Umbrella Schoolyard Roofs in Zurich

Reflecting on a 1:1 Seminar with Digital Sheet Metal Fabrication

Author(s):
Schindler, Christoph; Châtelet, Maud; Wiskemann, Barbara; Zieta, Oskar

Publication date:
2007

Permanent link:
https://doi.org/https://doi.org/10.3929/ethz-a-005960654

Originally published in:
https://doi.org/10.52842/conf.ecaade.2007.035

Umbrella Schoolyard Roofs in Zurich

Reflecting on a 1:1 Seminar with Digital Sheet Metal Fabrication

Christoph Schindler[1], Maud Châtelet[2], Barbara Wiskemann[3], Oskar Zieta[4]
[1,4] ETH Zurich, Department of Architecture, Chair of CAAD, Prof. Dr. Ludger Hovestadt, http://www.caad.arch.ethz.ch
[2,3]ETH Zurich, Department of Architecture, Chair of Architecture and Construction I /II, Prof. Andrea Deplazes, http://www.deplazes.arch.ethz.ch
http://www.ethz.ch
[1]schindler@designtoproduction.com

The paper discusses a 1:1 student workshop on digital sheet metal fabrication organized in collaboration between ETH Zurich and the City of Zurich in 2005 and 2006. During the workshop a structure of fifteen sheet metal schoolyard roofs was designed, produced, and constructed by the participating students. The workshop was set up to explore how current academic topics such as CAD/CAM, digital fabrication with minimal tolerance, and design optimization with genetic algorithms could be incorporated in a permanent structure with legal building standards and a professional construction sequence.

Keywords*: Teaching seminar workshop 1:1; digital sheet metal fabrication; pavilion roof structure; genetic algorithms.*

The academic and the professional construction site

Architectural education at academic institutions worldwide has made a shift from producing scaled representations of a design such as plans and models to producing 1:1 samples and structures. Besides the intention to teach materials and processes (Dean 2002, Deplazes 2003), an initial motive for many projects is the fascination with digital fabrication technology. Rapid prototyping production samples (Sass, Shea, and Powell, 2005), furniture (Fricker and Zieta, 2006; Kilian, 2006), interior pavilions (Schindler and Zieta, 2003; Rüdenauer, 2005; Schoch, 2005; Sowa, 2005), interior design (Artopoulos, 2006; Schindler, Braach, and Scheurer, 2006) and inaccessible exterior pavilions (Fritz, 2003) have been manufactured at university workshops with 3-axis routers, laser cutters or likewise at many institutions with impressive results. In those projects the potential of information technology in planning and fabrication is pushed to its limits, while weather, climate, safety, and durability are considered negligible. However, permanent architectural outdoor structures are to comply with many practical requirements such as rain drainage, structural needs, user safety and other legal building standards. How compatible are academic ideas on all-embracing digital fabrication with the requirements of a professional construction site?

Figure 1
The result of the student workshop at ETH Zurich: a permanent 50m2 schoolyard roof

A metal roof for a schoolyard

Two chairs at the department of architecture at ETH Zurich set up a project to explore the connection between academic design and professional fabrication with information technology. To create a realistic scenario, the Chair of CAAD of Prof. Dr. Ludger Hovestadt and the Chair of Architecture and Construction I/II of Prof. Andrea Deplazes contacted the City of Zurich who generously offered to cooperate on the construction of a small permanent shelter of 50m^2 for a schoolyard at Kernstrasse in Zurich. While ETH Zurich contributed the labor of academic staff and students, the City paid for the materials and all works that could not be completed by the students. As for two reasons, metal was initially selected as the preferred building material:

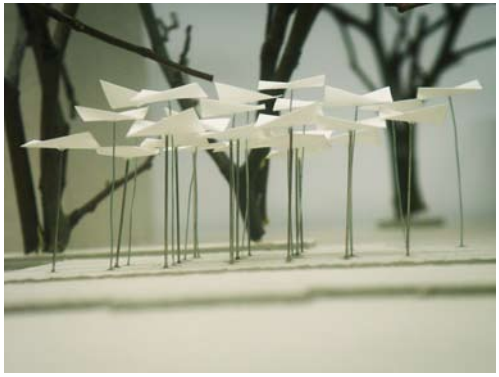
First, metal is a resistant material for public structures that have to face vandalism.

Second, there is a wide range of CNC metal processing machines especially for sheet metal (laser cutter, bending, punching) but as well for profiles (tube laser cutting, tube bending).

First seminar week: Introduction to metal processing and design competition

The workshop was integrated into the teaching program at ETH in the form of two successive seminar weeks: The first week was meant for the design of the structure, the second week, one semester later, for producing and building

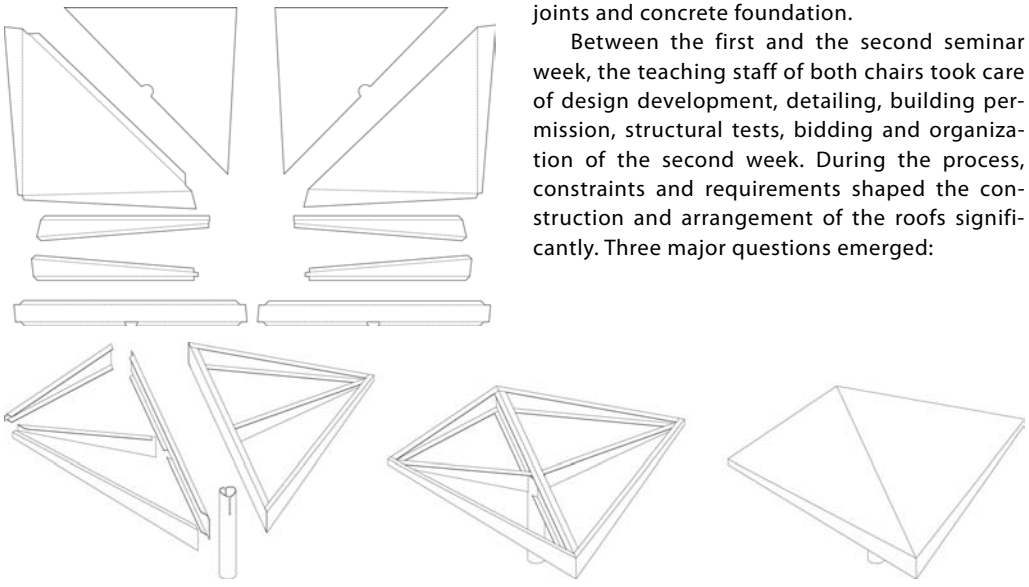
Figure 2
The winning competition proposal – how to build folded paper on pins in scale 1:1?



it. Before, between and after those weeks the academic staff at the two chairs organized the building process.

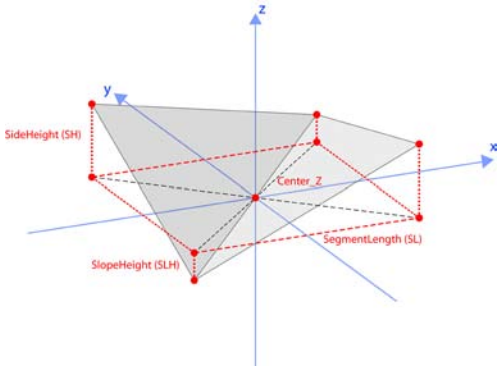
The first seminar week took place in the winter semester 2005/06 with fifteen participants. As an introduction to metal processing, every student was asked to design an object of his choice from a sheet of metal 2000 x 1000 x 1mm.

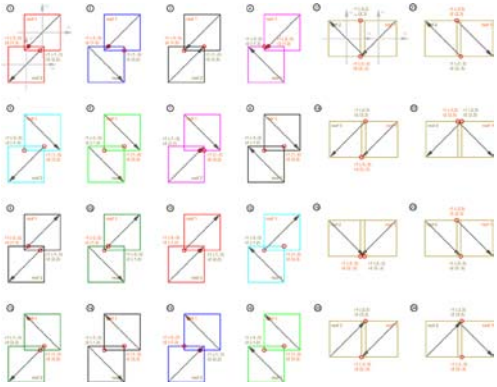
Figures 3 and 4
The frame elements and the cladding are digitally manufactured from sheet metal



In the process, the participants learned at different departments at ETH how to work with both manual (sanding, welding), mechanical analogue (bending, drilling, sawing,) and computer-aided technologies (CNC laser cutting, nesting and post-processing with related CAM software). With this knowledge, the students developed six proposals and appropriate metal process chains in teamwork. The ideas included designs made from tube profiles, sheet metal and even discarded metal. A jury consisting of representatives of the City of Zurich, the involved chairs, and a structural engineer selected a structure consisting of various small roofs that drained rain water cascade-like from roof to roof to the ground – the umbrella roofs. In top view, each roof is a square folded along a diagonal. The diagonal is inclined and mounted on a column. The winning design was presented in three scales: A sketch model 1/500, consisting of folded paper on pins, a design model 1/20 with a folded metal supported by four bent tube profiles, and a detail model 1/3 explaining the same idea including joints and concrete foundation.

Between the first and the second seminar week, the teaching staff of both chairs took care of design development, detailing, building permission, structural tests, bidding and organization of the second week. During the process, constraints and requirements shaped the construction and arrangement of the roofs significantly. Three major questions emerged:





Figures 5 and 6
Global variables (left) and 24 different possible overlap types with critical points (right)

Construction: Exploring the range of application for non-standard elements

The detailed umbrella roof design from the competition proposal was difficult to realize. Based on the sketch design with paper on pins, the teaching staff sought for a construction that could be manufactured as digital as possible. Instead of using standard profiles, a sheet metal construction processed with laser cutter and CNC bending machine was the desired solution. A paper-like construction was approached, using metal like origami with large folded surfaces as tested in former 1:1 academic experiments built at ETH (Fritz 2003; Schindler and Zieta, 2003; Fricker and Zieta, 2006). The sheet elements were to be both structure and cladding. However, as soon as analyzed and adjusted by the structural engineer, the numerous 'origami' variants turned out to be heavy and inefficient. Eventually, structure and cladding had to be separated like in most steel frame construction buildings: The final construction consists of a structure of non-standard profiles, cut and bent from 4mm sheet metal, and a cladding, cut and bent from 2.5mm aluminum sheets. The work space of the machines designed to process standard sheet metal of 3000 x 1500mm narrowed the solution space for the construction significantly and limited the dimensions of the roofs to a square of 1.80 x 1.80m.

The structure reminds of a distorted set of I-profiles that are assembled to a frame. Every frame consists of nine elements and weighs in mounted state about 250kg. It is completely wrapped by the aluminum cladding. The columns are 140mm standard tube profiles. By using a round standard profile for the accessible part of the roof the risk of injury could be minimized.

Arrangement: Exploring the range of application for genetic algorithms

The second challenge was the arrangement of the roofs: The number of roofs, their positions and their relations—in terms of drainage—were flexible. The number was depending on the budget and the cost per unit, the position of the roofs was determined by a grid of possible locations, and the relations between them had to be optimized in order minimize the number of drainage points and the height of the total structure.

The search for optimal solutions for this set of requirements seemed to be a perfect opportunity to apply genetic algorithms as used for similar questions earlier by Scheurer (2005). Within an elective course, one of the participants coached by the Chair of CAAD developed an automatic arrangement-tool for the roofs. The program was written in VBA and used Microsoft Excel as user interface for the input of global parameters and the output of results, and

AutoCAD for graphic output. The grid of possible locations and the number of roofs were predefined. All roofs had an identical geometry, differing only in the height of the column (infinite possibilities) and the direction of the inclination (four possibilities). The fitness value for a configuration of roofs was calculated from the number of collisions between roofs (penalty criteria) the number of drainage points and the height difference between the lowest and highest roof.

As the schedule of the project was tight, a limited period of time was given for the optimization project. To have a fallback solution, manual solutions were developed simultaneously. As the moment came to fix the arrangement and define the foundation, the manual solution turned out to be superior: While the programmed strategy did not manage to generate solutions with less than six drainage points, the manual solution only needed three. At first, this result was very surprising for everybody as the number of relevant design parameters was considered beyond manual control. However, the amount of fifteen roofs was still controllable with an effort of three-dimensional variant drawing far below the programming effort. Advantageous for the manual solution was especially the possibility to change the habitat and other predefinitions very quickly.

Production: Exploring the range of application for university machinery

The initial seminar conception was to manufacture as many elements as possible on university facilities, particularly on an industrial laser cutter at the ETH Department of Mechanical and Process Engineering that had served for the former 1:1 academic experiments (Fritz 2003; Schindler and Zieta, 2003; Fricker and Zieta, 2006). But for two reasons, university facilities were soon out of question: First, they just could not process the metal thicknesses required for a permanent, durable structure. Second and more important, ETH as an institution could not assume liability for the construction.

Therefore, the production phase for the roof had to be set up in a professional workshop. A metal workshop in the Greater Zurich Area kindly agreed to cooperate. A detailed process plan including laser cutter, bending machine, welding station, assembly station and storage units was carefully prepared for the second seminar week in the summer semester 2006. A 1:1 mock-up of one of the roofs including column and foundation was produced at the workshop to test the workflow. The mock-up was transported to the campus where structural performance (with hanging weights), leak tightness of the cladding, and flow conditions of the drainage system (both with rain simulation) were studied thoroughly.

Figures 7 and 8
Learning by doing on automated (CNC-bending) and manual tools (welding)

Figure 9
Fifteen galvanized roof frames waiting on the ETH campus for assembly

Second seminar week: Production of the elements

The second seminar week took place at the professional metal workshop. Seventeen students and four tutors inhabited the shop for one week. Professionally instructed by the owner, the participants learned CNC laser cutting, CNC bending, sanding and welding. Within this week, the structural frames (15x 9 elements) and the cladding (15x 4 elements) were cut, bent, welded, and sealed.

Construction: Assembling the elements

Subsequent to the production in the workshop, the structural frames and the cladding were surface treated: While the cladding received a white paint, the frames had to be galvanized. The galvanization process was performed very crudely and the frames returned deformed with several open welds that had to be fixed.

In the meantime, foundation works had started on the construction site. As each roof is supported by just one column, a strong continuous reinforced foundation plate had to be poured. The columns were fixed with adhesive anchors. The cladding was mounted on the frames and subsequently the whole roof was lifted by crane to the columns. The last roof was lifted and fixed with suspense: At one point in the structure, it seemed as if two roofs would intersect and the added tolerances of all processes were bigger than the intended minimal distance between the roofs of 100mm.

After one year of succeeding seminar weeks and elaborate preparations, the umbrella schoolyard roofs were inaugurated by the director of the Zurich Building Department in September 2006.

Conclusions

By integrating an academic approach in a professional environment, the workshop put several much-lauded characteristics of computer-aided design and manufacturing into perspective:

Percentage of digital fabrication in the entire project

The schoolyard roof is a pure metal structure. But only one third (32%) of the total building cost of 112'000 CHF in this pure metal building was actually spent on digital sheet metal processing. The entire metal work with manual and mechanical processes was only 56% of the project – all the rest was spent on foundations, installations and fees. Considering that academic staff and students contributed their labor for free, the cost of the building process controlled by digital fabrication is an even smaller fraction. The same image is visible in the time schedule: The project was roughly one man-year of work and consisted mostly of planning and manual labor. The

digital fabrication on the laser cutter and bending machine at the workshop was done in just two days.

Benefit of optimization with genetic algorithms

Genetic algorithms are definitely a very promising strategy for complex problems. But, apparently, arranging fifteen roofs on a plot is not complex enough. The effort for programming and the effort for manual planning were in an unfavorable ratio. As long as manually manageable complexity is not exceeded, automation is only advisable if the program is applied more than once (e.g. in a customized serial production). Complexity seems to start around several hundred different pieces.

Benefit of digital fabrication

An obvious but most prominent benefit of digital fabrication is the automated positioning of the tool. In an industrial production the position of joints and connectors is not automatically determined. In spite of mechanization, an element is drawn by hand twice: Once with ink on paper and once with the scriber for marking on the element itself.

With the interconnection of information and material processing the machine executes a plan directly: The production step 'marking' is skipped, as the information (CNC electronic G-code) contains the positioning. Jigs become unnecessary. Automatic positioning quickens the production process independently from the elements being equal or individual.

The result of this positioning is an efficient production with very low tolerance. The laser cutter used in this project has a tolerance of about 0,1mm. However, in the following processes the low tolerance got lost: At the CNC bending machine, the tolerance added a power of ten to 1mm. After the rough galvanizing process, surprisingly another power of ten was added: some elements had a tolerance up to 10mm. Apparently, the exactitude of digital production is far beyond the tolerance of other processing steps. It turned out that the crucial part in the project was not the digital production, but the joining of the elements. The advantage of low tolerance can only be used for the final result if retained by the successive processes both in the workshop and – even more difficult to predict – on the construction site.

Benefit of teaching 1:1 digital workshops

Maybe the greatest benefit of the project was the educational effect: The participants watched the huge laser machine cutting exactly the same drawing they had drawn minutes earlier on their screens. If there was a mistake like a double line in the file, there was a mistake in the element. At the same time, they experienced that an element is not finished after pressing the start-button at the laser cutter. The students got an impression of the kind of problems they would face in the process between design and production in their future professional activity.

Summary

Although information technology in planning and fabrication is certainly the contemporary force in building industry, it became evident that it does not substitute manual or mechanical labor. Manual, mechanical and automated fabrication does not replace, but amplify and complete each other. Including information technology in the contemporary building process does not mean an exclusive use of digital tools, but a smooth integration with defined interfaces to existing manual and mechanical technologies.

Acknowledgements

This project has many more authors than the ones listed above. First of all, we wish to thank the City of Zurich for the fantastic collaboration, namely Sandra Zacher, Mark Ziegler and Ruedi Detsch.
Ludger Hovestadt and Andrea Deplazes gave us the possibility of organizing this course at their chairs at ETH Zurich. This structure could not have been realized without the participating students of architecture: Corinne Aebischer, Roman Bieri, Raphael

Bollhalder, Benjamin Bollmann, Rosanna Borsotti, Simone Buchmann, Silja Ebert, Manuel Gross, Jens Jaschek, Mirjam Kägi, Michael Keller, Simon Kraus, Fabian Landolt, Lorenz Leuenberger, Milena Vuletic, Thomas Raoseta, Michael Reiterer, Pascal Rosé, Michael Schiess, Mick Schneider, Stefan Vetsch, Samuel Waehry, Christian Walser, Arne Weiss. We are much indebted to Lorenz Leuenberger and Fabian Scheurer who worked hard on finding an optimal arrangement of the roofs with genetic algorithms.

References

Artopoulos, G., Roudavski, S. and Penz, F.: 2006, Adaptive Generative Patterns: design and construction of Prague Biennale pavilion. in: Computing in Architecture / Re-Thinking the Discourse: The Second International Conference of the Arab Society for Computer Aided Architectural Design (ASCAAD 2006), 25-27 April 2006, Sharjah, United Arab Emirates.

Dean, A. O. (ed.): 2002, Rural Studio: Samuel Mockbee and an Architecture of Decency. Princeton Architectural Press.

Deplazes, A.: 2003, 1:1 Wood works : ein experimenteller Massivbau. Zürich: GTA Verlag, ETH.

Fricker, P. and Zieta, O.: 2006, CNC Compliant Methods of Design - Understanding Technology. in: Communicating Space(s) [24th eCAADe Conference Proceedings / ISBN 0-9541183-5-9] Volos (Greece) 6-9 September 2006, pp. 352-357.

Fritz, O.: 2003, Bauen mit Computern. in: Archithese 02/2003. Zurich: Niggli. pp. 46-51.

Kilian, A.: 2006, Design exploration with circular dependencies: A chair design experiment. in: CAADRIA 2006 [Proceedings of the 11th International Conference on Computer Aided Architectural Design Research in Asia] Kumamoto (Japan) March 30th - April 2nd 2006, pp. 217-226.

Rüdenauer, K.: 2005, Web Based Configuration and CNC Production. in: Digital Design: The Quest for New Paradigms [23nd eCAADe Conference Proceedings / ISBN 0-9541183-2-4] Lisbon (Portugal) 21-24 September 2005, pp. 17-25.

Sass, L., Shea, K. and Powell, M.: 2005, Design Production: Constructing Freeform Designs with Rapid Prototyping. in: Digital Design: The Quest for New Paradigms [23nd eCAADe Conference Proceedings / ISBN 0-9541183-2-4] Lisbon (Portugal) 21-24 September 2005, pp. 261-268.

Scheurer, F.: 2005, Turning the Design Process Downside-up. in: Computer Aided Architectural Design Futures 2005 [Proceedings of the 11th International Conference on Computer Aided Architectural Design Futures / ISBN 1-4020-3460-1] Vienna (Austria) 20–22 June 2005, pp. 269-278.

Schindler, C. and Zieta,O.: 2003, 7-Tage-Pavillon. in: archplus 164/165 Das Arsenal der Architektur, Aachen : archplus, p. 111.

Schindler, C., Braach, M., Scheurer, F.: 2006, Inventioneering Architecture: building a doubly curved section through Switzerland. in: Synthetic Landscapes [Proceedings of the 25th Annual Conference of the Association for Computer-Aided Design in Architecture] pp. 136-145.

Schoch, O.: 2005, Applying a Digital Chain in Teaching CAAD and CAAM. in: Digital Design: The Quest for New Paradigms [23nd eCAADe Conference Proceedings / ISBN 0-9541183-2-4] Lisbon (Portugal) 21-24 September 2005, pp. 125-129.

Sowa, A.: 2005, Computer-Aided Architectural Design vs. Architect-Aided Computing Design. in: Digital Design: The Quest for New Paradigms [23nd eCAADe Conference Proceedings / ISBN 0-9541183-2-4] Lisbon (Portugal) 21-24 September 2005, pp. 229-236.