Teaching Design Sensitivity

Stefan RUTZINGER*; Kristina SCHINEGGER, Rupert MALECZEK, Jens-Ole KLINGEMANN

University of Innsbruck, Faculty of Architecture, Structure and Design
Technikerstrasse 21c, 6020 Innsbruck
Stefan.Rutzinger@uibk.ac.at

Abstract

In a post-digital era, students have a preexisting understanding of digital tools and methods when starting their architectural education. At the same time increasing computational capacities enlarge the potentials of modelling and simulation software and the sizes of solution spaces. Consequently, the focus in teaching digital design strategies shifts to a more reflective and integrated approach. The authors discuss two experimental vertical prototypes developed with first year students in research-led design courses. The courses' briefs aimed at enabling an immediate feedback through material-based design processes. Students are trained in how to articulate individual design criteria and make them productive within digital set ups, develop and navigate a design solution space and gain design-sensitive control of structural processes. Consequently, they become aware of the reciprocal relations between deign intentions, digital set ups, structure, material performance and constraints of fabrication.

Introduction

Although students nowadays have a previous knowledge in digital tools, they often lack a basic understanding of design. This is due to our education system that still maintains the dichotomy of science and art: education in the sciences operates and communicates in numbers and, on the other hand education in arts and humanities is based on language and expression. According to Nigel Cross, designers are acting in a "third culture" and have fundamentally different problem-solving strategies than other fields. Instead of applying generalized rules and methods, they follow an experimental approach based on trial and error strategies. While experimenting they simultaneously explore the problem until they have found an "acceptable" solution. Rather than being analytic they learn through synthesis. Since design problems are often "ill-defined" and lacking information, the designer adds to the problem and actively interferes with his object of investigation. Generally speaking, designer operate through abstract patterns in relation to a given task and stepwise turn them into an applied pattern. Although the methods and strategies vary according to the different objectives and intentions, an underlying "deep structure" or a "designerly way of thinking" which is inherent to all design professions can be observed [1]. Nowadays, through the availability of digital modelling and fabrication tools, designing objects turned from a specialist's towards a common ability. [2] It can be assumed that this development might turn design into a "basic" competence and that a general design education will gain in relevance.

Design skills depend to a large extent on experience and hands-on experimentation. Design processes based on material systems allow students to receive immediate feedback and gain an understanding of the reciprocal relation of form, materiality, experiential qualities and structural performance. They enhance design experience and sensibility while quality and consistency of the design output is enhanced.

What has been broadly discussed in the past years as Material Systems or Generative Material and Design [3], has already been investigated at the German Bauhaus. In the foundation courses co-taught by Josef Albers and László Moholy-Nagyin the 1920ies students explored the complex relations between material properties, geometric constraints and aesthetic and experiential qualities. The creative but at the same time analytic approach of using material behavior as a driving force within form finding resulted in a multitude of spatial structures and new ways of resource efficient fabrication techniques [4].

The two discussed design courses adopt the Bauhaus approach by deploying material and geometry systems in an intuitive method. The aim is to achieve complex structures through self-regulated assembly processes, as well as establish a bottom-up approach in creating a design solution space. Design knowledge is not only tied to the designer itself, but also encapsulated in the designed objects. Therefore, it is of great value to capture various attempts and design studies to a specific design task in order to revisit them throughout the process. Iterative studies and the generation of variance – even in ascending scales or focusing on special problems – are fruitful since the encapsulated design knowledge can be read, extracted and transferred to future design problems.

1. Teaching Method

Fig.1 Digital Studies for paper strip models.

In order to define and narrow down the problem-space certain limitations are made: Both courses develop component based vertical structures, in the first example from flat paper strips in the latter from irregular wooden triangles. Both prototypes are constructed in a self-regulated assembly process. The introduction of the material system and the geometry system is a key factor since design freedom and individual expression have to be balanced with a required level of pre-determination within the system. In the case of the Bifurcation Tower the geometry system is loosely defined through the use of the plug-in Ivy [5] which enables sufficient variety in the development of the components, while the material system (600g paper) is fixed in order to meet the project budget. In case of the Reticular Tower, the triangular components are pre-defined (15mm OSP panels).

The individual participants of the course are given the same amount of material (identical set of triangles, counted sheets of paper) in order to retrieve comparable results which are discussed in regard to aesthetics, structural complexity, material efficiency, height of tower and other criteria.
Initially students create a broad pool of individual solutions and ideas to the given task (e.g. create a vertical structure with triangles). The relation between used design principles, processes and aesthetic and structural output is explored and articulated by students and tutors during pin-ups and reviews in order to formulate further design investigation tasks for student groups. Stepwise a design solution space is created from the pool of structures and their observed potentials. Design parameters and fitness criteria such as material consumption, tower height, count of components (production time) are established, tested and refined.
A main focus of the studios lies on how to guide the simultaneous development and refinement of design intents, digital process and physical prototypes, as well as enabling feedback between physical and digital models. A special focus lies on soft and rigid constraints that are necessary for the self-regulated assembly process.

The teaching is divided into several sections:

(1) Theoretical introduction and practical seminars in CAD and parametric modeling using Rhino and Grasshopper (including various Plug-ins) with the aim to adjust and adapt predefined

“definitions” in order to individualize the output. Introduction to workshop and basic digital fabrication machines (e.g. laser cut, CNC-cutter, printers, etc.).

(2) The first design task involves control of shape (geometry) as well as size and resolution in order to fabricate a physical model (laser cutting of sheet material). Evaluation of the physical models by various criteria such as ambition, originality, complexity, structural stability and efficiency. Revising the design due to the evaluation. Increasing the scale and model size (stepwise until M 1:1); eventually adapting material and model building techniques to establish a working material system.

(3) Development of a connection strategy in the parametric environment (abstract; involving experience from step 2) as well as in physical models (real joints); exploring various techniques in respect to different materials and fabrication methods in full scale – selection due to reasoning and physical feedback; improvement of the material system.

(4) Testing various design versions against fabrication constrains (material consumption) and on efficiency (e.g. time consumption due to fabrication method).

(5) Planning of the digital fabrication line (preparation of digital information to be fabricated, setting up the fabrication line and handling of material, postproduction, sorting and storage); planning of the foundation and implementation on site (including safe and sanity requirements); planning of disassembly and disposal.

Fig.2 Bifurcation Tower (left) and the Reticular Tower (right)

2. Bifurcation Tower

The tower consists of a component based material system, namely paper strips. Latest since the Bauhaus [6], paper is implemented in the design education, as it has many interesting aspects. On behalf of this material that cannot stretch or tear, students can make important experiences. It can be cut or manipulated in flat state and brought to a three-dimensional load bearing state through folding or bending. The relation of curvature and stability can be investigated in a very direct and haptic way.

For this project, the individual paper strips were developed on a triangulated mesh [7] as shown already by Fornes [8]. In contrast to Fornes’ strategy of linear strips, where the mesh resolution in combination with bending plays a major role in the smoothness of the object, the authors used bending only to generate a smooth object, from a roughly triangulated mesh. Both approaches generate a self-explained assembly process, that replaces measurement by digitally defined and fabricated assembly points.

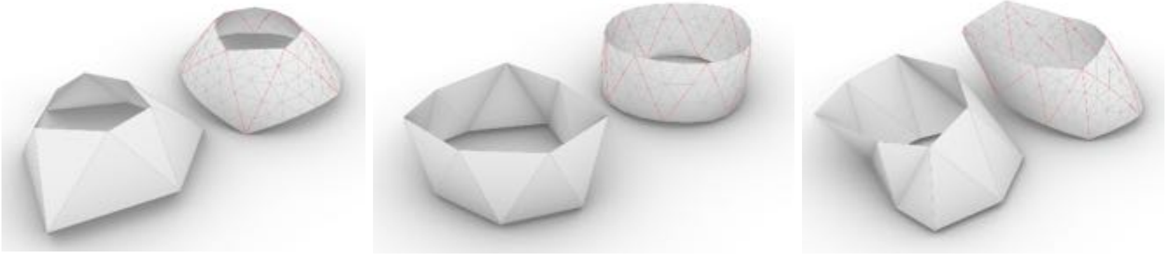

Fig.3 simulation of a bend rough mesh

The bending of the strips generates surfaces with single curvature. Each strip is bent by the connection to its neighboring stripes. As shown in figure 3, each stripe deforms based on this boundary condition. As the exact final state deviates from its original state, not only on the surface but also at the boundary edges, two neighboring strips will only have random identical connected edges. To solve this issue, the authors used a pointwise connection with a constant distance between the adjacent open strip edges. This solution allows a free deformation of the edges in space, preventing touching or intersecting neighboring edges.

The manipulation of the strips, as e.g. the shrinking or the connection generation, was done in developed flat state. Manipulating in flat state with knowledge of constrains in three-dimensional state has also been shown by Chandra et al. [9]. This strategy allows for a fast generation of fabrication files for a smooth object, but makes a prior visualization and control of the final state an additional work step, that is often over jumped. As the bifurcation tower is an individual free standing object with no further connections that would require this visualization or geometric control, the authors decided to trust the strategy for educational and time schedule reasons.

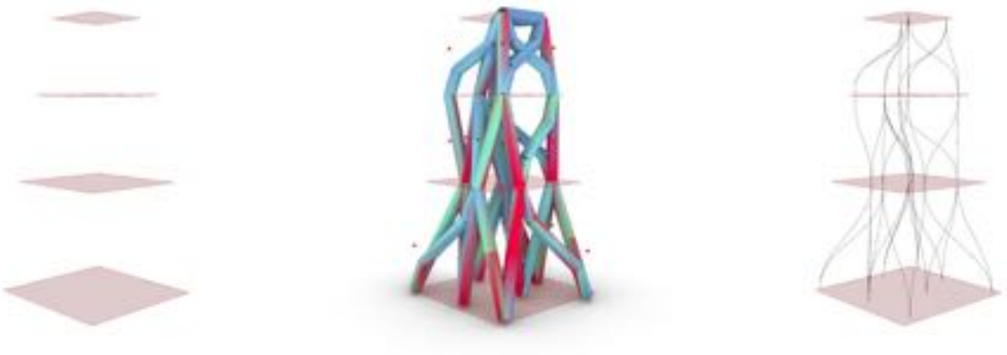

Fig.4 the generation and evaluation setup with the resulting line geometry

In order to understand and learn the material systems constraints, the students were asked in a first step to generate multiple mesh-based geometries in Rhino [10]/Grasshopper [11]. Mainly a physical simulation named Kangaroo [12] was used by the students as it provides a simple setup and fast results. With this digital geometries, the first studies for the material system in paper were made. These results led to the above described component based material system.

For educational reasons, the tower geometry was developed in multiple consecutive and partly simultaneous steps that were arranged in a cyclic feedback loop. In a first step a parametric solution space for the tower was established in form of a bounding box of 4*4*6 meters. Within this solution space, the students task was to define a self-supporting structure, that consists of a reticular smoothly piped line system.

Fig.5 The piping process of the reticular line network and the re-meshed version of the tower

Therefore, a digital setup was generated that consists of two main parts. A set of parameters which can be changed and influenced by the user in order to generate a geometry, and an evolutionary solver, namely Galapagos [13] that optimizes the structure's parameter set on defined fitness criteria. As shown in figure 4, the line network is generated from several sets of points. Their number and relative position in height can be regulated by the user. The exact position is optimized through Galapagos with the structural performance as fitness property. Using Galapagos allows the students to see that a set of variations can be generated and evaluated in a very short amount of time.

In a consecutive step, as shown in figure 5, the line network is transformed in a pipe-like structure with the line as center for different radii. This geometry is re-meshed with a given minimum of edge lengths with a tool named MeshMashine [12]. This mesh was then divided in developable strips with the help of the tool Ivy. In a final step the unrolled strips were manipulated to have a small offset and flaps for the assembly. The assembly itself was done with synthetic press buttons. As described above, the inner edges of the strips were deleted, in order to bent the strips instead of fold them. As the strips build closed loops no additional boundary constraint is necessary for the entire structure. The entire structure was then cut on a flatbed cutter from 600g paper that was white on one side and pink on the other. This two-color scheme generated in combination with the distance of the strips, a spatial color effect. The fabrication and assembly was done in less than two weeks by 25 students and presented at the 1st years exhibition in the faculty hall.

Fig.6 the final tower (right) and the color bleeding detail of the construction

1. Reticular Tower

The course focuses on developing a bottom-up design approach based on the capabilities of a component based material system. The final prototype is constructed from wooden plates and metal joints, for initial physical studies cardboard is used. In order to develop a variety in bottom up design strategies students individually aggregate vertical structures out of a similar set of cardboard triangles. The only instruction is to apply a consistent logic ("manual algorithm") while constructing the structure and fulfill two requirements: it should be as high as possible and have distinct aesthetic properties. Students articulate the used composition logics (the underlying manual algorithm) and precisely describe the intended structural and aesthetic abilities. The variance of outcomes creates the base for a design solution space to be developed and allow students to formulate aggregation logics and design questions for the next iterations, see figure 7.

Fig.7 physical studies: different studies generated from the same set of cardboard triangles

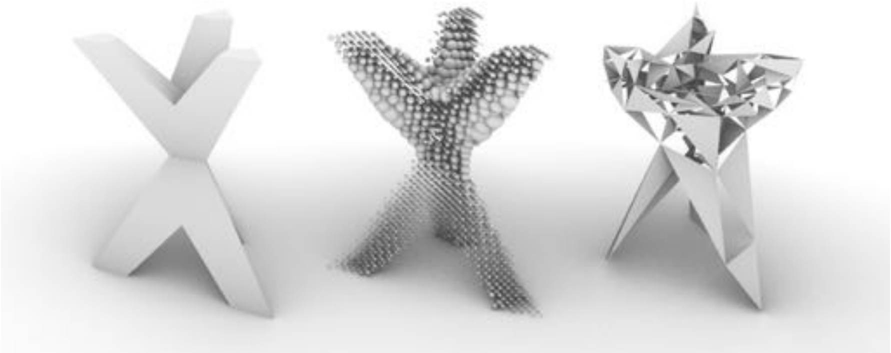

Fig.8 digital set up: study of a density point-cloud from a given geometry

Geometry and topology of point-clouds

In parallel to physical studies, students experiment within digital setup based on point clouds that allows the manipulation of a hull geometry in order to discover possible triangle formations and develop a matrix of approaches. The digital design setup is implemented in Rhino [10]/Grasshopper [11] in order to allow modification of the geometry and the density distribution of random generated point-clouds, see figure 8.

Using the Delaunay triangulation as an alternative interpretation of a Voronoi structure, a network of connecting lines between the points of neighboring Voronoi cells is generated from these point-clouds. A customized algorithm is developed which interprets the line network as triangular faces. Triangles are connected via their vertices only, face connections via edges are not possible. This results in a decreased number of triangles and connections, yet the self-stiffening capacities of the system have to be enhanced. and optimizing by adjusting the initial parameters and observing the stability of knots. The resulting structure is a self-stiffening three-dimensional aggregation of irregular triangles.

Construction detail and development of multidirectional joints

A classical joint problem occurs as too many members of the structure are to be connected in one point. In regular space frame structures this has been solved e.g. with the Mero ball node. A strategy for jointing several irregular triangles together in one point is therefore developed which then also coins the aesthetic appearance of the final design, see figure 9.

Connecting metal stripes are positioned off the center axis of the node to generate more space for multiple connections. Due to this eccentric transmission of forces the force-flow in the triangular panels is distorted. As result a reticular line network is generated which visually and structurally ties all panels of the structure together. The emerging pattern not only represents the distribution of loads and forces but also defines the positions of all metal strip joints. Each strip comprises two bends with individual angles and every joint and strip is different. Here the relation of the triangle side's length to the offset of the stripes from the triangle corners is crucial for the resulting bending angles and failure of overlapping stripes. For this purpose, a custom script is implemented in Grasshopper in order to explore the solution-space for local joints.

Computational design of the final tower

Based on a strategic distribution of individual triangles (e.g. larger parts at the bottom, smaller at the top) a computational process is set up in order to generate a structurally sound tower design. The initial setup is optimized for multiple fitness criteria like height to mass ratio or stress distribution with the use of genetic algorithms by the Grasshopper plugin Galapagos [14]. Thus, the overall hull arises together with a high-resolution point cloud, which is further evaluated for structural loads and deflection to generate the final connecting lines together with a random-walk algorithm starting from there ends, see figure 8.

Students use this digital tool in the skilling modules to study the possible emerging designs and to evaluate them recursively with the use of the Grasshopper Plugins Millipede [15] and Karamba [16]. Out of these design solutions, a final tower structure of five meter height is selected for fabrication.

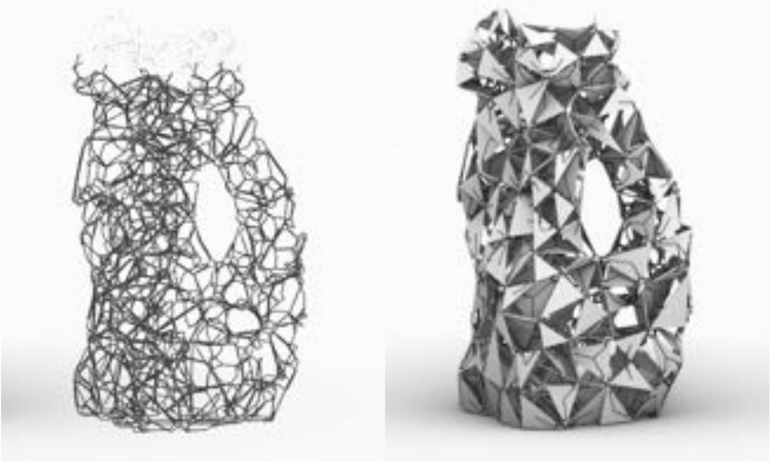

Fig.9 generation of the final design: evolving reticular topology (left), triangulation and joints (right)

Digital fabrication and deployment

Finally, a fabrication module for all the wooden plates and joints with metal stripes is implemented seamlessly into the digital tool. Over 1000 metal stripes are cut, drilled and bent in three dimensions. For the wooden OSB-panels a robot is used to mark the components on both sides and 400 triangles are produced with all markers and graphical lines in one step, see figure 10. Then clusters of triangles are pre-assembled with bolts in parallel and assembled on-site in two days for the exhibition in the faculty hall, see figure 11.

Fig.10 a part of the final fabrication file (left) and robotic fabrication of the wooden triangles (right)

Fig.11 the final tower and a detail of the joints with generated pattern

3. Conclusion

Conducting design iterations is becoming a faster and more effective process, still in order to navigate an extended solution space, a designer has to clearly articulate his intentions and be able to implement them purposefully in a digital set-up in order to prevent a pure trail-and-error workflow. In order to conduct design decisions a designer has to be trained in negotiating various design objectives within complex design processes and finding the “acceptable” solution. In the first year courses at i.sd_structure and design at University of Innsbruck we are aiming at educating students in designerly ways of thinking, and this is – in our understanding – open-ended: designing means to evolve a solution space and explore the potentials of a design intent rather than finding a solution that confirms it. Both design courses establish a material-based design strategy which defines certain aspects and constraints yet provides creative freedom for design intentions to develop. The main goal is to evolve a design system (based on components that allow self-regulated assembly) and explore its potentials, thereby the system can be altered and modified during the process. In both courses the co-evolution of design system, digital set-up and practical fabrication solutions is highlighted. Although material and geometry systems are different, the courses share the educational framework, a learning by synthesis through feedback between physical and digital experimentation, design exploration and evaluation, aesthetic intentions and practicability.

In bottom-up design approaches generating a great variety of ideas and possible outcomes is essential. In order to purposefully navigate them, a comprehensive understanding of the complex relations of the various domains in architectural design has to be developed. To experience the whole process – from designing to fabrication as cyclic rather than linear – helps to understand the relations and interdependencies, but also allows out-of-the-box thinking and cross-breeding of creative and practical ideas.

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