

The Trondheim Camera Obscura

A Case Study on Digital and Analogue Project Development in Timber Construction

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This paper discusses a project where we, together with a group of 15 graduate students, designed, produced, and built small timber structure (a Camera Obscura) in Trondheim, Norway. The project was part of a full semester course at the Faculty of Architecture of the Norwegian University of Science and Technology (NTNU). The main purpose of the course was to explore the possibilities of prefabrication in timber construction based on file-to-factory processes (digital fabrication). Moreover, we wished to give the students the experience of building a permanent structure in 1:1.

Keywords: *Teaching project 1:1; industry cooperation; digital fabrication; CAD-CAM; camera obscura.*

Introduction

Since the introduction of the first CAD systems for architecture, the working processes in building construction are changing quite substantially. However, the “fundamental redefinition” of the relationship between designing and producing through the integration of computer-aided design with computer-aided fabrication – envisioned by William Mitchell in 1995 – seems to be misleading. Instead of “bridging the gap between designing and producing that opened up when designers began to make drawings” (Mitchell 1995), architects and fabricators are even more separated by the increasing specialization going along with the use of modern fabrication technology.

The potential to design whatever non-regular shape imaginable with the aid of modern CAD systems has successfully entered the realm of architecture and the curriculum of architecture schools. Rapid prototyping equipment like 3D printers is becoming more and more common and allows the materialization of such designs on a model scale. But the 1:1 realization is too often (in schools) not even attempted, or (in reality) just handed over to specialists, assuming that fabrication methods in full-scale architecture follow the same principles as model making.

To really bridge the gap between design and fabrication, it is necessary to acquire knowledge about the real building process and the methods and tools involved. We strongly believe that this will not only



*Figure 1
The Trondheim Camera
Obscura completed in
December 2006. Photo:
Øystein Hermstad*

lead to a smoother and more successful building process, but also to an enhanced quality in design itself. Therefore we organized a full semester course (15 weeks, 30 ECTS credits) at the Norwegian University of Science and Technology (NTNU) with the goal to design, plan and finally build a small timber structure in Trondheim and explore the possibilities of those new technologies in a real-world building process.

The course aimed to provide the students with knowledge and experience in the use of digital technologies for the planning and production of timber structures. We wished to explore what we may gain in terms of new architectural possibilities when establishing a digital chain from concept development via detailing to production of the structure's components and final assembly of the parts at the building site.

The project

With the course aim in mind we were looking for a building need from a client for a project we could

design, produce, and build. Through a local artist we came in contact with the Trondheim Science Center. The Center wished to build and operate a camera obscura to illustrate the principles of light and optics. The camera should demonstrate the pinhole principle as well as projection through a lens and mirror device (a "periscope") mounted on top of the camera. We agreed with the Center to design and build the camera while all other aspects of the project, such as application for building permit, financing etc. would be handled by the Centre. However, in the end the students also managed these aspects of the project.

The digital chain

The concept of the "digital chain" or "file-to-factory" processes has been explored by researchers and also in several teaching projects during the last few years, see for instance Kolarevic, 2003; Sass, 2004; Aitchison, Friedman and Siebom, 2005; Rüdenauer, 2005; Fricker and Zieta, 2006; Neumann, 2006 and 2007. There are also several projects in full scale

based on a digital production chain; see for instance Surjan and Horton, 2004; Harfmann, 2004; Iwamoto, 2004; Stacey, 2007; Neumann, 2007.

Our project may thus be regarded as a contribution to the line of 1:1 experiments realized through a digital chain. However, there are a few special characteristics to this project: The seemingly simple function of the Camera Obscura requires quite specific conditions to be fulfilled, such as absolute darkness inside the camera. Moreover, the building should have a permanent location on a prominent site in the city center. Finally, another particular aspect of our project is that for the production of the timber components we cooperated with companies that use industrial standard CNC equipment in their daily production.

To our knowledge this is one of the very first projects where computer-controlled manufacturing tools for timber construction are used in the context of architectural education. This is interesting in two respects. First, CAM software and CNC tools in timber construction differ from other applications in the building industry. While routers, lathes and mills were well introduced in machine engineering before they were used in building construction, automated joinery machines for timber construction were specifically developed for their trade. Second, timber construction holds a large share of the Norwegian

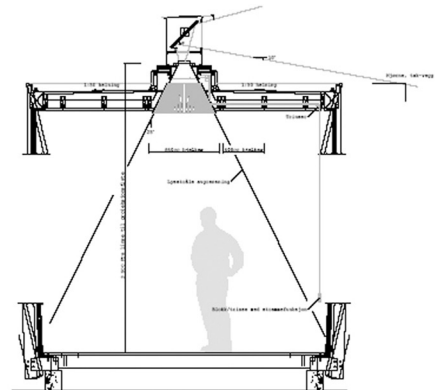
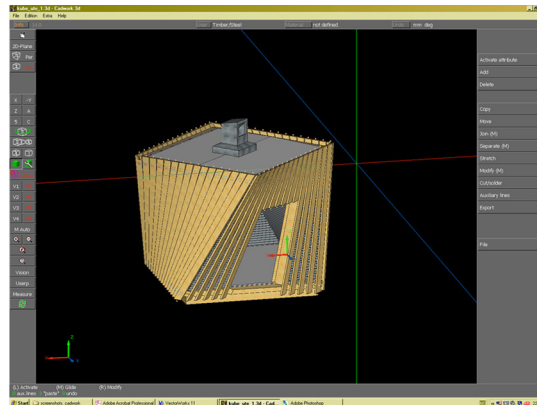
building market, especially in housing projects, but there are hardly any architects involved in the design.

Course introduction

During the two first weeks of the semester we (1) introduced the students to the principles of the camera obscura; (2) discussed forestry, timber and wood quality, and, (3) organized a workshop at the premises of the company that was going to produce the timber components for the camera obscura on their CNC machine.

By designing and producing small samples the students were introduced to both the software and the hardware that we would later use to produce the camera components. The production machinery, a SpeedCut SC1 from the German Hundegger company, is an automated joinery machine capable of processing lumber with a five-axis saw blade and various drilling and milling tools. It was developed mainly for the rapid and precise cutting and the processing (milling, drilling, marking, and lettering) of simple wooden constructional components (Hundegger 2007). The software package Cadwork was chosen because it has a proper CAM/NC interface with the Hundegger machine. Cadwork is a CAD/CAM system specially tailored to the demands of timber

Figure 2
Cadwork screenshot of the
“twisted cube” (left) and section
showing the “periscope”
(right)



construction providing a fully integrated solution for all stages of design and fabrication (Cadwork 2007).

It was important that the students should learn the possibilities and limitations of the available software and available machinery before starting the design phase.

Concept development

In order to find the design for the Camera Obscura we organized an architectural competition between five teams with three students in each team. This phase lasted four weeks. Design explorations were mostly done through sketching and the building of physical models but also in various 3D design tools, such as Form-Z, Sketchup, 3D Studio Max, and Rhinoceros). Commentaries were given by the studio instructors through daily meetings. External instructors gave their input through the use of an online conferencing tool (www.gotomeeting.com: May 2007). External teachers included Ruth Berkold of yes architecture (Munich) and Chris Sharples of SHoP Architects (New York). The Greenport Camera Obscura designed by SHoP was a great inspiration for our project; see Sharples and Sharples, 2006.

The competition entries were evaluated by the studio instructors as well as external members. The scheme that the jury considered to have the best potential for further development may be described as a cube with a side length of four meters in plan and height and where the top is twisted 45 degrees.

Detailing

After the competition all the 15 students worked together as one team in the detailing (three weeks) and final realization of the project. Various methods of design exploration were used, including analogue (sketching and building of physical models) and digital methods (various 2D and 3D CAD packages as well as Cadwork). The process gradually moved more and more towards a full detailed Cadwork model but some parts of the structure (e.g. the lens

housing or “periscope” were detailed exclusively in 2D (Autocad).

For the building permit the structure needed approval from a structural engineer regarding its ability to withstand snow loads. However, it turned out to be a rather difficult task to calculate the loads in the outer members of the structure. Finally we were aided by an engineering firm (Teknisk Data AS) for finite element analysis of the structure. The program used for the purpose was Robot Millennium by Robotat. The program can import IFC-format files. We assumed that it would be a simple task to analyze the IFC-file we exported from Cadwork. In reality, we realized together with an engineer from Teknisk Data that it was necessary to build a separate model for analysis directly in Robot Millennium, making no use whatsoever of the IFC-format.

Production

The structure consists of four gluelam sill beams and four gluelam top beams with rather complicated cuts to accommodate the 16 wall planks of each of the four walls. The plan was to produce all the timber components on the Hundegger SpeedCut SC1 machine at Eikås Sagbruk. The Hundegger company defines this machine as an automatic cutting machine. It was developed mainly for the rapid and precise cutting and the processing (milling, drilling, marking, and lettering) of simple wooden constructional components. According to Callicott (2001) the machine may thus be described as a kind of CNC router.

Eikås Sagbruk had purchased the machine to automate their production of roof trusses and to produce precut components for their building system, mainly using the sawing and drilling capabilities of the machine. The production of the more sophisticated components for the Camera Obscura was therefore quite a welcome challenge for the company's operation engineer.

As we were going into production it became evident that our communication with the producer had not been adequate. This was mainly due to the fact

that we had not thought of acquiring the simulation module of the machine software. If this had been the case we would have discovered the problems we under heavy time pressure had to solve. Then, all processes could have been simulated in the studio and possible flaws could have been corrected before we were entering into production.

The first problem was related to the wall planks. These were to be made of standard strength sorted spruce (*Picea abies*) of the dimension 48mm x 198mm and 4 meters long. The challenge here was to model and produce an intricate cut being different on each plank and going from zero to several centimeters in order to allow the fastening of the internal horizontal wall planks; see figure 4.

The second problem was more severe: the tools of the Hundegger SpeedCut machine operate in three axes. We were told that it would not be possible to produce the complicated cuts in the sill and top beams on this machine. For the purpose we would need a 5-axis machine like the Hundegger K2. Luckily, the company Trebyggeriet AS located in a village near to Eikås kindly agreed to help us out and produce the parts on their Hundegger K2. The

K2 is described by Hundegger as a fully automated joinery machine or beam processor; see Neumann, 2007.

At Trebyggeriet we realized the next problem in the production. The custom made gluelam beams we had ordered for the project were too short because of the many cuts along the line of each beam. This leaved no clamping area for the machine. Therefore, the beams should have been one meter longer than the beams we had at our hands. The engineers at Trebyggeriet managed, however, to find a way around the problem, but some of the cuts had to be made manually by the students after the machine production was finished.

Construction

The building phase was remarkable smooth and without incidents. No doubt this was due to the high degree of prefabrication and the file-to-factory process. All parts necessary for the geometry of the structure had been realized from the same Cadwork model, and they fit perfectly together on the site. Before assembly all external members were

Figure 3
The cut along the wall planks
(left) and assembly of the sill
beams on concrete founda-
tions (right)



pretreated with a high-tech primer based on nano-technology. The students had organized themselves in two teams working in shifts from 8 AM to 8 PM. They managed to stay on schedule despite delayed deliveries of important parts. On 8 December 2006 the Vice Rector of NTNU inaugurated the Trondheim Camera Obscura on behalf of the university.

Digital workflow and tool use: a summary

The Cadwork model for production was treated as an isolated file, managed by one student being responsible for the editing and to keeping it updated with the rest of the project work. The students used various tools for visualization and design exploration including 3D tools (3D Studio Max, Rhinoceros, Form-Z and Sketchup) as well as 2D tools (mainly Archicad and Autocad).

For design exploration in 3D Cadwork was in this case not an ideal tool, as it was both faster and more intuitive for the students to work in other programs. Many design decisions can be explored with a simpler model as long as modeling speed and flexibility are important factors. However, modeling in

Cadwork is vital for production but also for the design, as many potential problems were identified and solved because of the precision and level of detail in the Cadwork model. In this respect, Cadwork can be regarded as a CAM software, used to translate the geometry *designed* in a CAD system into the *production* data needed to control the fabrication. Since some constructive problems only become visible after the additional information needed for fabrication is added, the CAM system is an important part of the prefabrication process. The crucial point in regard of the digital production chain is the interface between the CAD and the CAM model, which up to now still requires a lot of manual interaction.

Construction of the lens housing was done almost exclusively in 2D because its metal parts were to be manually built in one of the mechanical workshops at the university. The craftspersons required precise 2D construction drawings. This gives an example of how production technology and method influence the design process.

The use of several different computer programs for design evaluation and exploration has been an important lesson for both teachers and students.

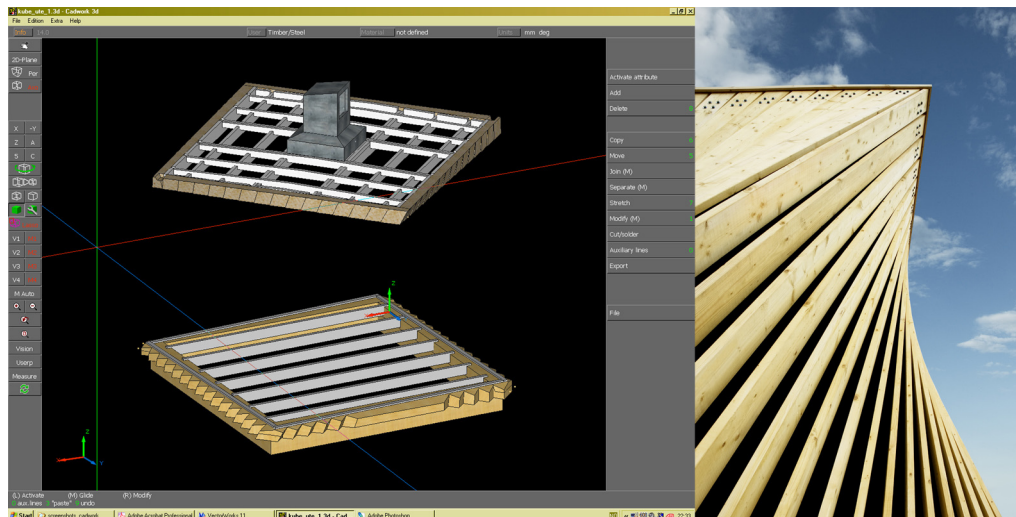


Figure 4
Cadwork screenshot of the timber foundation and top of the structure made from glue-lam beams (left) and details of wall planks of the finished structure (right)

Using different programs gives different insights, contributing to the design process in a positive way. We learned that different techniques for modeling lead to different models in which various problems may be highlighted or hidden. When working with physical models it is important to vary materials, scale, and level of precision in order to explore a design fully. We feel that the same logic also applies to the digital model.

It was not our intention to teach the student the use of a specific computer program. The reason for using Cadwork was simply that it has an adequate export function to the production machinery that was available for us. It was rather an underlying intention that the students should learn to identify what program suits a specific need, making them more capable of finding the most appropriate tool for a given task.

Conclusion

All the significant components of the final structure were produced with the automatic joinery machinery at the two cooperating production facilities. The course thus explored the potential to build a complex shape with computer-controlled joinery machines. The project took the machines' production capacities far beyond their normal use. By doing this the project showed how contemporary

fabrication technology can be reflected in design. To our knowledge this is the first attempt by architecture students to explore and use in reality the design potential of automatic joinery machines or beam processors.

Although the concept, design and detailing phases were accomplished in a conventional setting, the realization of the structure's complex geometry would have been impossible without the feedback between the analogue project development and the digital project, and the final export of data from the 3D model to the CNC machinery.

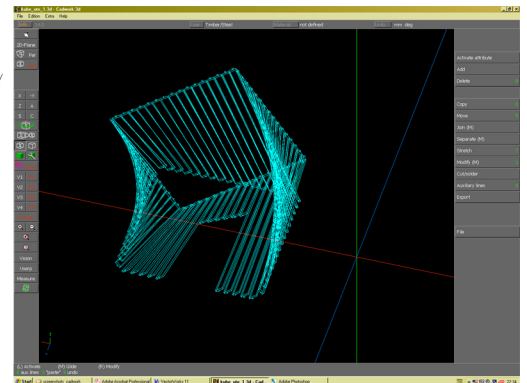
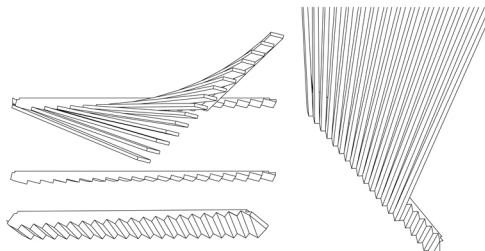
The final result is a documentation of the merging of the ancient technology of the camera obscura with contemporary use of digital fabrication technology.

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Without the open minds of John Anker Telhaug, managing director of Eikås Sagbruk AS, and Sigbjørn

Figure 5
The sill beams and wall
planks (left) and Cadwork
screenshot of the walls (right)



Daasvatn, managing director of Trebyggeriet AS, the course would not have been possible.

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References

- Aitcheson, R., Friedman, J. and Seeböhm, T.: 2005, 3-Axis CNC milling in Architectural Design, *International Journal of Architectural computing*, 02(03).
- Cadwork: 2007, Corporate Website, www.cadwork.de, accessed May 2007.
- Fricker, P. and Zieta, O.: 2006, CNC compliant methods of design. Understanding technology, in *Communicating Space(s)*, 24th eCAADe Proceedings, Volos, pp. 352-357.
- Callicott, N.: 2001, *Computer-Aided Manufacturing in architecture*, Architectural Press, Oxford.
- Harfmann, A.: 2004, Implementation of component based design. A pedagogical and practical case study, in P. Beesley, N. Yen-Wen Cheng and R. S. Williamson, *Fabrication. Examining the Digital Practice of Architecture*, University of Waterloo School of Architecture Press, Cambridge (CA), pp. 220-229.
- Hundegger: 2007, Corporate Website, www.hundegger.de, accessed May 2007.
- Iwamoto, L.: 2004, Embodied fabrication: computer-aided spacemaking, in P. Beesley, N. Yen-Wen Cheng and R. S. Williamson, *Fabrication. Examining the Digital Practice of Architecture*, University of Waterloo School of Architecture Press, Cambridge (CA), pp. 270-281.
- Kolarevic, B.: 2003, Digital production, in B. Kolarevic (ed), *Architecture in the Digital Age. Design and Manufacturing*, Spon Press, New York, pp. 29-53.
- Mitchell, W.J. and McCollough, M.: 1995, *Prototyping*, in *Digital Design Media*, 2nd ed., 417-440. New York, Van Nostrand Reinhold.
- Neumann, O.: 2007, Solid wood wall cabin + outdoor theater roof structure, in O. Neumann and P. Beesley (eds), *Futurewood. Innovation in Building Design + Manufacturing*, Canadian Design Research Network + Riverside Architectural Press, Cambridge (CA), pp. 51-55.
- Rüdenauer, K.: 2005, Web based configuration and CNC production, in *Digital Design: The Quest for New Paradigms*, 223rd eCAADe Proceedings, Lisbon, pp. 17-25.
- Sass, L.: 2004, A wood frame grammar system for digital fabrication, *International Journal of Architectural computing*, 01(04), pp. 51-67.
- Sharples, C. and Sharples, W.: 2006, Drawing in the digital age, in A. Chaszar (ed), *Blurring the Lines*, Wiley-Academy, Chichester, pp. 28-35.
- Stacey, M.: 2007, Canonbury canopy, in O. Neumann and P. Beesley (eds), *Futurewood. Innovation in Building Design + Manufacturing*, Canadian Design Research Network + Riverside Architectural Press, Cambridge (CA), pp. 40-43.
- Surjan, T. and Horton, P.: 2004, Appealing to the masses, or serious play with blocks, in P. Beesley, N. Yen-Wen Cheng and R. S. Williamson, *Fabrication. Examining the Digital Practice of Architecture*, University of Waterloo School of Architecture Press, Cambridge (CA), pp. 138-149.