150 000 – Parametric Control of PET Bottle Structure

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Abstract. In this paper we describe the pedagogical and methodological approach to a parametric project and workshop for the design of a tower which consists of 150000 PET bottles. The ultimate goal of the project is to actually realize the PET bottle tower; therefore the constraints on the projects are very strict. Additionally, because of the large number of bottles to be used in the design, the problem lends itself well to a parametric approach.

Keywords. Pedagogy; garbage architecture; workshop; parametrics; PETower.

GENERAL FRAMEWORK

This paper is focused on the suitability of parametric design tools for the generation of a tower design that consists of 150000 PET bottles. The tool is taught and used in a 6-day workshop, and is embedded in the context of an experimental collaborative design studio between two faculties of architecture of two different countries.

The problem lends itself well to a parametric approach, as it concerns a composition of many similar units and students need to have control over the total number of components. However, parametric tools may not be sufficient and the only method of designing suitable in all phases of this task. We observed that our students naturally hand-sketch as well. The precedence we could find in Sanguinetti and Abdelmohsen (2007), where the authors successfully describe integration of sketching and parametric modeling in conceptual design task. However, they could also see extreme approaches such as ready sketch design followed by modeling of the same in computer, the use of parametric tool to actually generate the design and the switch back and forth among the two tools. Our report differs in integration of physical material tests into the task and the tested group regarding rather novice students.

Before the workshop we invited expert users (colleague teachers of those programs) of various CAD programs (3D Studio Max, Revit, AutoCAD, ArchiCAD, and Rhino) to create an arbitrary three-dimensional structure of 150000 similar objects. The choice of object and composition were left completely open to the experts (Table 1).

Manipulation of the designed object failed due to the computer capacity in three of four programs. From their feedback we selected Rhino in combination with Grasshopper as the most promising tool in

<table>
<thead>
<tr>
<th>Criteria of choice of the design tool</th>
<th>3D studio Max</th>
<th>Revit</th>
<th>Autocad</th>
<th>Rhino</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possibility to generate</td>
<td>yes</td>
<td>yes</td>
<td>design unsatisfactory</td>
<td>yes</td>
</tr>
<tr>
<td>Numeric control</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Manipulation of model</td>
<td>impossible</td>
<td>impossible</td>
<td>impossible</td>
<td>yes</td>
</tr>
</tbody>
</table>
the project. Compared to the other programs, it was able to control the high amount of units and also provided numeric control over the design.

We followed the scheme of a traditional architectural design process, where hand drawing comes in the beginning and manufacturing of a model is in the end of the process [1]. Because of the experimental nature of the material and the specific nature of PET bottles it was important that the model was in 1:1 measure. The workshop was open for students at any level of expertise. During the workshop we observed the work flow of the students.

The first two to three days we were teaching Grasshopper. The students discovered that parametric design tools not only generate interesting and cool pictures, but they are also an inevitable part of the design process to support the conceptualization of the design. Last but not least hand drawing played a significant role during the design process.

DESCRIPTION OF THE PROJECT
Both setup of the workshop as a part of the experimental design studio are informed by the context of the project. The project of the experimental design studio is located in Zurich, Switzerland. The city of Zurich organizes a very large festival every three years, called the Zürifäscht. In the current edition, to take place 5-7 July 2013, the festival runs under the theme of recycling. The theme has three subtopics: Recyclata, Recyclodge and Recyctower (PETower). The Recyctower (PETower) is the subject of the experimental design studio [2, 5] in our institution and in the workshop reported in this paper. The task is quite challenging: the tower must be built from recycled PET bottles and contain 150 000 pieces. The structure must be self-standing and lit. It must be built and demolished in no more than three days. For the construction process school children must be involved to assemble the units of the tower. For transportation purpose the units may not be bigger than 2x2x8 meters.

Originally we were contacted to advise on the PETower design. It seemed logical for us that students of architecture would take part on the development of the plans.

PET bottles are not an uncommon material for experimentation in architecture. Several projects exist where PET bottles are used as infill material in facades. The notable EcoARK [3] building utilizes 1.5 million specially fabricated PET bottles. The American architect Michael Reynolds uses waste and PET bottles in his projects [4]. Experimental structures with PET bottles are presented for example by Baerlecken et al. (2012).

METHOD OF TEACHING

First semester: problem exploration
The first semester we led a collaborative design studio between our faculty and the Faculty of Architecture at ETH Zürich. For this project we developed and tested a new software called ColLab sketch, which was implemented in both faculties’ media facilities [6]. The advantage of such a collaboration was that part of the team was situated at the site, so that they could supply the team with maps, photographs and sketches of the building place.

The major problem the students faced was visualization of such an amount of units such as 150 000. Figure 1 shows the total number of about 150 000 bottles in a flat area.

In the first semester a number of 3D designs were made with PET bottles starting by coupling single bottles into bunches wrapped in food foil, which worked well but was not of convincing visual quality. Also the stability and reliability of such a structure was doubtful. Some informal tests were done to verify the strength but without reliable results. Finally, having an overview of number of the single bottles within the designed tower was almost impossible, together with the limited design expression. Apart of the communication software which students had to learn we had not recommended any software or design method and we had left their choice open (Figure 2).

The final designs resembled towers, but it could not be proven that they could actually be built.
Second semester: focus on design tools

In the second semester the project was developed at our faculty only, but we had consultation sessions with advisors from the partner university. Different students than from the previous semester took part in this studio. In the first semester we mainly focused on feasibility of the project and did informal material tests and based designs on these findings. The second semester [7] was supported by a 6 day long workshop devoted to information visualization tool lectures and manufacturing. The results were regularly communicated over distance to the advisors in partner faculty and other parties involved in the project.

The scheme of teaching varied in both semesters. In the first semester we allowed the students to design only after analyses were ready: analyses – design – fabrication. In the second semester students could re-use the earlier gained knowledge from their colleagues and shift the start point, so that we could start designing earlier. We also intensified the switch between design and material experience according to the scheme in the table (Table 2).

Most of the time during the semester was devoted to laboratory tests of the PET bottles, where students got the reliable values of the load capacity of bottles and pull capacity of the cap, which we report on at CESB13 conference in Nováková et al. (2013). They also worked on analysing the possibilities of connections using PET materials in a sheet form. We noticed that the designs of the previous semester were limited to regular shapes such as cubes, hexagons or cylinders. In the second semester the students obtained more freedom for their PET bottle designs. Towards the end of the second seminar (during the workshop) we encouraged stu-
students with correlating ideas to group and work out one project. Half of the students formed teams of two or three people (Table 3).

During the workshop students took their initial sketches and tried to model them within Rhino. In the first two days they learned basics of grasshopper and understood parametric thinking, on the third day we introduced several ways of generating tower-like objects (Figure 3).

After the initial phase they constructed their virtual models with the data constraints (150 000 bottles, minimum 20 meter height, one component of maximum size 2x2x8 m³). We found that they could easily change their design towards the initial hand sketch without losing the awareness of the numbers. Consequently we allowed the students to play with their newly acquainted skill. By allowing them the “play phase” within the teaching hours, the students were more motivated to experiments, deepening their understanding of parametric modeling and got quicker feedback from the teachers. Together with this parametric attitude to the problem, the 4th and 5th day was devoted to building the actual prototypes of the components. Students not only had to

<table>
<thead>
<tr>
<th>Activity</th>
<th>Hours</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture (film)</td>
<td>2</td>
<td>Motivation of the students, primary introduction of topic</td>
</tr>
<tr>
<td>• Waste land</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Wall I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Midway [8]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>4</td>
<td>Initial ideas, concepts, hand sketches</td>
</tr>
<tr>
<td>Measurement tests</td>
<td>2</td>
<td>Tests of PET bottles in Civil Engineering (CE) material lab</td>
</tr>
<tr>
<td>Design</td>
<td>4</td>
<td>Specifying design strategies</td>
</tr>
<tr>
<td>Excursion to PET bottle production plant</td>
<td>8</td>
<td>Learning material generation principles</td>
</tr>
<tr>
<td>Design</td>
<td>6</td>
<td>Implementing knowledge from tests and excursion into design</td>
</tr>
<tr>
<td>Cap tension tests in CE laboratory</td>
<td>2</td>
<td>Tests of the screw and cap connection, the strength of the screw.</td>
</tr>
<tr>
<td>Pressure and behavior tests in CE laboratory</td>
<td>2</td>
<td>Tests on manufactured building blocks in CE laboratory</td>
</tr>
<tr>
<td>Workshop - tools</td>
<td>24</td>
<td>Learning of parametric tools</td>
</tr>
<tr>
<td>Workshop - prototyping</td>
<td>16</td>
<td>Prototype fabrication</td>
</tr>
<tr>
<td>Design</td>
<td>4</td>
<td>Final design + presentation</td>
</tr>
</tbody>
</table>

Table 2
Scheme of activity switch during the semester.

Figure 3
Examples of different possible principles for tower generation. Combination of geometrical shapes and mathematical formulas.
collect the bottles, but also tried to set the connection between them according to their previous research. We could observe students sitting by the screens and sketching their technical ideas on the paper. This workflow programming-sketching was efficient for them and it proved to be the fastest (Figure 4).

Because the material was experimental, not all assumptions and designs were successful and students had to change their virtual models again according to the real scale component prototypes. Students grouped again in this phase of component generation.

**OUTPUT OF THE SECOND SEMESTER**
The projects of the first semester did not result in feasible designs which could be actually constructed. We assume that the main reason for this was the lack of expertise in sophisticated CAD tools.

We collected several physical prototypes of PETower building modules together with connection strategies (Figure 5).

In contrast to the first semester we did see thirteen feasible projects in the second semester, which were consequently communicated to several parties in Zurich (municipality, festival organizers, potential

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**Table 3**
**Table of project developments.**

<table>
<thead>
<tr>
<th>Students' sketch</th>
<th>Grasshopper model</th>
<th>Physical model of the building unit</th>
<th>Project</th>
<th>Evaluation according to feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petr</td>
<td>yes</td>
<td>no</td>
<td>PETower</td>
<td>10</td>
</tr>
<tr>
<td>Simon</td>
<td>yes</td>
<td>yes</td>
<td>Wall</td>
<td>3</td>
</tr>
<tr>
<td>Lenka</td>
<td>yes</td>
<td>no</td>
<td>Tripod</td>
<td>9</td>
</tr>
<tr>
<td>Adam</td>
<td>yes</td>
<td>yes</td>
<td>Mobius</td>
<td>8</td>
</tr>
<tr>
<td>Petr</td>
<td>yes</td>
<td>yes</td>
<td>Lighthouse</td>
<td>7</td>
</tr>
<tr>
<td>Sori</td>
<td>no</td>
<td>no</td>
<td>Twisting Tower</td>
<td>6</td>
</tr>
<tr>
<td>Ondrej</td>
<td>yes</td>
<td>yes</td>
<td>Atomium</td>
<td>Not feasible</td>
</tr>
<tr>
<td>Ivana</td>
<td>no</td>
<td>no</td>
<td>i</td>
<td>Not feasible</td>
</tr>
<tr>
<td>Jiri</td>
<td>yes</td>
<td>yes</td>
<td>worked</td>
<td>2</td>
</tr>
<tr>
<td>Karel</td>
<td>yes</td>
<td>yes</td>
<td>T</td>
<td>4</td>
</tr>
<tr>
<td>Honza</td>
<td>yes</td>
<td>no</td>
<td>Swiss cross</td>
<td>5</td>
</tr>
<tr>
<td>Maria</td>
<td>yes</td>
<td>yes</td>
<td>failed</td>
<td>5</td>
</tr>
<tr>
<td>Leila</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>Not feasible</td>
</tr>
<tr>
<td>David</td>
<td>yes</td>
<td>no</td>
<td>Growing Tower</td>
<td>5</td>
</tr>
<tr>
<td>Peter</td>
<td>yes</td>
<td>no</td>
<td>Plasticienne</td>
<td>1</td>
</tr>
<tr>
<td>Jean</td>
<td>yes</td>
<td>yes</td>
<td>Plasticienne</td>
<td>Not feasible</td>
</tr>
<tr>
<td>Pauline</td>
<td>yes</td>
<td>yes</td>
<td>Pentagon Tower</td>
<td>Not feasible</td>
</tr>
<tr>
<td>Vera</td>
<td>yes</td>
<td>no</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4**
Students programming and sketching designs simultaneously.
sponsors). Three projects were highly realistic and one of them was accepted as a realization project (Figure 6).

**CONCLUSION**

We collected all sketches, made screenshots of the developing projects and made documentation of the 1:1 models. We observed that students not only computer modeled in the middle phase of designing, but all the time of project development they were sketching even when sitting by the computer. Especially in the phase of moving towards construction we could see simple drawings of connection details or patterns of assembled units. The parametric tool proved to be very important. Some students tried to develop the project with other CAD tools,
but failed. Thus they responded very enthusiasti-
cally to the parametric tool when they saw how the
design remained flexible while keeping also numeri-
cal control. As we observed, teams of two or three
people were able to deliver results, which fulfilled all
conditions of the project, while individuals did not
progress beyond trials and failures. For all students
it was interesting to see how much the parametric
tool enabled them to deal with the real problem.
Furthermore they were able to follow their initial
hand sketch graphics giving it exact numerical and
structural control (Figure 7).

For our experimental design studio and this
special task using parametric tools proved to be of
critical importance. Also the hand sketch technique
seems to be crucial. Parametric tools enabled stu-
dents to experiment with the tower design, while
also keeping control over the various constraints
that apply to the project. Exploring various con-
struction methods with PET bottles was on the other
hand made on paper and parametric tool turned out
to be unsuitable. Hand sketch helped developing
initial designs, visualizing partial ideas, generating
details and clarifying technical solutions. In general,
we feel that it is necessary to introduce similar work-
shops focused on parametric design in the begin-
ning or middle of the design studio together with
the same focus on hand sketch, where we believe in
better impact of using of these tools directly in the
design studios by project development.

**FUTURE WORK**

In the next semester of the experimental design stu-
dio we shift focus to the design of shelters and small
service structures made of PET bottles for the same
festival event. We would like to observe the direct
impact of using parametric tools on final designs
and the role of sketching in this process.
ACKNOWLEDGEMENT
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REFERENCES