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Research based teaching as a model for developing complex pre-cast concrete structures

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Abstract: *This paper describes the potentials of utilising research-based teaching as a method for developing advanced concrete structures in an architectural context. A novel technique for casting concrete elements in PETG plastic is described as a body of research that formed the basis of a case in which master students assisted in the development and realisation of an amorphous, catenary grid-shell. Development in many areas simultaneously was essential for the success of the case studies, which made them suitable for a research-based teaching setup, where didactic considerations on a general and specific level were important: On a general level, three didactic tools were used: the first being the presentation of knowledge generation as something that happens between researcher and student. The second involved presenting students with a narrow focus before presenting a wide one, and the third: viewing the teaching studio as an interdisciplinary laboratory. On a specific level, didactic considerations involved a division of responsibility into smaller areas of investigation, allowing the students to conduct relevant experimentation while negotiating other areas of the research. Also, the presentation of the concept of* tectonics *provided a means for discussion, evaluation, and qualifying of decisions.*

1. INTRODUCTION

In schools of architecture there is an increasing focus on involving in students in research. One reason is the possibility of saving resources when students contribute to research findings, as opposed to making arbitrary projects, the findings of which are discarded by the end of semester. More importantly, involving students in research as collaborators, not helpers, creates a strong incitement with the individual student for learning and reflection within complex and highly specialised areas of architectural investigation. From the perspective of the researcher, working with students infuses the research with resources and ideas otherwise out of reach within the research framework.

This paper present a case study 'ReVault', set forth as research based teaching. Based on a theoretical framework, didactic consideration, previous research, and earlier workshops that inspired the setup, the aim of the workshop was to work with students in developing a novel concrete construction technique. This led to the realisation of an amorphous concrete grid shell (figure 1), as well as the proposal of three didactic tools relevant to this mode of teaching.

Figure 1: The research pavilion 'ReVault' - a result of a research-based teaching setup at the Aarhus School of Architecture in 2011.

2. BACKGROUND

2.1 THEORETICAL BACKGROUND

The theory of *Tectonics* is used as a conceptual apparatus to qualify decisions in developing the casting method. Tectonics can be described as the relation between material, technique, and form (Figure 2 left) [Christiansen 2004]. This definition is derived from the German architect and theorist Gottfried Semper, who describes tectonics as the description of a unity between idea, action, and construction [Semper 1851]. Or, generally speaking, the unification of means and end [Frampton 1995].
In order to effectively investigate geometry and techniques related to concrete casting, the MTF-model has been developed to include construction and the mould, in a *relations model* (Figure 2 right). The mould has the central position in the model, because it directly generates form. (Pedersen 2011)

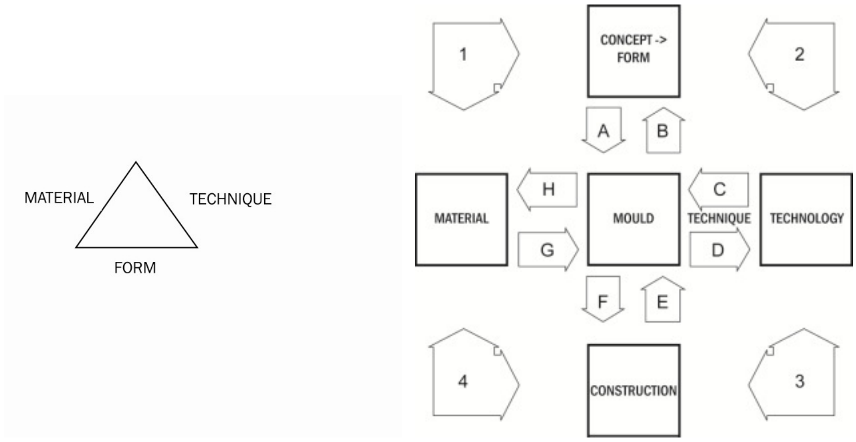

Figure 2: Left: Tectonics defined as the evaluation of relationships between material, technique, and form. Right: A proposed relational model that places the mould in the centre of a realisation process addressing complex shaped constructions.

2.2 PREVIOUS CONCRETE WORKSHOPS

The workshop setup builds on a student driven research-workshop format developed by Architect Professor Karl Christiansen and Architect, Lecturer Anders Gammelgaard, who conducted two workshops, testing aspects of their research into concrete casting in hotwire-cut polystyrene molds. In these workshops, one in Rome in 2004 (figure 3) and one in Berlin in 2005 (figure 4), students worked on exploring the potentials for creating two typologies, the column, and a column-beam assembly, respectively.

Figure 3: Workshop result, La Sapienza, Rome.

Figure 4: Workshop result, Berlin

2.3. BACKGROUND-RESEARCH

The research here presented acted as input for a masters studio where the research-based teaching environment, and specific concrete development, described in detail in this paper, took place.
This research is an investigation into new ways of casting unique concrete elements, in which there is a close connection between the material, the technology, and the form of the concrete element. The project addresses two problems in the current production of concrete elements:

- The lack of connection between the intention of creating variation in our build environment, and the current ways of shaping concrete elements.
- The environmental challenges, which primarily call for a reduction in waste products generated in the production of concrete elements.

The hypothesis is that these problems can be addressed by taking a starting point in the term tectonics and the modern technological situation, new industrialised methods of producing individualized concrete panels, can be developed. Methods which are capable of competing with a traditional production of standardised elements, and at the same time have an inherent, added architectural value, and a better environmental profile.
This hypothesis was presented to the students, and served as a framework for the study brief and assessments. The study brief presented the students with the following question:

How can modern technology unfold the formal potentials of concrete, creating concrete with a high architectural value while maintaining a production line that is environmentally sustainable?

A series of theoretical and material investigations were conducted prior to initiating the studio in order to generate a foundation for the studio to build on.

2.4 BACKGROUND – TEACHING

The teaching setup in which the research was utilised focused around a specific methodological approach. Central to this was a responsive design process shifting between design techniques with potential digitalization,

material qualities and digitally based fabrication. This approach framed the work and challenged the collective as well as the individual process and project development in uncovering potentials for a tectonic approach to architecture.
This architectural analysis considered parametric terms and the script language, in order to deal with the complexity of adaptability in architecture. In other words, the aim of the teaching was to make students consider how digital technology can resist becoming an objective in its own right but rather a means for supporting the human being as the objective of architectural creation.
The semester assignment and individual project development were based on 3 elements:

- The tectonic approach, focusing on the Material – technique – form relation. (As described in section 2.1)
- The workshop, investigating a responsive design process, also referred to as a digital tectonic approach.
- Site & Program narrative story - Uncovering the existing conditions and fantasizing of future potentials.

This paper focuses on the two first focal points.

2.5 MATERIAL BACKGROUND

As a material basis on which to build the research-based teaching setup, a novel casting method was developed.
To ensure the feasibility for full-scale production before using the technique as a basis for research-based teaching, the casting method was conceived and developed by the author in a sculpture entitled 'Hello World' (figure 5).
Since the moulds would all be unique, and therefore not reusable, a materially efficient and low or zero-waste production method was desired. This was achieved by the use of PETG plastic, which is part of the PET plastic family. It is easily recycled, by melting, at 260 °C, evaporating only CO_2 and water, and its molecular structure allows for infinite use and re-use without degradation if it is kept in a closed recycling process. In terms of the design theory Cradle to Cradle, the PETG is used as *Technical Nutrient,* in a zero-waste production [McDonough and Braungart, 2002]. Importantly it does this while adhering to the basic requirements of being an appropriate mould material that is easy to laser cut and easy to fold. The plastic sheet comes covered with a thin protective film, used to protect the material against scratches during transport. This film was left on during casting and then removed to leave a clean sheet ready for recycling.
When exposed to fluid concrete material, 1 mm PETG sheets have a high degree of deformation. It was practical to perform stress and deformation simulations as part of the development of components, in order to check that the PETG could withstand the weight and hydrostatic pressure from liquid concrete. (Figures 6) [Pedersen 2011].

Figure 5: Material research background: A series of parametrically defined, reinforced concrete beams and columns, cast in PETG plastic.

2.6 DIDACTIC BACKGROUND

In order to point towards possible ways of merging research through design in with research-based teaching on a masters level, it is relevant to present some basic consideration regarding theory of learning. This is particularly important to prevent what is referred to as misalignment [Keiding et.al 2007] – a situation where a discrepancy occur – often inadvertently-between the presented learning goals and the actual learning. In this case a misalignment may arise between the narrow focus of research as opposed to an architecture study programme that is required to provide a much broader perspective on architecture. (Studieordning for kandidatuddannelsen på Arkitektskolen Aarhus, 2012)

The learning theory *constructivism* offers a view of the individual as a constantly active part in the generation of knowledge, as opposed to an active recipient of instructions. As such, learning is formed by the individual and individual´s capabilities to build up knowledge, not a direct translation of knowledge from teacher to individual. (Dewey, 1938)

It follows that the teacher must acknowledge that the student is a participant in forming realisations about architecture.

This is in contrast to the tightly controlled workshop, where the workshop leader / researcher has a clear idea about what the output of the workshop should be. This approach draws on behaviouristic learning theory, in which the master dictate solutions, which the students acquire by means of copying the master.

When the teaching is taking place on a masters level, a challenge occurs, because the level of specialisation is high, while the area of investigation is complex and abstract, requiring a great deal of self study and reflection from the students.

The studio setup described in the following is an attempt to achieve both a high degree of specialisation, while insisting on students taking initiatives to take decisive steps, something that is essential in a workshop with a high level of complexity.

3. CASE: THE WORKSHOP

A case study was built on the background research and didactic consideration, and was carried out as a focused investigation, where students and researchers collaboratively developed and realised an amorphous, catenary grid-shell.

Specifically, the workshop investigated the application of small-scale components with triangulated surfaces and a small casting height, in order to eliminate deformations due to the hydrostatic pressure of concrete. The case study was carried out at Aarhus School of Architecture in the fall of 2011 (Figure 7). Over the course of three weeks the authors, with the aid of Civil Engineers Jacob Christensen, and Ronni Madsen and 12 Master of Architecture students, designed and built a 16 square metre by 2 metre tall pavilion consisting of 110 discrete concrete elements, cast in PETG (figure 6).

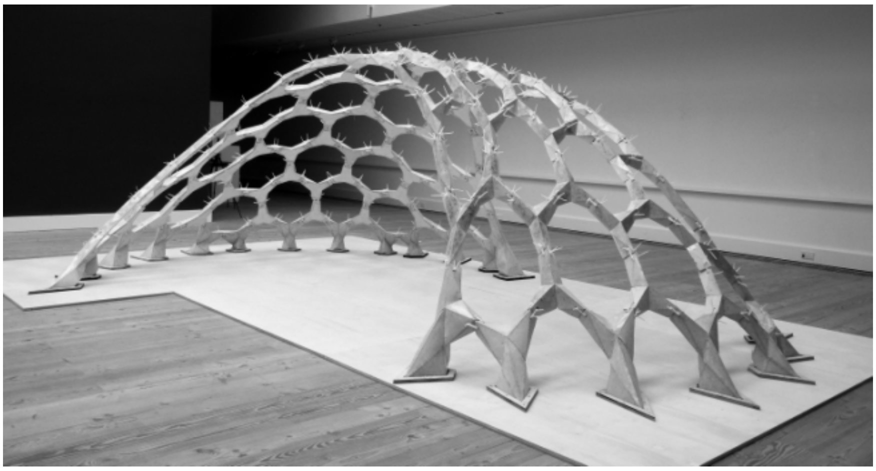

Figure 6: The ReVault case study: A concrete grid shell pavilion made up of 110 discrete elements.

3.1 DIVISION OF RESPONSIBILITY

To allow students to conduct focused investigations and development,
The students were organised in four groups:

- Overall geometry / form finding
- Component design
- Falsework
- Connections

OVERALL GEOMETRY / FORM FINDING

The overall geometry group used a method for form finding using dynamic relaxation of a network of flat curves. This created a three-dimensional wireframe mesh, from which the task was to generate volumetric concrete components (Figure 7). This meant that the group had to work closely with the component design group, as well as with engineers, who conducted Finite Element analysis to calculate the shear forces and bending moments in the joints.

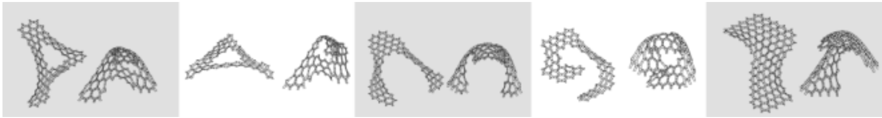

Figure 7: investigation of different geometries by the overall geometry group.

COMPONENT DESIGN

The molds had to be manufactured from 900 x 1600 millimetre sheets of PETG. The component design group determined the size and shape of the individual components, so they were able to meet the pavilion shape suggested by the overall geometry group, while respecting material and production restraints (figure 8).

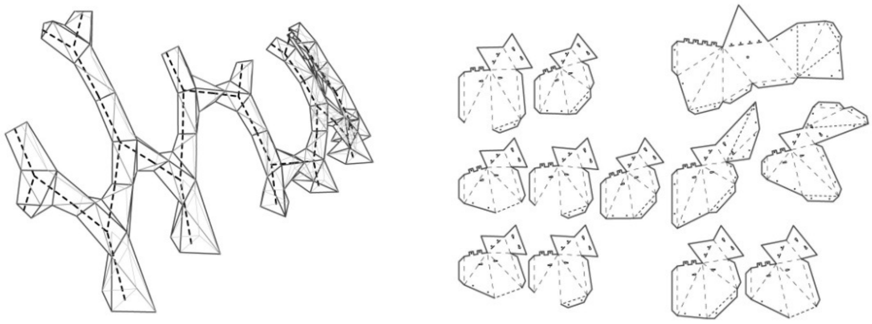

Figure 8 right: the final component design. Left: The component design group learned a scripting language to parametrically generate templates for lasercutting.

One important development in this area was the triangulation of each component arm, which added stiffness to the mold while allowing the component to meet the many different angles that occur when an amorphous overall form is panelised. Development also addressed the need to stay within tolerances. The PETG moulds were fixed to a blueprint, generated from the digital model, which enabled positioning of the ends of the three component arms with a tolerance of less than one millimetre. Flaps added to the ends dictated the angle of the component arms (Figure 9).

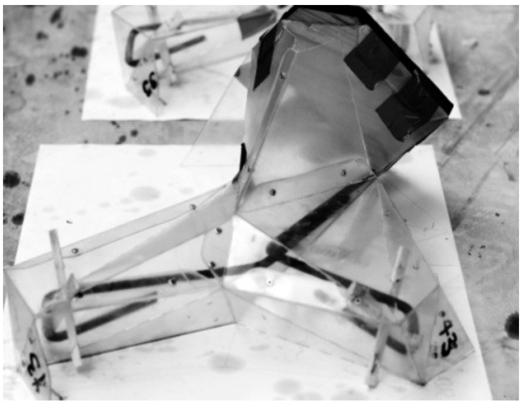

Figure 9: The mold for one of the base components

FALSEWORK

A prototype test (figure 11) disclosed that precise falsework would be important to position the components correctly in the compressive arc. This led to the task of designing and drawing a viable, parametrically defined falsework, generated directly from the spatial components model using *Grasshopper,* a generative modelling plugin for *Rhinoceros*. Fabrication was done by means of laser cutting recyclable cardboard (Figure 10) [Pigram et al. 2012].

Figure 10: The structure being assembled against the parametrically generated falsework.

CONNECTIONS
Principally there would be no shear forces in the joints, the structure being in pure compression. To test this, a worst-case prototype, with no connections, was constructed. Also, Finite Elements analysis was used to calculate the shear forces in the joints. Failure of the prototype and the appearance of shear forces in the FE analysis provided the students with evidence that a connection pulling elements together would be important.

Figure 11: The 'worst-case' prototype after structural failure.

Shear happened due to the large passage openings in the mesh, and due to lack of precision, both in the production of the components, and in the process of assembling the structure. The development of several connection details began, and resulted in the implementation of zip-tie connections.

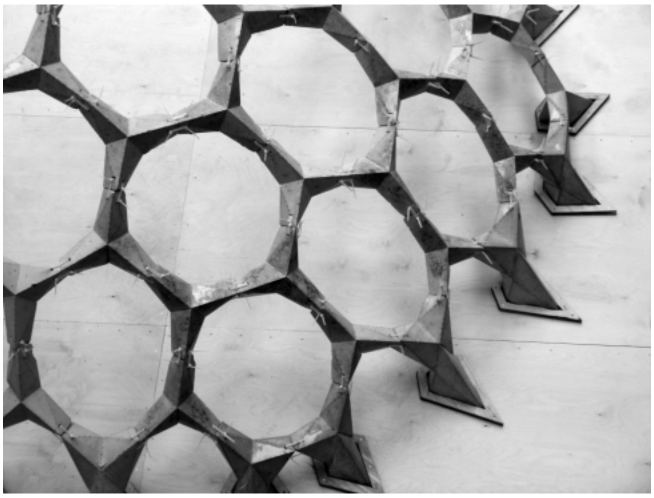

Figure 12: Component connections

4 IMPACT ON TEACHING

The semester projects that followed the ReVault workshop were qualified by both the methodand the findings, regarding material observations as well as parametric and algorithmic workflows. As an example, one student developed a fabric casting system using gravity simulation software to generate templates for casting concrete in catenaries arches using fabric molds (figure 13).

Figure 13: Concrete casting by master student Jon Andersen.

5. FINDINGS

5.1 DIDACTIC TOOLS ON A GENERAL LEVEL

On the basis of the case study three didactic tools have been identified. They serve to qualify both teaching and research output, when the mode of inquiry is research by design, involving students. In other words, they are proposed as tools that may help bridge the gap between research and teaching, between the specific problem and the generalist nature of studying architecture.

- Knowledge generation between researcher and student
- The advanced investigation as a booster
- Interdisciplinary collaboration

TOOL #1: KNOWLEDGE GENERATION BETWEEN RESEARCHER AND STUDENT

Typically students produce a semester project, which is conducted as project work. This tool includes a widening of the term "project work" to include the research into this project work. This is done by including the workshops int the curriculum, and most importantly, by creating an environment where the goals for the studio and research are achieved *with* the students, as opposed to being an assignment posed by the teacher / researcher for the students *to* carry out. Importantly the establishment of a common ground also involved the alignment of a theoretical and methodological framework, in this case tectonics and research by design.

This happened by initiating the semester with he ReVault workshop, in which the students took responsibility for the different experiments needed to develop a complex case study. Importantly, the study should be one in which the teacher has an incentive to participate in, because of its relevance to his or her research. The relevance to students should be secured by inscribing the learning outcome in the study brief in such a way that the students can use the findings in the following semester project.

TOOL #2: THE ADVANCED WORKSHOP AS BOOSTER

This leads to the second tool, which is more of a strategy: To start with a narrow and framed exercise, that enable the students to produce an output with a very high quality, while introducing and encouraging a research-like approach to the following semester project. In other words, to raise the bar. The ReVault workshop serves as an example of this strategy. An important part of the strategy is to formulate an open problem for the reminder of the semester, allowing the students to demonstrate indepedence and to establish a learning environment in following a constructivist approach.

TOOL #3: INTERDISCIPLINARY COLLABORATION

It is important to prevent the research from becoming too specific and peripheral to the students. Equally important is that the output from teaching has relevance to the researcher. This may be prevented by establishing a cross-disciplinary collaboration between multiple researchers, in which the researchers define a theme that has relevance to teaching as well as their respective fields of research. This broadens the field, increasing the relevance for students thus minimising the risk of mis-alignment. Also, it creates an opportunity for researchers to have their field of research meet another, which puts the research into perspective and open the possibility for findings that would not be otherwise possible. In the case described here, research into the tectonic potentials of concrete by the author, was infused with research into parametric and algorithmic design by Architect, Adjunct

Niels Martin Larsen and Architect, Associate Professor Dave Pigram, which, along with the inclusion of Engineers, made the case study possible.
On a more specific level, didactic considerations involved a division of responsibility into smaller areas of investigation, as described in section 3.1, allowing the students to conduct relevant experimentation while negotiating other areas of the research. Also, the presentation of the concept of tectonics, as presented in section 2.1, provided a means for discussion, evaluation, and qualifying of decisions.

6. CONCLUSION

A research based teaching setup is described, in which students and researchers work collaboratively on the same project, proved to have several advantages. The quality of learning outcome and research output was maintained by the establishment of a setup including researchers from multiple fields within material and computational research. This broadened the field, preventing a too specific learning environment. Utilisation and development of algorithmic, parametric and material techniques necessary to create a complex pre-cast concrete construction technique was possible only because students and researchers worked side-by-side. The workshop served as a booster for the following semester project, in which students utilised the workshop findings in their own projects.

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