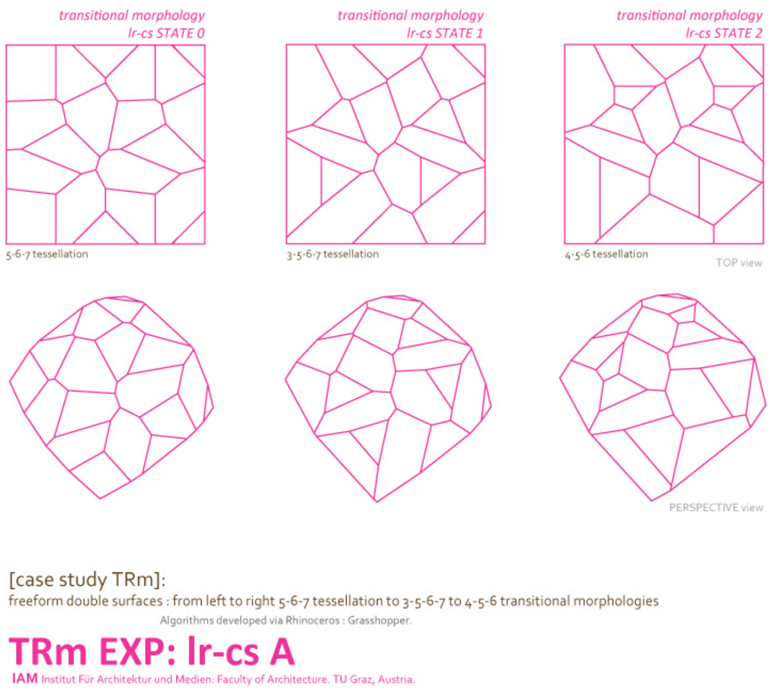

Fig. 2: Transitional morphologies are generated based on very simple rules enclosed in the overall system.

3.3 Performative algorithms 2.0: esthetical advantages

Once the flat panels are populated on the given surface the designer may like to take further decisions. Figure three shows the so-called Cairo tessellation –5,5,5 pentagon's pattern. Aside from the very complex task of approximating a pentagon tessellation out of flat ornaments the sequence of images demonstrate, among other different possibilities, five different decisions that the designer may take advantage of: precision of the resultant pattern, scale of the components, esthetical control, pattern's porosity concentration and self-organisation.

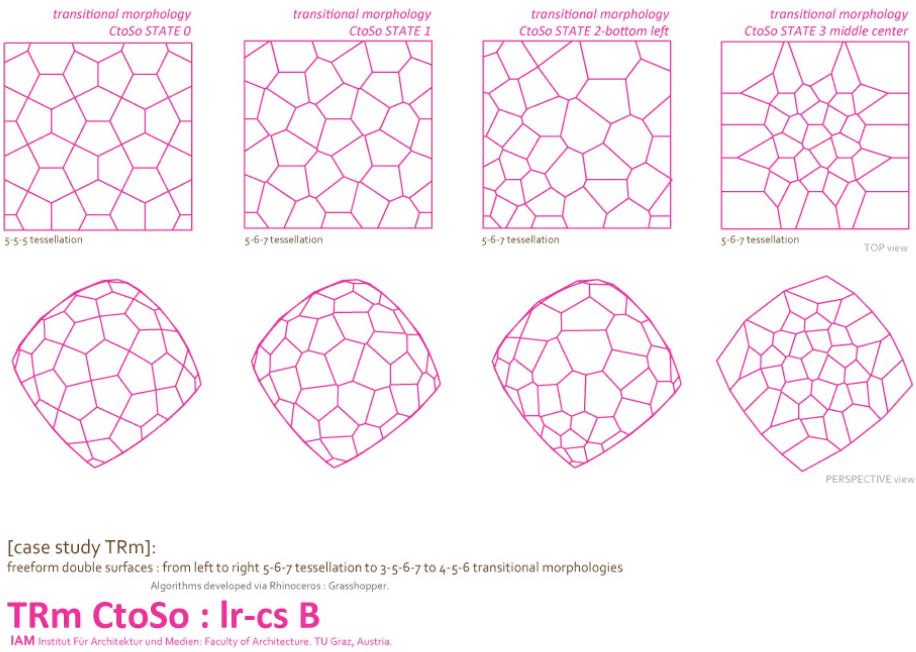

Fig. 3: Transitional morphology states. The designer may vary from standard ornaments where complex systems arise to non-standard geometries where symmetry stands.

4 Performative algorithms 3.0: fabrication and construction issues

Definitely some of the ornaments that are being part of our explorations may cause construction problems. More recent explorations are shown in *Figure 4*. The proposal is intended to aid the designer to control the fitting angle of the resultant flat ornaments. By varying the topological relationships on the algorithm definition the designer could control the number of elements and the structure of the fitting ornaments. One constraint of the assembling process is that it is much simpler when only three panels meet in one point. As soon as four or five panels intersect, the so-called offset problem occurs, which makes it much more difficult to arrive at a clean construction detail.

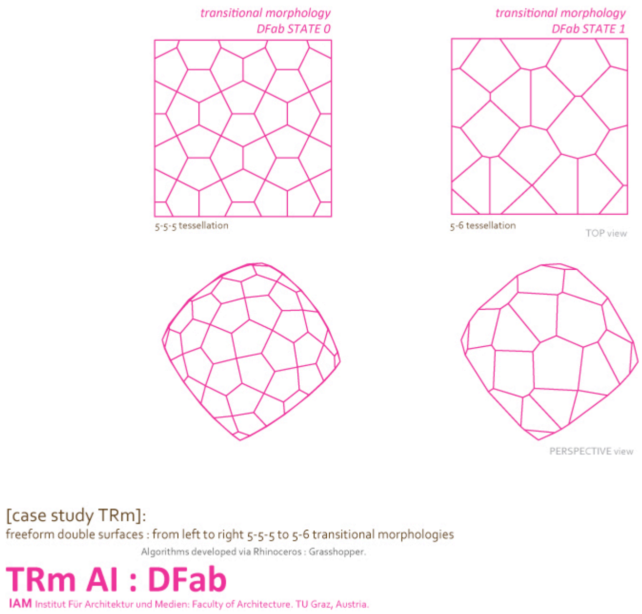

Fig. 4: Shows that by varying the fitting ornament criteria on the algorithm definition the designer would have the opportunity to decide the number of elements that may fit in one point.

5 A glimpse ahead: an overview of the digital platform

The post-overall meaning of the presented research is to design a platform for aiding designers and engineers to integrate design and structural criteria where non-standard geometries, flat ornaments and esthetical opportunities intersect. Figure 5, shows the process that the designer or user will use as an opportunity to decide between different stages of the platform that will eventually enclosed the algorithms presented here. Top left of the image shows a post-processor, which would be based on a somehow intelligent computational design solver. This latter is intended to evaluate between different possibilities that the designer may use for enhance esthetical criteria, type of ornaments or structural control.

Figure 6 is a close up to the interface's optimization for the problem of the given surface deviation. When the components or output panels approximating the given surface become flat an amount of problems arise. The general optimizing features described on figure 6 give different opportunities for enhancing design and structural criteria that the designer may use on key design stages. The image shows the opportunities that the designer may take in order to optimize the given surface according to u-v number of elements (flat panels to be calculated), sized of the panels or angles of the output panels. It's important to note that in all the optimization cases a cross-interrelation between esthetical, fabrication, construction and structural control is needed.

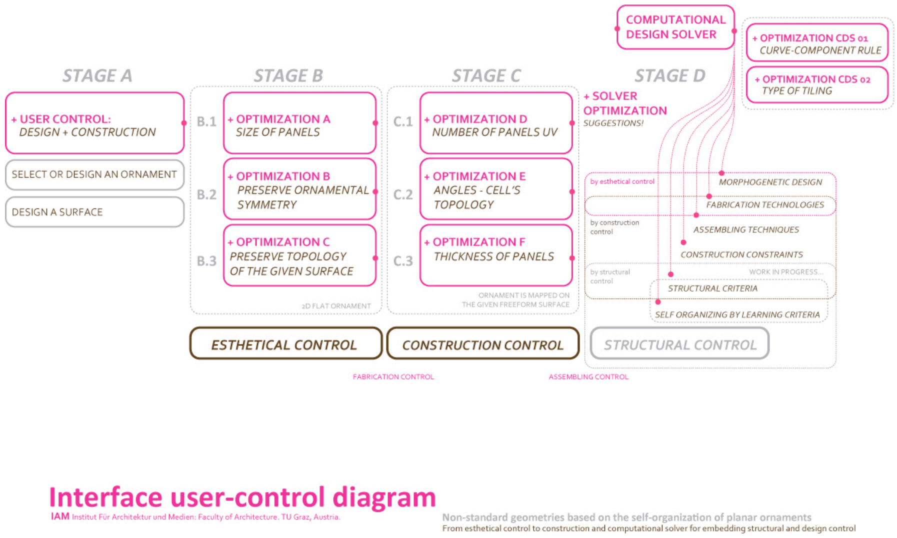

Fig. 5: Flow diagram of the platform to be designed that will eventually optimize both the deviation of the given surface and preserved the selected tessellation. Esthetical, construction, assembling, fabrication and structural techniques are expected to be part of both user decisions and computational intelligence.

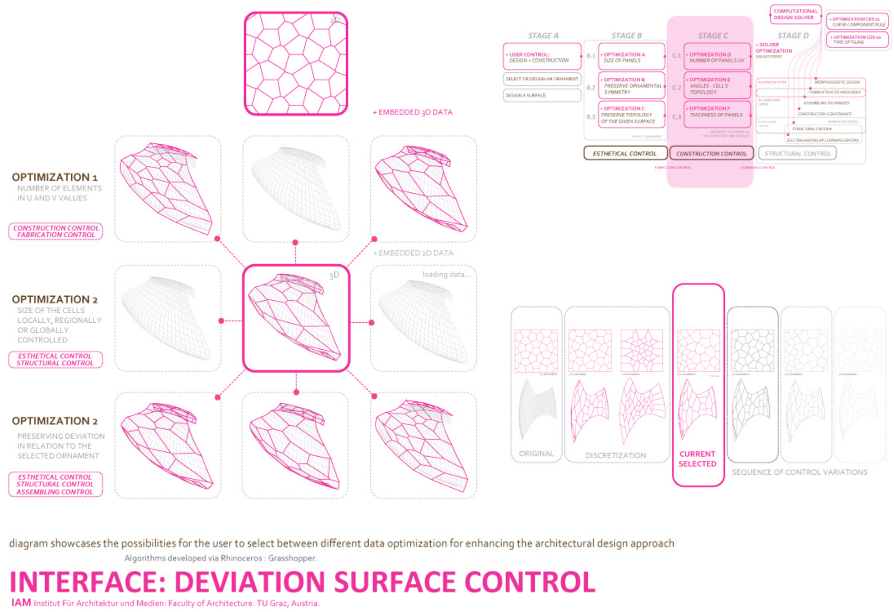

Fig. 6: An overview of the interface where the user will interactively and visually select and work from a 2d to 3d environment. It shows the optimization of the surface deviation issue.

In the other hand figure 7 shows the possibilities for modifying and varying the ornamental tessellation into the already flat panels. It clearly demonstrates different possibilities that the designer could control in order to decide between esthetical variations and construction strategies for designing a resultant ornament. The latter may generate an opportunity for integrating construction and structural criteria on early design stages. Overall figure 7 summarizes the algorithms appointed out in the present paper. Thus the core aim lies on the intention to create an opportunity for a major collaboration between artists, designers and engineers.

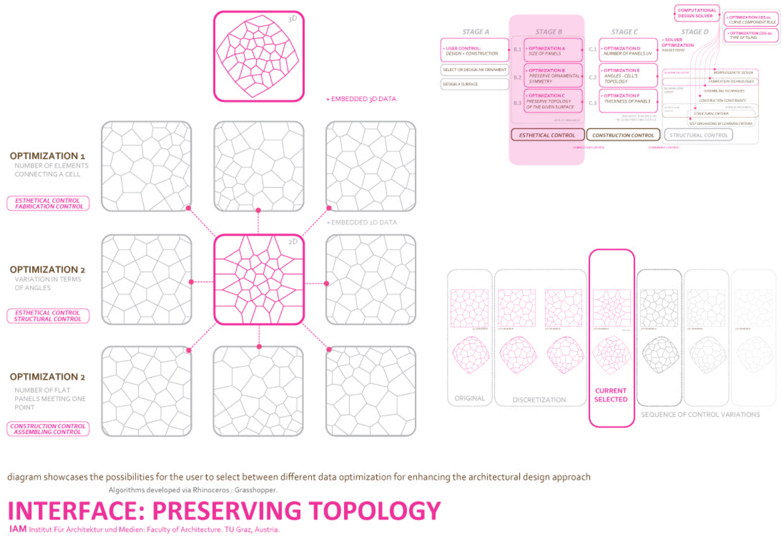

Fig. 7: An overview of the interface where the user will interactively and visually select and work from a 2d to 3d environment. It shows the optimization and possibilities of the ornament variation.

Conclusion and further discussion.

I have presented preliminary results of an ongoing research project that is currently under development at the Institute for Architecture and Media at Graz University of Technology in Austria. This approach has the purpose to introduce the project in a way that explores new criteria for facing the approximation of freeform surfaces out of flat ornaments. I would underscore this approach in the sense that it generates differentiation where symmetry stands and may generate standard opportunities where complex asymmetries arise.

Certainly in the near and long future architectural design will continue becoming more and more flexible and complex in terms of freeform and shape design. For facing this emerging approach I consider that parametric strategies should be based on somehow growing systems, which may allow the user to face different circumstances involving at least from two to three issues in one major system. Clearly this approach is not intended to generate a unique system for non-standard geometries, but a flexible one capable of hosting more opportunities and chances to operate and apply for facing different circumstances. The difference here stands in the intended algorithms since a learning process is expected to happen, consequently this process may be applied to other particular strategies on a dynamic simultaneous way.

As a consequence rapid advances are needed in design thinking in order to face this “revolutionary transformation” that will eventually have an impact on the practice and on the education fields for architectural design and engineering construction.

Acknowledgments

This project is supported by the FWF Austrian Science Fund Government under the grant L695.

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