The Magnified Pixel: Digitally Fabricated Prototypes at the Intersection of Art, Mathematics and Architecture

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Abstract

This paper presents an experimental teaching protocol for algorithmic design and a digital fabrication, addressing the cross-disciplinary domain of creative tectonics at the intersection of art, mathematics and architecture. It will present digitally fabricated prototypes that combine an algorithmic strategy (forcefields, attractors, heightmaps) and a digital fabrication strategy (contouring, intersection, triangulation). The aim is to introduce students to a cross-disciplinary approach where mathematics enable the digital morphogenesis, as well as the seamless transfer of information from design to fabrication.

Introduction

The paradigm shift computation has brought to architecture addresses not only design thinking and creative processes, but also the entire workflow from design to construction. During the early years of digital design in architecture, the projects remained on the computer screen, their lifespan was short, they were seen as research projects, aiming to visually test out new ideas, and in rare cases construct some prototypes. But in the last two decades, the broad use of digital fabrication technologies in architecture boosted the desire to test out things physically, while digital technologies were seen as an "enabling apparatus that directly integrates conception and production in ways that are unprecedented since the medieval times of master builders" [1]. Kolarevic further explains that the avant-garde designers of the newly introduced formal complexities, were left with no other choice than to closely engage in fabrication and construction. In this respect the actual "making" phase gains importance, not only as a sub-process of a building's lifecycle, but also as an exploratory medium, to develop new forms, new methods and new thinking processes. The integration of digital media in tectonics obviously affects different aspects of the discipline including the design process, the style, and the entire ecosystem of design knowledge.

It is evident that style and technology affect each other. Mario Carpo remarks that "all tools feed back onto the actions of their users, and digital tools are no exception [and] manufactured objects can easily reveal their software bloodline to educated observers" [2]. At the same time, contemporary aesthetics push the technological boundaries aiming at the utilization of new media, while new technological achievements in architecture, such as the integration of CAD-CAM workflows give rise to morphological innovation. The aim of the studio work presented in this paper was to introduce students to a computational way of thinking [3], [4] where art, mathematics and architecture and mutually affect the design. As Terzidis explains "Algorithmic design is a conceptual framework for the exploration of forms, structures, and processes of architectural design" [5].

Research and Teaching Workflow

During the initial phase of the studio the students experimented with algorithms and digital fabrication. The aim was to understand mathematical principles and associative modeling, while testing out ideas with a variety of materials to understand thicknesses, material resistance and assembly logics. The students worked mainly with paper models and digital 3D models. The great majority used the Grasshopper plugin for Rhinoceros CAD program, which is a graphical algorithm editor and offers a visual interface for programming, therefore it is more user friendly for students with no previous background in mathematics or computation.

The introductory course included basic vector functions, explaining the rules of associativity with examples of attractors, forcefields (Fig. 2), Voronoi diagrams (Fig. 3) fractal geometries, discretized topographic models. At the same time students were introduced to digital fabrication machinery and methods of producing 3D geometry from 2D laser cut parts. This included contour models (Fig. 1), intersection (waffle) models, triangulations, unrolling of developable surfaces among others, while there were students that experimented with origami techniques and rotations of components in space. The design brief was to produce a *Magnified Pixel* that can be inscribed in a 50x50 cm panel (Fig. 5). Each project was required to present parametric differentiation of components with at least three different parameters affecting the shape locally and globally. All projects should present an overall double curvature, which could be addressed differently with regards to construction. Therefore, unlike real pixels, three-dimensionality was a requisite for the *Magnified Pixel* project. Among the requirements was that the mathematical rules should be evident in the design, that the prototype would have an efficient construction logic and stability.

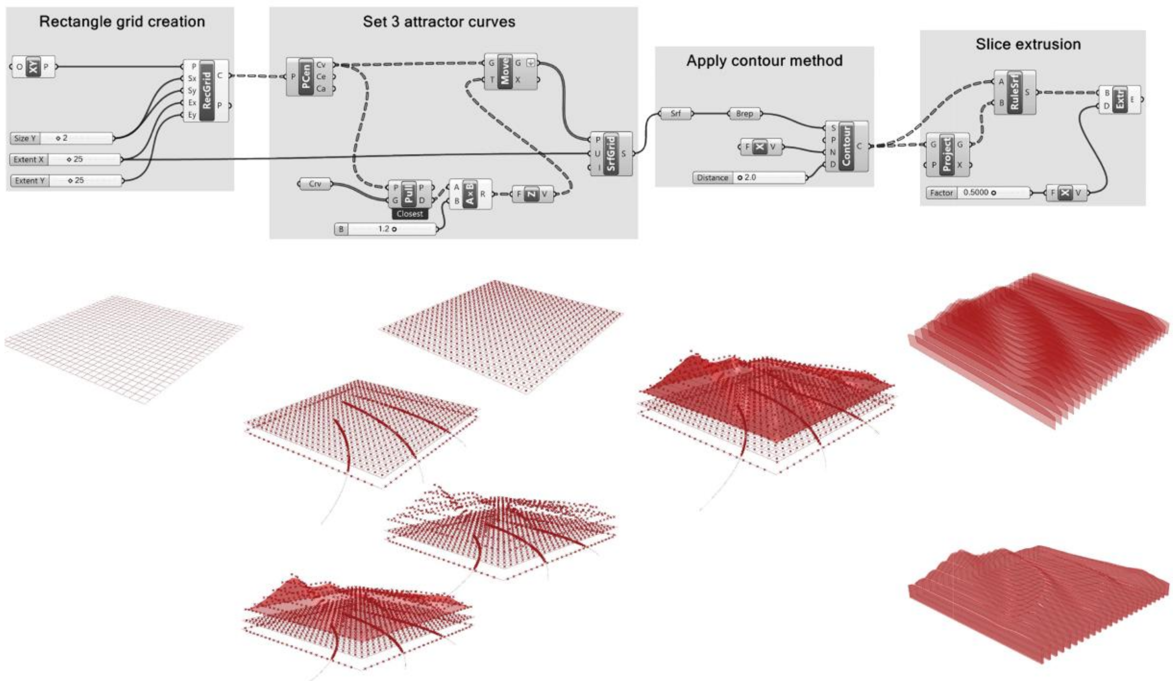

Figure 1: *The algorithmic model of the Contour panel*

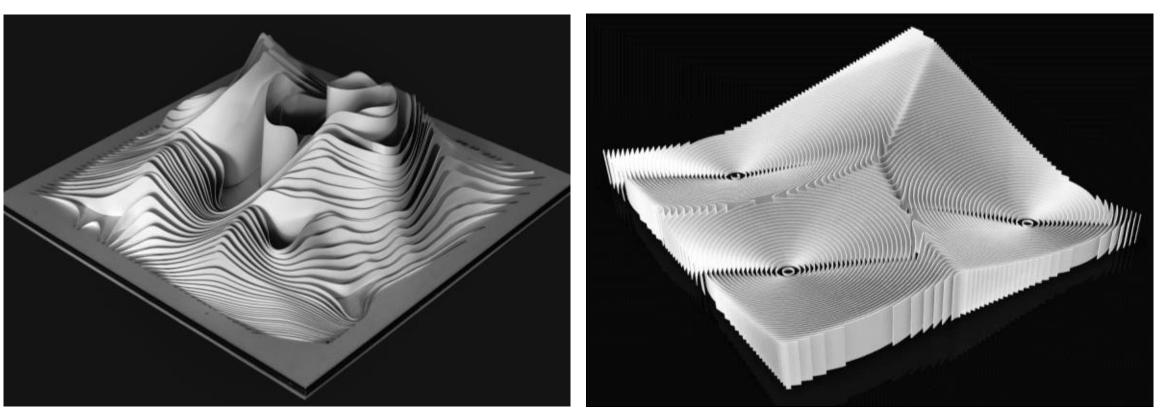

Figure 2: *The digital prototypes of the Forcefield and the Vortex panel*

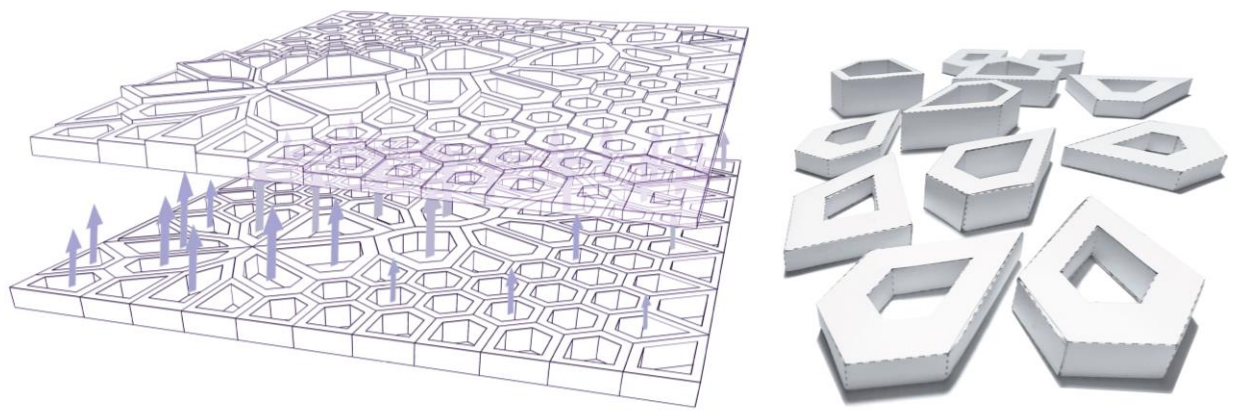

Figure 3: *The 3D model and the fabricated components of the Voronoi panel*

Complexity, Algorithms and Design

The digital explorations of the *Magnified Pixel* involved “continuous differentiation, versioning, iteration and mass customization”, concepts that Schumacher consider features of Parametricism [6]. He claims that “there is a global convergence in recent avant-garde architecture that justifies the enunciation of a new style: Parametricism”. The constant development of digital design tools and scripts has accelerated a cumulative build-up of virtuosity, resolution and refinement. He alludes to “the elegance of ordered complexity and the sense of seamless fluidity, akin to natural systems”. The hype for algorithmic design is well diffused among architecture schools, it is understood that with the use of mathematics and programming code a designer can create complex geometries using relatively small amounts of data. The algorithm for the doubly curved triangulated model (Fig. 4) contains all the necessary information for the construction. This wouldn’t have been easy to construct without an algorithmic model that embeds this information. The studio aimed to address a generalized tendency within the field of architecture. “While previously architects were obsessed with the reduction of complexity through algorithms, today they are invested in exploring complexities based on the generative power of algorithms and computation” [7].

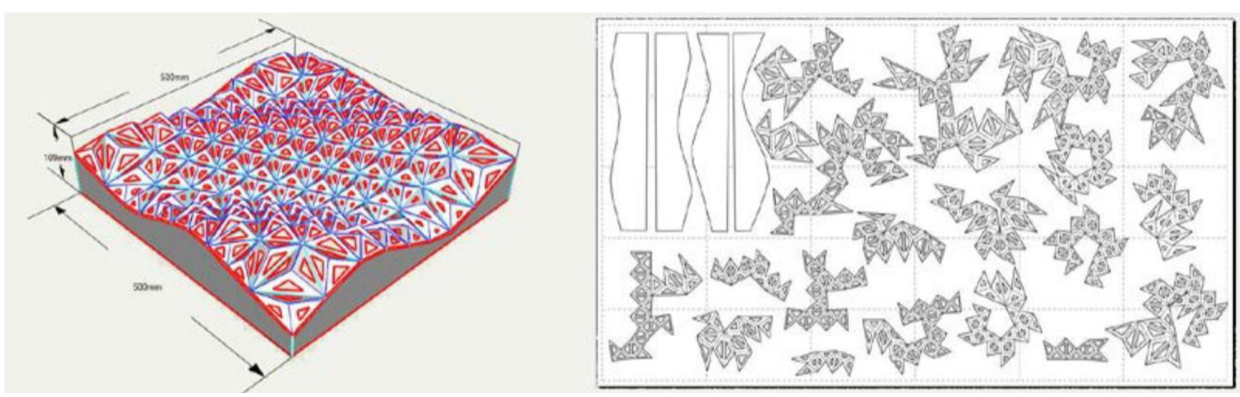

Figure 4: *The triangulated model of the doubly curved surface and the cut pattern of the 2D elements*

Summary and Conclusions

The paper presents a teaching protocol for introducing architecture students to algorithmic design and digital fabrication, based on mathematical models that parametrize forms and shapes according to different criteria. Students experimented with force fields and attractors, fractal geometries, Voronoi diagrams and other mathematically derived shapes. They understood the reciprocal relationship between mathematical rules and shapes, and the effect of each design parameter on the produced form. Furthermore, they had to consider construction logics and material economy as the panel prototype was to be digitally fabricated. While computational tools are gaining ground within the architectural community, students need to revisit the role of mathematics and algorithmic design processes, as this seems to be a very fertile domain for architectural research and innovation. The mathematical rules are evident on the student projects at a first glance. By looking the digitally fabricated topographies of the prototypes, the observer is able to identify the main parameters influencing the design, their rate of change, and geometric relationship among components. Furthermore, the necessity to create a physical prototype of the *Magnified Pixel* motivated the students to look into the construction logic and parametrize slots and flaps to enable a seamless transfer of information from the 3D file to machine code for laser cutting (G-code), adapting to changes, such as thicknesses and material types and sizes.

Despite the fact that the teaching of computational design is already present in most architecture schools, which has led to a great wealth of design projects and algorithms, there is still plenty of space for experimentation with mathematics and algorithms within the field. A hands-on approach where students fabricate prototypes is a source of tacit knowledge of mathematics, art and architecture. Computation was not only liberating formal expression in novel ways, but it has brought a new dimension to the workflow from design to production. The design challenge of the *Magnified Pixel* encouraged students to collaborate and through an experiential approach address the cross-disciplinary domain of the studio.

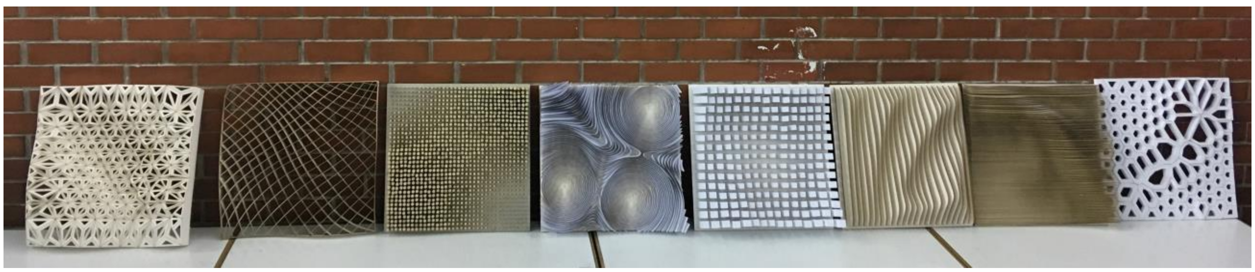

Figure 5: *The digitally fabricated models of the Magnified Pixels*

Acknowledgements

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References

[1] B. Kolarevic, *Architecture in the Digital Age: Design and Manufacturing*, Taylor & Francis, 2004.

[2] M. Carpo, *The Alphabet and the Algorithm*, Cambridge, Mass: The MIT Press, 2011.

[3] A. Menges and S. Ahlquist, *Computational Design Thinking: Computation Design Thinking*, Chichester, UK: Wiley, 2011.

[4] N. Senske, "Evaluation and Impact of a Required Computational Thinking Course for Architecture Students," in *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education*, New York, NY, USA, 2017, pp. 525–530.

[5] K. Terzidis, "Algorithmic Design: A Paradigm Shift in Architecture?," in *Architecture in the Network Society [22nd eCAADe Conference Proceedings / ISBN 0-9541183-2-4] Copenhagen (Denmark) 15-18 September 2004, pp. 201-207*, 2004.

[6] P. Schumacher, "Parametricism: A New Global Style for Architecture and Urban Design," *Architectural Design*, vol. 79, no. 4, pp. 14–23, Jul. 2009.

[7] I. M. Rocker, "When code matters," *Architectural Design*, vol. 76, no. 4, pp. 16–25, Jul. 2006.