DIDACTICAL INTEGRATION OF ANALOG AND DIGITAL TOOLS INTO ARCHITECTURAL EDUCATION

From the geometric sketch to the rapid prototyping manufactured artifact

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Abstract. This paper describes the new syllabus of the course “Methods of representation” that has evolved in the first year of architectural study at our university. Due to the rapidly growing digital possibilities students need to know/learn the new topics and tools which are relevant in modern architectural design practice. Our students should be empowered rather than overwhelmed by the arsenal of digital tools available today. In this course we try to define the essential skills in representation which we achieve through the synthesis of digital and analog methods and tools. Digital and analog methods and tools we use are: study and construction of complex geometry, observation and analysis of organic forms and their representation through hand drawing, collaborative work through peer-to-peer learning on our web interface, NURBS-modelling, rapid prototyping and desktop publishing.

1. Introduction
Architects are constantly searching for new tools – digital inspiration – in other disciplines and manufacturing processes and they are seeking for a combination of analog and digital tools in order to define an aesthetic which can reflect the new phenomena in architectural computing. Due to these rapidly growing digital possibilities, students of architecture need to know/learn the new topics and tools which are relevant in modern architectural design practice. They should be empowered rather than overwhelmed by the arsenal of digital tools available today.
2. Design education

Modern architectural design education has to teach students how to apply the knowledge and skills of digital techniques and methods using digital and analogue tools by emphasizing the understanding and research of specific characteristics of different media. Digital tools modified the approach to the design process and today they are an undeniable part of design. The new technology provides the designer a way to control and integrate all steps of the design process starting from the sketch on a digital table to the virtual 3D product and finally to the physical model. This is called integrated 3D design process chain and the direct link between CAD and CAM is known as integrated technology. The new possibilities create pros and cons. On the one hand the designer manages the whole process by himself. On the other hand it is necessary to know how to handle with all the used techniques.

For the first steps of designing one still uses two dimensional representation tools (paper or digital tables for sketches and screens for the 3D models) to externalize and represent the "three dimensional ideas in mind". From our experience there is a great lack of knowledge in the area of spatial thinking and visualising and transferring this knowledge onto a “technical medium” Piegl (2005). Therefore we put a main focus on the improvement and training on this by using a funded geometric education to develop the spatial and visual reasoning.

Because of the importance of the above mentioned in the “new architecture practice” we implemented the following in the curriculum “Methods of representation” already in the first year of architectural study.

In a first stage students are instructed in funded geometric knowledge and trained in developing spatial and visual thinking. In a second (progressive) stage integrated design process and integrated technology is taught. Our course covers a wide range from handmade sketches to rapid prototyping produced products.

From our point of view this is a new approach to the understanding of CAAD teaching because in combination with funded geometric instructions we teach integrate both analogue and digital techniques.

3. Representation

In the past three decades a great number of publications have described, explored and summarized a relationship between representation and design process. Representation and design can be examined by categorizing them from a number of perspectives. For our research, two approaches are relevant: external representation in visual reasoning and representation as a tool for design visualization. We choose these approaches because architects are constantly confronted with spatial shapes and structures, with internal
and external representation and with the communication of this matter. The link between visualizing an idea in mind and its externalized transfer in order to be aware of oneself and to communicate with others is a very complicate subject-matter. This must be trained from the very beginning of architectural education. The visual representation on a two dimensional medium and the converse way of understanding a sketch or drawing and their transformation into a spatial form in mind are the crucial points thereby.

3.1. EXTERNAL REPRESENTATION OF VISUAL REASONING

From a psychological point of view, our design thinking operates through externalized representation in visual reasoning (Oxman 2002). Visual reasoning and visual cognition may be considered as a keystone of design emergence. Visual cognitive richness is related to perceptual components. Perceptual components, according to Marr (1982) are shapes, which in design have a function of representation of the physical object. The characterization of these shapes is mainly based on their geometrical properties and relation between a geometrically derived secondary-form to its primary shape (Liu 1995). The ability to represent these shapes, their interpretation and reinterpretation is a central point of creativity. Thus, in a design process also shape ambiguity makes a creative process possible. Ambiguity may enable new interpretation of existing shapes and gives new meaning to the design process (Figure 1).

![Figure 1. New configurations of the same shapes enable various interpretations](image)

For our methodological approach in our second stage of teaching, the theoretical foundation can be found in Eizenberg’s, analysis→transformation→synthesis method (Knight 1999). With the
appropiate geometric grammar, free computational forms based on NURBS technology we established a process for generating organic forms. Through shape generation by basic geometry we refer to the design process as a non-accidental phenomenon. We agree with Oxman (2002) who proposes that basic knowledge guides design. Therefore we say that knowledge of geometry and its grammar guides the students to transformational emergence.

Students start with an analysis of organic forms, as a representation of an abstract architecture and form. A second part is the extraction of rules by emphasizing the understanding of geometry, and then playing with these rules and eventually formulate own rules for design that satisfy a given program.

3.2. REPRESENTATION AS A TOOL FOR DESIGN VISUALISATION

The choice of a representational medium as a tool for design visualisation has a huge impact on the character of the design results. The long tradition of Euclidean geometry and a traditional medium for representation (paper) led to the consequence that architects “drew what they could build, and built what they could draw” (Mitchell 2001). New digital tools have opened new tracts and possibilities of representation of non-Euclidean geometries. Today the question is no longer whether a particular form is buildable or not, but rather the deduction of new instruments of practice (Kolarevic 2003). The development of tools is dependent on design theories and vice versa. The protagonist of the radical conceptual and formal architectural research from the early 1980 is Zaha Hadid, who found in new media a helpful tool which was already established as an architectural language. For many designers in the second half of 1990ies new digital tools inspired the conceptualization of new digital esthetic and a new terminology was adopted like hyper surface design, blob architecture, parametric architecture, hyper body etc (Oxman 2006). Therefore the medium of representation defines and limits the design process and enables or disables the continuum from design process to production.

Today’s digital representation media enable us to represent a wide range of complex geometric forms with constructing complexity (Mitchell 2005) like organic forms.

4. Didactical Methods

“A creative person is one who can process in new ways the information directly at hand - ordinarily sensory data available to all of us. A writer needs words, a musician needs notes, an artist needs visual perception, and all need some knowledge of the techniques of their crafts. But a creative
individual intuitively sees possibilities for transforming ordinary data into a new creation, transcendent over the mere raw materials.” (Edwards 1989)

We propose to redefine didactic methods to teach the use of new digital tools at an early stage of design education. Geometry is the core of most digital designing tools, a basis for understanding and performing handmade (analog) representations of design ideas, processes and structures. A number of enquiries worldwide (Saito 1998, Leopold 2001) proved direct connection between the study of the subject matter of space geometry and the improvement of visual spatial intelligence (Gittler 1998) as one of the most important abilities for an engineer. Hence it was obvious to us to build up the training of analog and digital tools as well as the introduction of design processes on a geometric framework.

Austria has a long tradition and great experience in teaching geometry in high school and university. Students are both instructed in hand made geometry which means space geometry constructed by pencil, ruler and compasses and in using CAGeometricD tools. CAGD-tools have been used for over than fifteen years. Not all the students choose the “geometric way” in high school. Consequently universities get experienced and unexperienced students in geometry. At a first stage we try to equate the gap of geometric knowledge with additional courses obligatory for the non experienced ones.

We take this great “educational advantage” as a base for further instructions of geometry at university. We build up a solid base in geometry with the help of the following tools: geometric freehand sketches; constructive space geometry; and, 3D-CAD-Packages.

In this phase students learn to carry out many topics from simple freehand sketches up to the modelling of complex 3D-structures derived from platonic shapes (see section Geometry). We engage the students to constantly evaluate the tools used in the course. They should identify the pros and cons as well as the grammar of these tools and how they can be used properly (Mark 2002). During this phase we conduct ex-cathedra teaching and no creative input from the students is expected. Students have to learn fundamentals first in order to develop their own ideas later on. The students reported that just the combination of analog and digital tools enables them to get a deeper insight. The result of a survey among 150 students shows that 75 % think that 3D-modelling on the computer leads to better understanding of 2D-representations of 3-dimensional objects but at the same time 80 % consider that hand made construction of geometry plays an equal important role.

The second phase is dedicated to the design process. On the basis of the geometric principles of the first phase the students should now be prepared to develop and present their own ideas and first digital products and finally build them using traditional output and rapid prototyping machines.
Now geometry plays again a significant role. The design process is now supported by geometric thinking, analyzing and problem solving which was trained before. Whatever strategy the students choose, it is independent of the tools involved if the process is set up on geometric principles.

Because of the complexity of architecture design we select issues which have the same characteristic as architecture design but in a more appropriate scale. We take organic forms like flowers, fruits, bones etc. and their structure to represent architecture. 3D modelling of organic forms enhances the students’ capability of developing free form design almost without limitation of functional characteristics. The didactical set up is funded by Eizenberf’s method (see Section 3.1). Students start with observation, analysis and sketches of organic forms followed by the modelling of individual chosen forms in a 3D-CAD-Program. After that they create their own hybrid forms by taking (downloading) design parts from colleagues’ work (Figure 2).

5. Geometry

In the first phase the students receive instructions in sketching and constructing axonometric and perspective views of 3D geometries. Additionally shadow constructions and reconstruction of perspective views are used to demonstrate the connection between a space configuration and its two dimensional representation (Figure 3).
Besides this we apply 3D-CAD-software to train solid modelling with standard primitives like boxes, spheres, cylinders and objects created by extrusion (Figure 4).

![Solid Modelling with standard primitives and “platonic” shapes](image)

*Figure 4. Solid Modelling with standard primitives and “platonic” shapes*

In the second phase (the design part) we use again sketching as a natural human tool to communicate first design ideas and as a companion for the whole process.

For the generation of organic forms we consider freeform surfaces – Bezier- and NURBS technology – as an appropriate geometric and digital tool. Students get instructions in the theory of freeform surfaces, which means generation, algorithms (e.g. Casteljau-algorithm), data structures, C1- and C2- continuity, blending, etc.

6. **Output – Rapid Prototyping**

Since students today are „Naturally born computer users“ (Pongratz and Perbellini 2000) we fully agree with Kvan (2004) and teach students a deeper understanding of the use of digital media right from the beginning of their career and not just before they graduate in advanced classes.

We do not consider digital tools as extensions to manual skills or digital design teaching as service role but rather as a holistic integration of computational design methods into architectural design culture.

It has become unquestionable to integrate Rapid Prototyping technology besides the more traditional output machines into the curriculum which we started three years ago with two CO2 Laser Cutters followed by an ABS plastic 3d printer and a CNC milling machine. After three years of employment of these machines within the digital design education we identified very clearly: Rapid Prototyping Technology, more precisely 3D-printers can be used to enhance the involvement into the architectural design process and motivate students tremendously through fully integrated 3d-
process chains (Schodek 2005) where students are enabled to review their work constantly with a physical model (cause-impact). Additionally students are engaged to use the machines independently in an experimental way (Figure 5).

![Printed ABS-models](image)

**Figure 5. Printed ABS-models**

Unfortunately production time and cost does not allow using RP to educate a large number of students (the course „Methods of representation“ is taken by more than 180 first year students every year).

But we assume that like other technologies (for an A3 laser printer you had to pay the price of luxury car) rapid prototyping will become more affordable and faster very soon. Then a larger number of students will be able to make expedient use of RP-machines in their architectural education.

**7. Collaboration – Single Work**

In our courses we established a database founded website at http://iam.tugraz.at/dm0/s06 which is both a presentation and communication tool. Every step of student’s work is saved and documented by upload. Evaluation of students work can be executed by the teachers and the students themselves can compare and exchange their work with each other. But above all this web based system is a tool for creative and collaborative work where users have the possibility to learn from each other and it serves as a forum for exchanging experience, to keep track and discuss architectural design teaching.
8. Evaluation

The course “Methods of representation” is evaluated every year by TUGonline - a information management system at the University of Technology in Graz (Austria). The outcome of the last two years shows that students are very satisfied with the course especially with the diversified content, various interesting examples, the tutorials, the organization of the course and the regular updated web site.

9. Conclusion and Outlook

New media has changed the way how we design today. This radical change has to be reflected in design education as well. However we consider analog tools as an essential complement to digital media. This paper shows how we merge both the digital and the analog within the curriculum of our teachings and research. Equipped with this knowledge we can face the challenge of identifying the core in an overwhelming pool of information. Solely if we understand the principles of geometry, the language of shapes, we can capitalize on the full potency of digital media.

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References


