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A *Component Assemblies* project as a case study for linking research and education

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ABSTRACT: Research into computational design tools is usually implemented as a design project. The experimental character of the computational approach involves new tools inspired by the state-of-the-art in other fields (computer science, biology, cognitive science, psychology, and so on). Such tools are tailored to particular tasks and developed directly for the project. The Component Assemblies case study project, implemented as a part of the Digital Architecture 2 course for Master's degree students shows the application, advantages and change to the education process implied by computational design and the fabrication tools. The project had two main goals. The primary goal was to use computational design methodologies in education and to guide students through the whole process from design, use and customisation of tools to fabrication. The secondary goal was to evaluate these methodologies by means of the created designs and to use this evaluation for further research.

INTRODUCTION

Computational design is arguably the most advanced branch of architectural research today. The Faculty of Architecture at Slovak University of Technology in Bratislava (FA-STU) researches in this area, and also introduces the conceptual background of computational design into its educational courses Digital Architecture 1 and Digital Architecture 2. The course, Digital Architecture 1 (DA1), introduces students to tools, basic principles and approaches to computational design. The Digital Architecture 2 course (DA2) aims to implement the knowledge base that is taught in DA1. An integral part of the educational workshops of DA1 and DA2 are lectures, which aim to introduce students to current research topics and activities related to computational design. Also, guest speakers cover a broader scope of related topics. Guest speakers might be architects, researchers, digital artists or theorists. Lectures and discussions are mostly open to the public and wider academic exchange.

The goal of the courses DA1 and DA2 is to introduce all stages of the computational design process, as follows:

- topic analysis;
- concept development;
- parametrisation of data and generating structures;
- development of custom notation system;
- fabrication documentation;
- fabrication;
- virtual reality implementation.

Students work in small groups on common topics. The component assemblies project was introduced into the DA2 course during the summer semester of 2017. The project was based on the research topics of PhD candidates Tomáš Tholt (emergent fabrication tools), Viliam Zajíček (generative and performative models in digital architecture), Roman Hajtmanek and Tatiana Vozárová (emotionality in digital architecture). In this way, students were participating in research and were introduced into the research milieu. Conceptually, the project deals with the interpretation of architectural meanings by the *language of components* and their aggregation to create proto-architectural structures.

CONCEPTUAL BACKGROUND

Architects conventionally use a range of materials, constructions, modules, colours and textures, and compose them into an architectural space or object. This range is defined and limited by contemporary fabrication technologies and the availability of materials. Together with architecture's notation system, these are the main determinants that limit and influence the process of creating architecture. It might be said, that the architect (artist, designer) creates the work in interaction with tools within limits [1].

In contemporary discourse, there are tendencies to shift the role of the architect and architect's interventions in the process of creation of the architectural form. This shift is from the well-known process of drawing and evaluating variations generated by arbitrary principles based on the author's decisions, to parametric and generative models. It is a shift from top-down methods based on often subjective decisions, to deeper implementations of generative bottom-up principles. The task of the architect changes to setting up the rules and principles defining architecture based on parameters (parametric approach); the definition of element behaviour (agents); and form is created by the simulation in time (generative approach) [2].

A generative bottom-up system where the author's role is that of a co-ordinator of a system of relations can be considered to be participatory architecture [3]. It is based on the phenomenon of collective intelligence - specific form as an emergent phenomenon. The bigger the number of contributors in the process, the higher the level of optimisation applied to the result. This principle is known as the wisdom of the crowd and is already widely used in Web design (e.g. refer to www.wikipedia.org) [4].

Structures aggregated of components without connotations of functionality, tectonics or aesthetics can form unfamiliar architectural objects and may, therefore, be subject to deeper analysis of emotionality. In the project, the user becomes the agent of the generative process of building the structure. The generative formative approach produces a design generated by computer simulation with a virtual reality (VR) interface [5].

HYPOTHESES

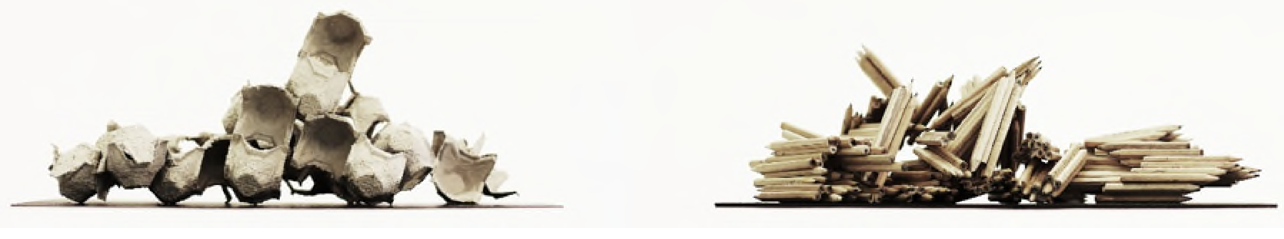
The project was based on two hypotheses in the fields of experimental education and architectural research. Computational design tools are usually developed through research by design projects and are predefined by the experimental character of the computational approach. It was assumed that the deeper engagement of students in the research process could bring a thorough understanding, higher motivation and, generally, better pedagogical results. Last, but not least, it was assumed that students could provide great creative input by designing content, while not being concerned by the research goals.

Using computer simulation in the creative process, on the one hand, and an uncommitted human agent on the other, results in different patterns in the resulting structures. This is caused by semantic associations of forms or the potential use and affordability [6]. However, it is possible to assume that forms generated by users may reflect local conditions more precisely compared to a computer simulation which uses, to a certain extent, random variables as done in the Foldit project) [7].

THE PROCESS

In the context of *traditional* architecture education, the most important and crucial aspect of teaching computational design is to introduce the process. To achieve this, the semester was scheduled in advance, with partial goals every few meetings. Students were always expected to proceed step by step and not to skip any of the milestones (students routinely following the conventional process tend to take shortcuts, omitting seemingly redundant steps).

The first part of the project was an introductory workshop, where the main methodology of formal language creation was taught. In the workshop, students used materials or objects from everyday life with the intention of creating aggregated structures. (inspired by structures of the artist Tara Donovan - see Figure 1). Neither context, nor function of the structure was assigned. This workshop in a short and simplified way described the methodology and provided the whole picture about the semestral assignment.



a) b)

Figure 1: Introductory workshop structures (a and b).

The objective of the next stage was to choose an artwork and evaluate its potential for translation (abstraction) into formal architectural language. The process of abstraction and interpretation of particular theoretical/scientific principles into design principles can be used in the development of contemporary architectural concepts and is an inherent part of the experimental architecture design approach.

Subsequently, students were introduced to the full scope of digital design, notation, fabrication and presentation tools or approaches. Limits of fabrication, material and overall setup of the system were defined, so students could work with common techniques and machines. This was necessary to provide a sustainable number of solutions and tools.

DIGITAL MODEL

The architectural concept was meant to be interpreted as a structure aggregated from a large number of one type of building element or component. The starting point of the design process was the conception of the component. Properties of the component were represented by its shape and connection points - possible mechanical connection of one component to another - in order to create complex compound structures.

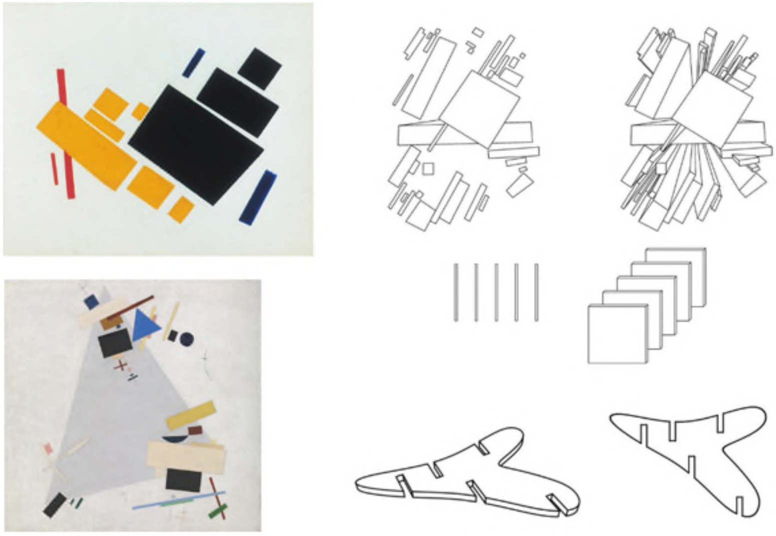


Figure 2: Artwork analysis and transition to the physical component.

The interpreted concept was then characterised by the interval between two extreme polarities. The resulting gradient was translated into the formal language of components. This process can be perceived as an investigation of the relationship between components (*words*) and the system (*grammar*) of the connections into structures (*sentences*). By increasing the complexity of spatial compositions (*stories*), it is possible to create contemporary interpretations of abstract artist concepts, such as density, chaos, distortion, scattering, etc (see Figure 2).

Showing the coherence between the element, system of connection and the complex structure in multiple variations of students' work is the conceptual core of the course. The structures could also be seen as a form of material, with components as basic units, reacting to outer or inner conditions derived from the artwork.

Figure 3: Computer-generated structure.

Created components with the system of connections were imported into a parametrised generative script prepared by the Rhino-Grasshopper software system, with additional plugins to generate compound structures [8]. In this stage, multiple attractor logics in 3D space were applied to demonstrate principles encoded in components in the resultant structures. This process ran over multiple iterations, during which not only attractors, but also formal properties of components evolved (see Figure 3).

Students evaluated the generated structures and made modifications in all steps of the project (component, parameters, connection points), to achieve optimal representations of the defined concepts. Students were using top-down decisions to influence the generative bottom-up system to generate desired structures. This human - computer collaboration is one of the principles unique to the computational approach to design. The final milestone of creating the digital model was to select one of the generated structures most representative to the initial concept (see Figure 4).

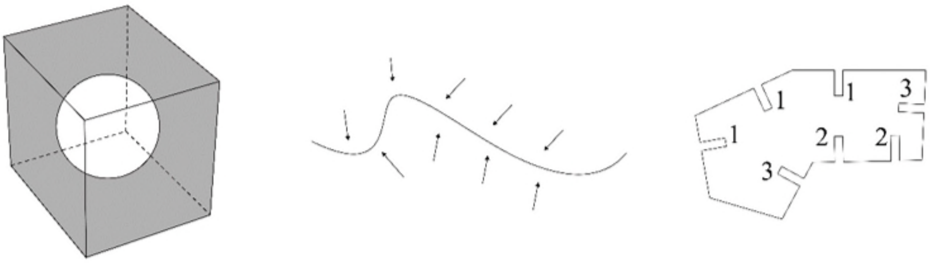


Figure 4: Attractor logics: from left to right - spatial growth limitation, object as attractor, connection point selection.

FABRICATION

One structure selected as a prototype case study of each concept was fabricated. The computer-aided manufacturing (CAM) technologies allow rapid prototyping of customised objects using various materials. The knowledge of these technologies and the skill to use them is necessary for students working with digital technology. Computational design projects usually require a custom fabrication process and notation system. Regarding this, the fabrication of models was one of the crucial parts of the semester schedule for the students. `

The fabrication technology and material was set for students in advance, so they could work within the fabrication limits during the design process. Models were aggregated from many identical component parts, laser cut from 3 mm thick, 600 mm x 400 mm MDF (medium density fibreboard) sheets. Students optimised the number of fabricated components, to get the maximal material usage of the sheets. The CAD vector files were directly used by laser cutters to cut out the components.

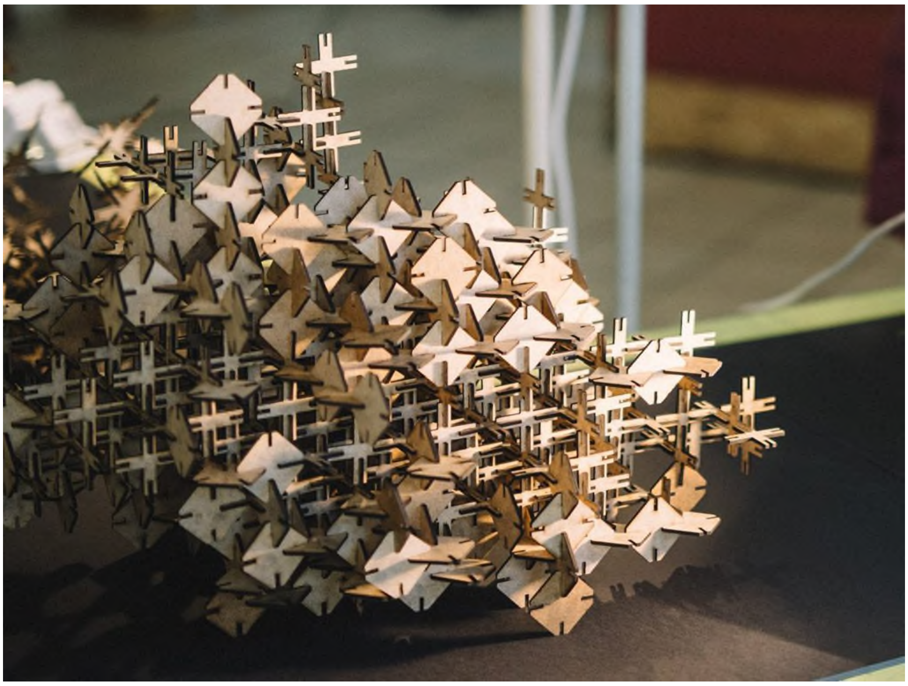


Figure 5: Fabricated structure.

The components had to be assembled to compose the structure as generated by the computer simulation. The conventional notation and documentation process (plans, sections, elevations, details, and so on) would not allow correct assembly of the structure. A suitable notation system had to relate to the generative process in which the structure was generated by adding one component after another. The order of components in the structure was recorded in the digital model.

The assembly documentation system was, therefore, a form of digital simulation, highlighting the component that should be added to the structure in each step, similar to kit-building instructions. This building documentation/simulation was prepared in the Rhino-Grasshopper interface, as well, with slight modifications corresponding to the specifics of each concept. Structures were assembled by hand following the documentation/simulation information. Students were able to precisely recreate the digitally generated structure in the form of a physical model. A fabricated structure is shown in Figure 5.

VIRTUAL REALITY INTERFACE

Components with physical connections were implemented in the VR environment to enable real-time composition - users were building the structure out of components not according to the pre-defined parametric inputs, but directly based on their own inclinations.

The VR user interface was set up to create structures with no limitations from spatial attractors. Gravity or other physical forces were neglected. Only rules of joining components were simulated. Components from different designs could not be combined. The environment enabled a visitor to move freely between different designs. All interactions of visitors were recorded, with the assignation of every user.

Final presentations have taken place during a semestral exposition, where visitors could view posters showing the conceptual framework and fabricated structures, as well as to try to build structures in the VR space (see example in Figure 6).

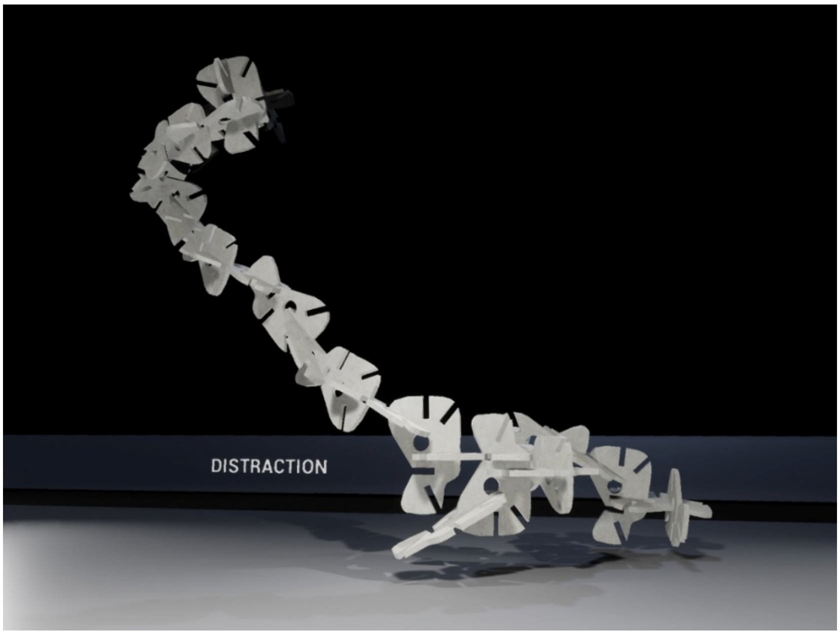


Figure 6: Structure built in the virtual reality interface.

CONCLUSIONS

Computational design comes with its own methodology, being closer to research in other fields. It involves experimenting with new tools, forms, materials, compositions and aesthetics. In conventional architecture education, the greatest challenge from a pedagogical point of view is the introduction of new methodologies and ways of thinking.

Computational design is being taught as the implementation of a methodology that involves analysis, concept creation and tool fabrication. The cross-connection between education and research was, therefore, helpful for the comprehension of the methodology. The introductory workshop provided an appreciation of the overall process. Though it was implemented as an analogue method of exploration of the properties of a simple object, the process was very close to the actual computational logic of aggregation. This introduction aided the comprehension of further steps during the main part of the Component Assemblies project.

Students were equipped with tools prepared for research purposes, i.e. generative script simulating the growth of the structure and the VR interface for building the structure. These tools were explained in theory and by example. Students, therefore, were able to adjust them for purposes specific to their architectural concepts. This approach allowed students to experiment with more sophisticated tools that they would be able to develop in such a short time. As well, it provided PhD candidates with valuable content, variations and new insights on the process.

Students were encouraged to work in groups in a collaborative way. This kind of environment, with similarities to the open-source software movement, leads to faster progress and a better exchange of knowledge and skills. This is true not only between teachers and students but, more importantly, between students themselves. This kind of supervised self-education (students bringing up topics and investigating them with the support of teachers) showed great advantages in garnering students' interests and led to a deeper engagement of students with the whole project.

The assumption of observable differences between structures generated by computer simulation and by users was confirmed. Authors consider digitally generated aggregated structures more as material and the transformations as the changes to the material, based on the defined environment. Changes in structures are fluid, which helps in understanding the structure as a topological whole and supports a semantic articulation of the space [9].

On the other hand, in using the VR interface, users were creating heterogenous spaces, influenced by associations discovered while playing with components and the possibilities for aggregation. Forms were differentiated and recognisable (towers, arcs, etc).

The most significant factor influencing the resulting structure in both cases (generated structure and built-in the VR interface) was scale. Students were thinking of a component in a scale of, for example, a pavilion, while the understanding of the generated structure was influenced by the perception of the structure as whole. On the other hand, the apparent scale in VR is much more obvious [6].

Participative generative modelling in VR was a suitable analytical method for the verification of the elements' functionality, and relations between them and to the user. In complex generative modelling, it is possible to recognise the advantages of the bottom-up approach, allowing more precise simulation of the structure.

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