CREATING PHYSICAL MODELS USING VIRTUAL RECONSTRUCTIONS: MIXED CAM-TECHNIQUES FOR A VIENNESE SYNAGOGUE SCALE-MODEL

Bob Martens
Vienna University of Technology
Faculty of Architecture and Regional Planning
Karlsplatz 13
A-1040 Wien
Austria
b.martens@tuwien.ac.at

Martijn Stellingwerff
Delft University of Technology
Faculty of Architecture, Section Form & Media Studies
P.O.Box 5043
2600 GA Delft
The Netherlands
m.c.stellingwerff@bk.tudelft.nl

Abstract

In the framework of a preceding SiGraDi-conference the virtual reconstruction work of Viennese Synagogues was elaborated. The focus of this continued research project is laid on historic/reconstructive modeling, which has specific requirements towards the modeling and subsequent production of scale models. In this paper, the prerequisites of 3D-printing and lasercutting technology for model making will be presented. This includes aspects of scale and handling of individual building elements regarding the possibilities and limitations for each specific CAM-technique. Compared to the rendering models, the modeling procedures for scale-model fabrication had to be adjusted. For example, certain dimensions for details and the structural strength of 3D-printed parts have to be taken into account. Due to economical and constructional reasons as well the printing time involved, a scale-model should be created by means of mixed CAM-techniques; building components have to be split up and assigned accordingly.

1. Introduction

Reconstruction of no-longer existent synagogues amounts to a "virtual comeback". Irreversible destruction - having permanently removed identity-establishing buildings from the urban surface - is the predominant reason for re-creating them. Following the destruction of the so-called "Reichskristall-Night" of November 1938 the synagogues of the Viennese Jewish community in the commemorative year of 1998 the first synagogue reconstruction was initiated. A contribution to the SiGraDi-conference in Rio de Janeiro (Martens et al, 2000) reports on the experiences gained from the initial modeling work.

Meanwhile, the number of realized reconstructions has become significant and therefore a systematic (fig. 1) was set out to support the unified modeling, as well as the future handling of these models in order to secure an enhanced level of sustainability (Martens and Peter, 2002a-b).

Virtual rebuilding activities in this working context are based on original (building) plans, historical images/photographs and in some cases statements of witnesses. However, besides the rather precise three-dimensional modeling work, the output of this research work has, so far, been restricted to renderings and (computer-based) plan depictions, etc. This could doubtless have been realized with a lower degree of accuracy. In contrast, the idea of "physical" computer aided model making depends on a specific level of 3D-details and a set of customized CAD-model files to direct the CAM-machines.

This contribution is written from a customer perspective (TU-Vienna being the visualisator with a physical modeling demand) and the supplier perspective (TU-Delft with a fully equipped Rapid Prototyping CAMlab). Explorations towards the preparation of model making are presented and this paper ends up with an outlook for further work.

2. Model Making: Context and Related Efforts

A strong interest towards digital fabrication can be observed in recent conferences and related journal articles. However, these efforts were predominantly aiming at realizations of building elements in full-scale size. The

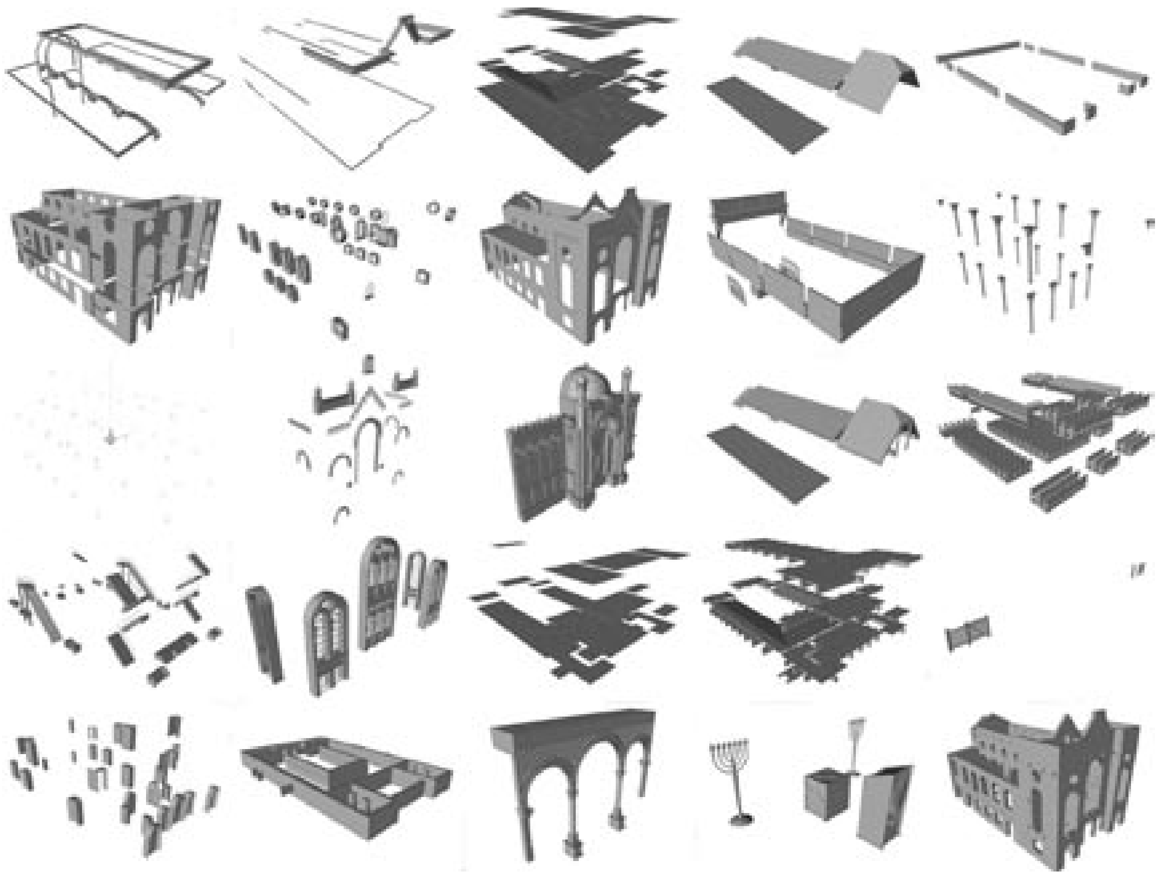

Figure 1: Overview on the layer structure (Reconstruction Schopenhauerstrasse).

conditions for creating a scale model out of digital data have not been widely published. Rapid Prototyping has potential applications for architectural modeling (Breen et al, 2002; Kvan et al, 2002), and limits have been explored already. An interesting overview on setting up a model-making lab at UAE University has been delivered by Benachir Kenzari (2005). It has to be stated that this paper builds upon these views and expands in the direction of modeling data management/preparation, as it is a misunderstanding, that once models are created, the 3D-printing as a scale model is straightforward in the sense of pushing the "print-button". On the contrary, careful considerations have to be made as to how the virtual shape can be split up into printable parts and elements - assigned to the "right" CAM-technique - in order to achieve an economic and durable delivery. The assemblage of individual (smaller) components and the structural considerations add parameters to the understanding of a completed design process. Analytical considerations in this respect are closely related to the building procedure and deliver new insight.

3. Procedure and Framework Conditions for Model Making

The synagogue in the yard of the Schopenhauerstrasse 39 was designed by architect Jacob Modern (1888/89) and destroyed in 1938. Using the framework of a diploma thesis, the virtual reconstruction work has taken place. Based on the setout systematic for layer and story definitions the digital model was developed.

Collaboration has been predominantly asynchronous through email contact and electronic data exchange; the modeling work being handled in Austria and the printing activity taking place in The Netherlands. Some elements were 3D-printed as a test pad in order to give the modeler an idea of the outcome and to get acquainted with the parameters of the production.

A *Versa-lasercutter* and a *ZCorp - 3D-printer* have been used for over two years at Delft University of Technology and valuable experience could be gathered from their experiences. The 30-Watt *Versalaser* allows handling several kinds of materials up to 6 mm in thickness. Besides laser cutting, engraving and marking of materials is also possible. Experiments have been performed to achieve experience on the use of the "right" materials. The term "engraving" seems to be misleading, as there is no precise control on depth of the burning effect. The surface can also be hatched with a surface pattern ("marking") but this takes much time and better effects can be achieved by means of painting. No cutting lines can be closer than approx. 0.7 mm to each other as a matter of principle, but it has to be noted that this is rather dependant on the material used. Stairs, for example, cannot be created by means of sticking a number of sections together. No single piece can be smaller than 5 x 5 mm or 3 x 10 mm as it will fall through the honeycomb-cutting surface of the lasercutter. The scale of the AutoCAD 2D drawing has to be set to 1:1 and drawn in millimeters. Double lines have to be avoided (for example, created by a copy of array orders) as these will result in different output. The maximum size of the whole plate, from which it will be cut is 609 x 305 mm and a margin of 5 mm has to be reserved. In case cutting lines of objects are shared, double lines have to be removed.

The *3D-printing capability* produces (24-bit color) models with a maximum printing volume of 254 x 203 x 203 mm. First, the printer spreads a thin layer of powder. Second, an ink-jet print head prints a binder in the cross-section of the part being created. Next, the build piston drops down, making room for the next following layer and the process is repeated. Once the part is finished, it is surrounded and supported by loose powder, which is then shaken loose from the finished part. Since a major part of the printing cost is determined by the amount of powder consumed (solidified by the binder), it may be necessary to modify the computer model by creating cavities or making walls thinner (if applicable). For example, printing a solid cube is rather expensive. Creating a cavity inside the cube and thereby printing only the walls with a reasonable thickness, will reduce the cost significantly. However, there has to be a way to get the unused powder out of the final part, either by leaving an opening in the bottom wall or by removing the bottom wall of the cube completely. Also, it is not preferable to stack the whole printer volume full with prints, as this makes it very difficult to get the (still brittle parts) out of the printer.

The ZCorp 3D-printer software was not only used in Vienna to test the model exports, but also to study the efficient use of the print volume and to estimate the costs. Practical experience was frequently needed and used to "optimize" the datasets. First of all, it was learned that exactly the same elements need to be exported just once, as a multiple print is practical. This required the export of parts and elements (for example a column) into single stl-files. However, this did not mean that the whole model to be printed was expected to be a breakdown of hundreds of individual components. In the case of the portal it seemed wise to have substantial parts as a whole entity within an individual stl-file. This also seemed reasonable, because the surrounding wall parts gave strength and protection to the small beams and details of the window casing. Furthermore, the decisions leading towards the choice of the appropriate manufacturing technique had to be learned and aimed to a fruitful mix, knowing that a lasercut is faster and cheaper. For example in the case of the portal, a combination of the laser-cutting and 3D-printing has been utilized. This approach lead to a meaningful "hybrid approach" of available CAM-techniques. Typically a lasercutter is chosen for use based on the consideration of flat parts consisting of details with minimum thickness of approx. 0.7 mm.

Surfaces need to have their normals consistently orientated in an outward direction as the 3D-printer evaluates each printed section whether binder fluid should be deposited

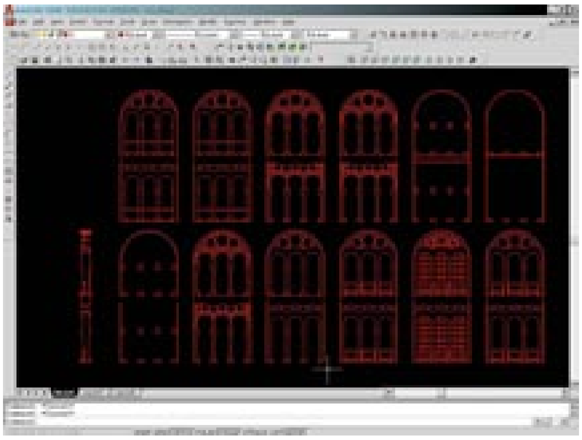

Figure 2: Example of the layers for a portal created by means of lasercutting.

or not. The machine-logic is very strict and one or more 'wrongly flipped faces' can corrupt the model integrity.
It proved to be of importance to know, that the calculation of the model printing costs takes the quantity of materials into account, which can be estimated by the ZCorp-software. This means that even if only smaller parts of the possible area within the printing boundaries are being used, the whole quantity of used powder etc. remains constant. However, the machine time used is also accounted for and can be estimated by the software as well.
In case of the lasercutting, the layout of to be cut elements has to be carefully considered as well, as the remaining material will be waste and the machine will have to work longer. Elements should therefore be positioned as close as possible to each other.

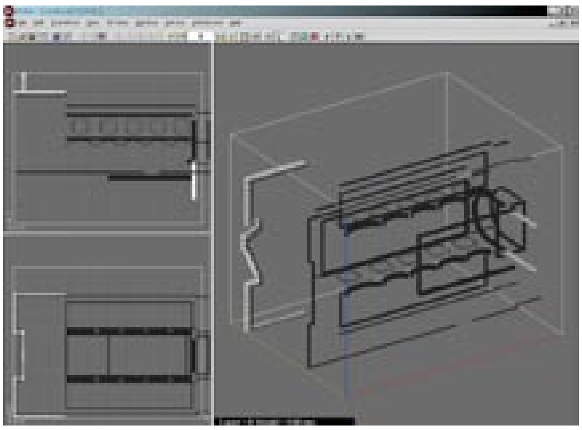

Figure 3: Inefficient use of the 3D-printing machine volume.

All in all, it has to be said that in most cases a simple split of a building model into partial volumes, which fit into the ZCorp machine will not perform well and leads to extremely high modeling costs. Therefore, a model must be disassembled into (groups) of building elements. Also a differentiation between "flat" and "non-flat" building parts is of high importance. Software packages such as *FormZ* and *Pepakura* support the translation into 2D-surface elements, which will be handled by the lasercutter. The parts and elements produced will be assembled after their completion.

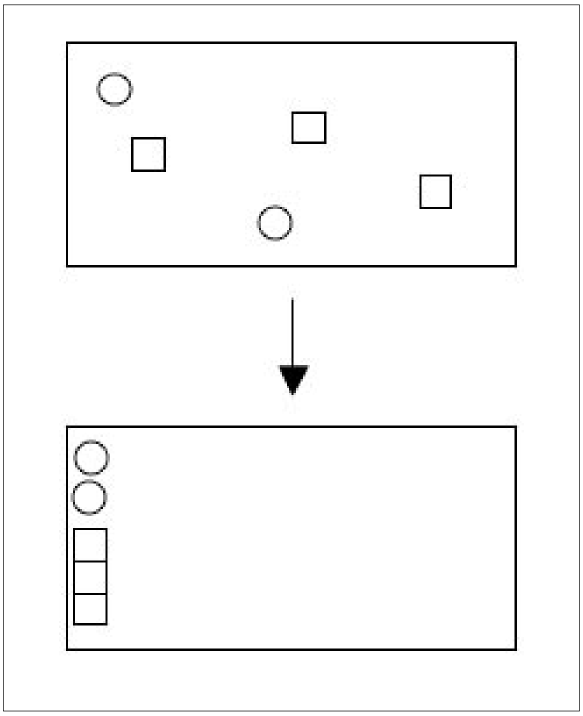

Figure 4: Lasercutting layout: Efficient use of material (Combining of cutting lines, etc.).

4. Future Work and Conclusion

It can be regarded as an innovative approach to produce a hybrid model, based on 3D-print and lasercut parts. However, care should be taken as printed parts are not 100% accurate in size and plaster has different physical properties (how they look and connect) compared to the lasercut materials. This can be seen as a challenge to setup an optimal model.

Figure 5: Example of detailed column created by means of 3D-printing.

First tests with the synagogue in the Schopenhauerstrasse (Vienna) have shown, that the consistency of the built up surfaces was well chosen, but an export in terms of building parts - differentiated towards CAM-techniques - was required after completion of the modeling. Eventually an export of data by means of a series of separate elements, as if it were a toy modeling kit, would suit as well. Some building parts seemed to be too detailed (small dimensions) - this might have caused problems especially if very thin materials (e.g. 0.5 mm) for laser cutting are used; also 3D-print parts cannot be too small, as they will crumble. A visit to Delft has been scheduled for the final printing work, but the result cannot be presented in this paper, as this working meeting will take place after the finalization of this manuscript.

The lessons learned concerned model making and the utilization of digital modeling data and can be summarized as follows:

- *Each level of scale comes with a distinct level of detail.* - Reconstruction by making scale models needs reinterpretation of the original building documents: details with their original architectural expression have to be translated to smaller scale with available CAM techniques in mind.
- *Each available CAM technique comes with a distinct range of possible form factors and levels of detail.* – Available techniques, in this case 3D-printing and 2D-lasercutting, have specific characteristics that have to be dealt with. The fact that the machines used are directed by data from computer models does imply that the translation from digital to physical needs knowledge about such characteristics. In collaboration projects (such as described here) this knowledge has to be shared and understood before further modeling decisions can be taken. Thus, while the machine produces the results, a level of craftsmanship is required from the modeler.
- *Each model material comes with a distinct image that could match original qualities.* – Under influence of scale, the iconic correspondence between the qualities of the original building and the qualities of the model allows certain reductions in details and in expression of the material. This implies that the architectural image of an original building can be reproduced with a reduced set of materials and colors in the model.
- *Telling an architectural story from the past needs careful choices regarding scale, modeling techniques and use of materials, in such way that a consistent overview can be shown.* – In order to bring across

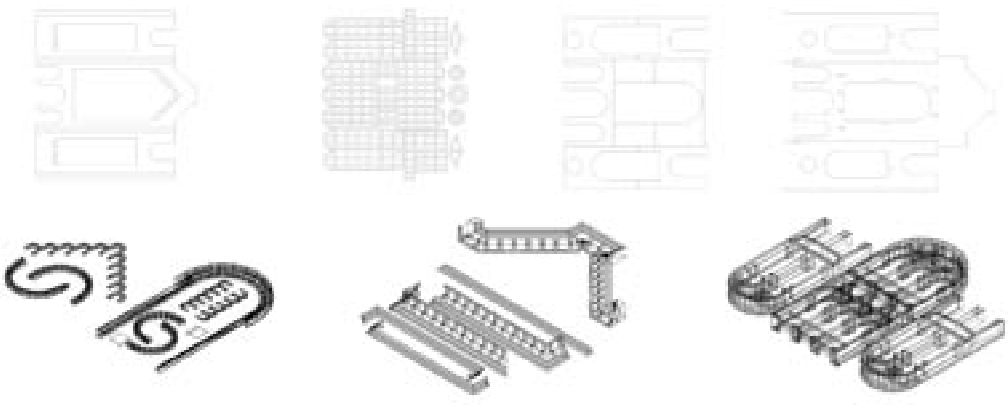

Figure 6: Example of data preparation for laser cutting and 3D-printing.

the heritage of a building and to gain knowledge, multiple approaches can enrich the understanding. Regarding the limitations of models related to their scale and materials, a consistent overview can be achieved by adding modeled parts of the building on a larger scale.

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Bob Martens
Assoc.Prof., MSc/DrScTech,
Areas of interest: Virtual Reconstruction,Spatial Simulation, CAD, CAM, Design Studio, Continuing Education, Electronic Publishing.

Martijn Stellingwerff
Dr. Ir., BSc/MSc/PhD TU-Delft Faculty of Architecture.
Areas of interest: Design Media, Design Methods, Research Methods, Contextual Design, CSCW, CAD, CAM, Fabrication.