Computer-Aided Architectural Design vs. Architect-Aided Computing Design

Architect/computer interaction in the digital design process on the example of advanced CAAD/CAAM project

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http://republika.pl/x_cube/

Abstract. *This paper presents a recent design project – a group work of postgraduate students of CAAD Chair at Architecture Faculty at Eidgenossissche Technische Hochschule (henceforth ETH) in Zurich, Switzerland. In this project a broad variety of possibilities provided by CAD and CAM in architectural design was used, in terms of both the design and production. The paper will present the entire process step by step from its conception to production. Nowadays CAAD technologies seem to dominate not only in visualization and drafting. They have also started to play a more important role in the generation and optimization of the design, which have always traditionally been perceived as the domain of architects. Therefore, the focus in the paper will be placed not only on extensive usage of digital tools, but also on analysis of advantages and difficulties in architect/computer cooperation.*

Keywords. *structure generation; structure optimization; rapid prototyping; CNC production; CAAD education*

Introduction/Project

CAD and CAM technologies have opened up new opportunities for the creation of very complex architectural structures, which until recently had been too difficult and expensive to design, produce and assemble. Digital tools can also assist the designer in his/her thinking process from the very beginning (Kolarevic, 2001).

During the postgraduates studies at ETH in the CAAD Chair, the students get to know the state-of-the-art methods and tools used recently in the digital (architecture) design process. They learn not only how to program sophisticated forms and graphics, which would look good on the screen, but also how to manufacture their designs with CNC machines and rapid prototyping tools. Because the focus is on the CAM processes, as a final group work the students are expected to design and build an architectural object in 1:1 scale, using all techniques and tools they learn throughout the studies. After four months of hard work, such as programming, production, experiments and discussions, the final result was achieved – the prototype of the designed structure was presented at an exhibition at ETH as so called “x-cube”.

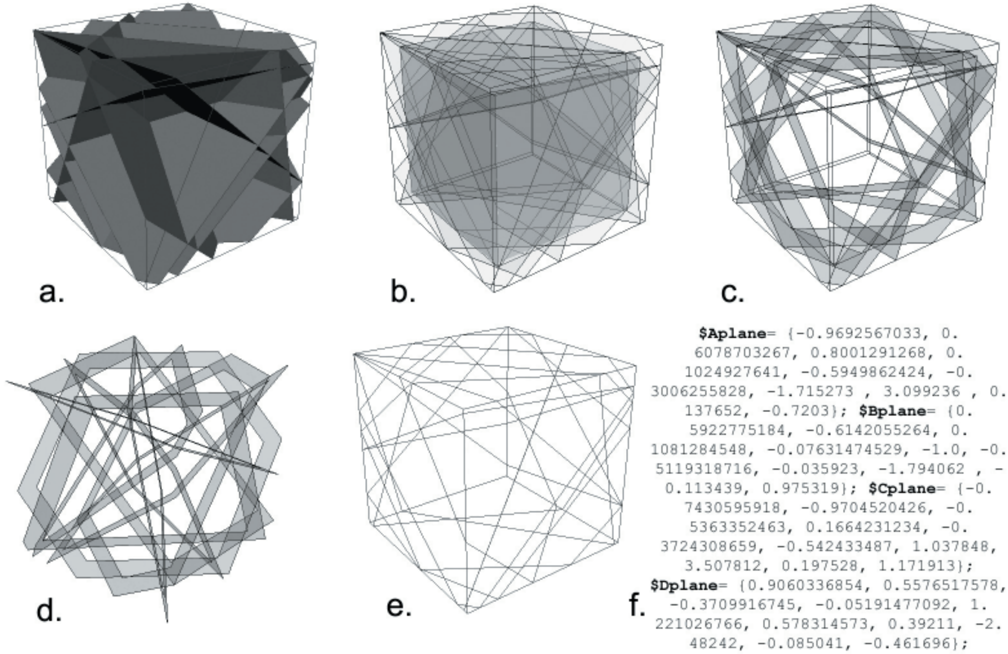


Figure 1. General idea of the structure. (1a) freely rotated planes inside a cube; (1b) subtraction of an inside form; (1c) frame structure with wireframe visible; (1d) frame structure; (1e) linear representation for calculation purposes; (1f) mathematical description of a frame set (four coefficients for every frame).

Idea

The first idea of the project was that it should not only be produced by machines, but also that the design process itself should be widely supported by computers. But the design did not proceed in the direction of free forms or "blobs", which seem to be the most visible manifestation of using digital technologies in architecture recently, easy to visualize on the computer screen but then difficult and expensive to build. Owing to tight deadlines and limited programming skills of the group members, it was decided to concentrate more on the complexity of joints and production, rather than the creation of trendy curvilinear forms. The initial idea of the project was to create a 3-dimentional irregular straight-linear grid for a small scale architectural form. It would then be used as a basis to produce real construction elements for 1:1 prototype, which should be easy to re-assemble and transport. The grid appeared as an intersection of freely rotated planes and a cube – an outside form of the object (fig. 1a). The inside space was also a cube, subtracted from the bigger one (fig. 1b) The result of this scheme was a structure build by irregular frames (fig. 1c, d).

The grid was expected to be parametrically generated so that it could have different densities as well as different levels of irregularity depending on designer preferences. (fig 2a, 2b). The size of inside space was also parametrically defined (fig 2c, 2d).

The choice of programming tool was made already during the conceptual work – it was MEL (Alias Maya™ Embedded Language) that was chosen. First and foremost it was because it seemed to be easy to use for the challenges expected during the work, and secondly because students were already familiar with its syntax and capabilities. As it turned out later, it was not the best choice – MEL and Maya were not stable enough to carry complicated calculations needed for optimization. As for other purposes (such as the generation, preparation of production drawings, etc.), the scripting language met the initial expectations.

Workflow

The work on the project proceeded as follows: firstly, a simplified digital model of the structure was prepared in MAYA for visualization purposes (fig. 1a). From the programming point of view, there

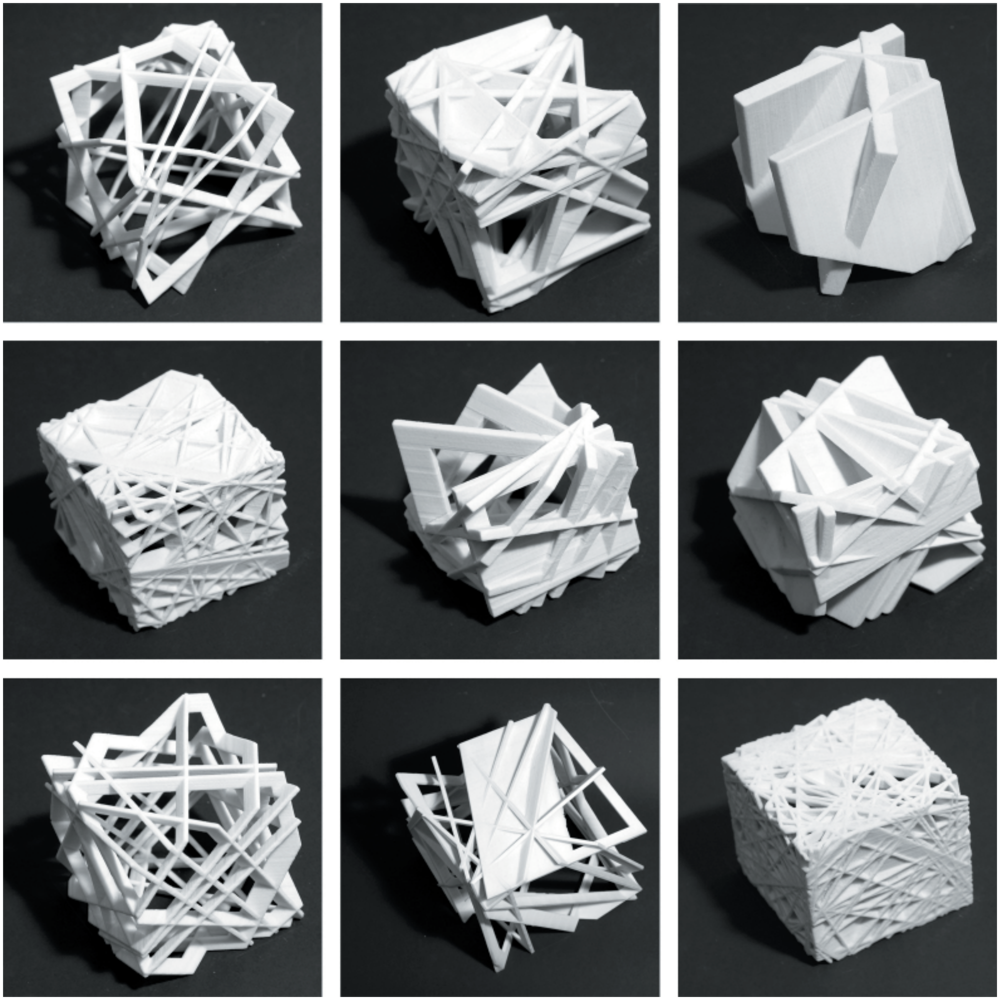


Figure 2. Examples of different cubes produced by a plaster 3D printer – showing different densities of the grid as well as a variety of possibilities offered by changing the frame thickness and proportions between the outside and inside cube.

is no need to visualize the data during and after the generation process. A visual analysis, however, can be useful both for the programmer and the designer since they can evaluate the scripting progress and aesthetic results as well as draw conclusions about the structure. Simultaneously with visualization tools, next MEL scripts were being designed to enable the generation of the carrying structure. The result of the generation process was a mathematical description of the created wireframe (fig. 1e) as a set of planes' coefficients. All other scripts were prepared in such a way that they needed just this very small amount of data (these four coefficients for every structure frame) to redraw the entire grid. Owing to this method information on very complex structure is stored in a relatively small text file (fig. 1f). The structure information could be easily exchanged between different scripts (e.g. for optimization, production).

The grid generated by the script cannot be used instantly as the carrying structure because it is created randomly and it does not satisfy all the conditions which have to be fulfilled by a buildable structure. A variety of these conditions can generally be quite large: the type and thickness of the material influence the structure and features of potential covering panels. The final shape is also dependent on the type of machines used to manufacture elements.

The aim of the optimization was to improve the structure so that it could be possible to build it with CNC machines; in other words, to translate an abstract mathematical model into a real form with all its limitations. In the optimization process it was

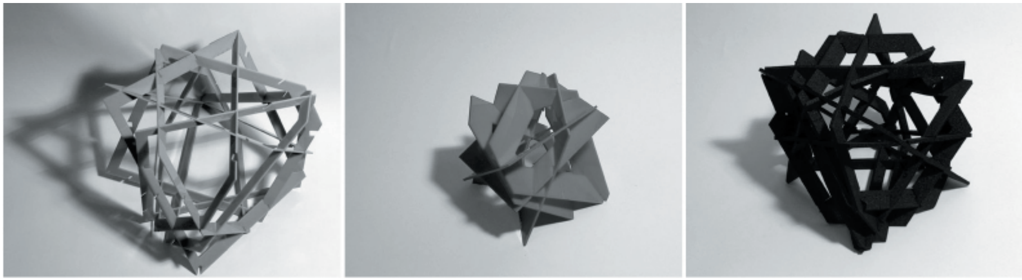


Figure 3. Examples of structures made from different materials – Plexiglas, cardboard, rubber, by laser cutter.

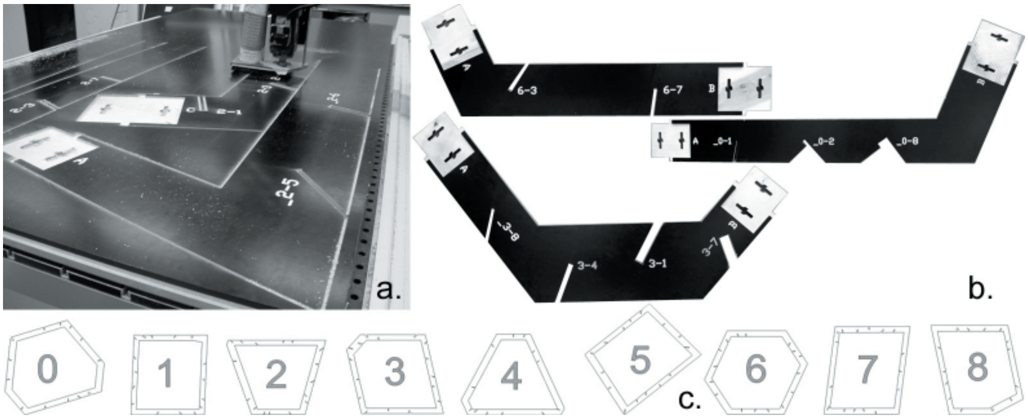


Figure 4. Production process. (4a) elements were cut by3-axis milling machine; (4b) elements of the frame with engraved descriptions; (4c) set of frames for the prototype;

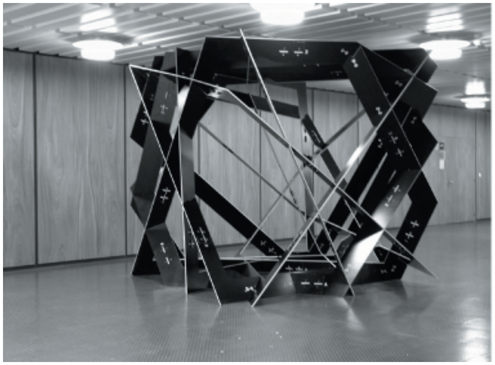
planned that the genetic algorithm would be used. Due to time constraints for programming, a simplified version of the evolutionary algorithm was finally created, which fulfilled the expectations only partially. Every plane was analyzed in the environment of other planes, i.e. to examine whether the joints it created with others have proper features for future production (e.g. the distance between joints, amount of connections with other frames, etc.).

The optimized structure constituted the basis used to automatically produce fabrication drawings for CNC machines, also generated by MEL scripts. The progress of the design was all the time controlled by the evaluation of models, digital as well as physical, produced by rapid prototyping machines (3D printer, laser cutter) from different materials (Plexiglas, cardboard, wood, foam) (fig.3). Joints design – from the first sketches until the final outcome – was also constantly supported with production of prototypes.

As was mentioned before, the structure was expected to be easy and fast to produce and assemble. These features were achieved first by making the elements ready to use already after milling (without post-production), and second, by preparing the system of elements coding (every element was engraved with a description of its position inside the structure as well as information about elements it is connected with). The final effect was the successful production of wooden 1:1 prototype, where the assembly rules were also programmed by the script (fig.4). All details, additional information and more pictures can be found in Sowa (2004) and in the NDS group work booklet (http://wiki.arch.ethz.ch/twiki/bin/view/NDS/Nds0304GroupWork, May 2005)

Additional research

Not all 13 members of the group were involved in the proper work on the structure. For some of them, it was more a starting point for additional studies, for example light analysis. The most impressive research was done by Anna Jach and Hanne Sommer on laser cutting and engraving different materials, as a preliminary study for panel production (the first idea of the cube was that spaces between frames were expected to be filled by laser-cut panels). The result of this research is a comprehensive analysis of laser cutting results on cotton and wood textiles, crimpline, polyester and fiber glass, mats of cork, silicon, latex, solid rubber, cellular rubber, foam rubber, acrylic sheets (transparent, translucent, colored), polypropylene, macrolon, epoxy resin and polyester resin, Teflon and polyamide plastic. On every material sheet the same vector and pixel graphic were lasered by "X-600 500W" (Universal Laser Systems). The re-



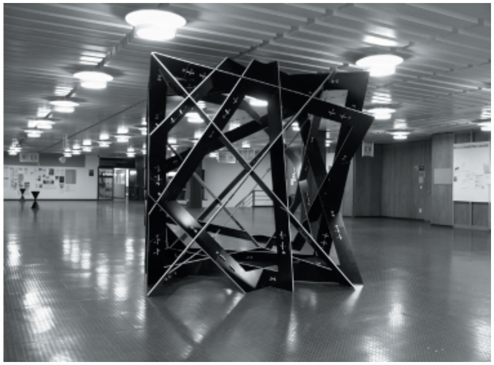


Figure 5. Final object "x-cube" – 2.70x2.70x2.70, nine frames, made of wood. Fabrication and assembly time 48 hours.

sulting engraved samples were gathered together with all the information about laser settings (power, speed and resolution) in two books which can be used as a reference guide for other laser cutter users.

Further research

Further work on the structure itself could proceed in the two main directions. Firstly, the programming tools could be developed so that they can handle other volumes: from non-regular but also non-curvilinear forms to NURBS, with different optimization factors influenced by different methods of CNC production and materials used. The other way to continue the initial idea is to work on other construction systems using the same grid for different scales (patterns and ornaments vs. construction systems) and purposes (for example kiosks, fair stands, etc.).

Observations and conclusions

Ever since the computer appeared in architectural design for the first time, architects have been afraid of the idea that machines will take over their role as form designers, artists, engineers in the sense of creative values. But in the digital design process, it is still the designer who "tells" the machine what to do. The computer, however, allows architects to regain control over the entire design/building process.

Form creator – could it be machine?

Sooner or later we will have to face the situation in which "(…) there won't be conventional drawings [in the design process]. There will be no paper, but fully documented three-dimensional models on CD (…). In the future we will have a digital model, then go directly to CADCAM manufacturing process" (Belmond et al, 2002). But even among CAAD students who had chosen this particular course to broaden their knowledge in the digital design, already during the conceptual work on the presented project, two main opinions clashed – the fascination with technology and opportunities it provides, with the idea about the architect as the form designer who has the influence on the appearance of every detail of the final project.

On the one hand, it seemed to be obvious and easy to accept that the computer plays increasingly larger role in project coordination and planning, or information exchange. On the other hand, the idea that the form could be generated by a computer program on the basis of different factors (for example environment features) resulted in controversies and protests. So even if the workflow is also a good example how to teach digital architectural design methods, the author as a student herself has one critical remark related to the coordination and leadership expected from the CAAD chair assistants at the initial phase of the work. It was expected that the final project would be a result of the work of all the members of the group (i.e. 13 people). It turned out at the very beginning that there is too many individuals to find fast a work idea which would be a compromise between "computer form generation supporters" and believers in the statement that "it is the architect who is the one and only form creator". Moreover, during the work it was also difficult to cooperate and coordinate work of so many people as well as to communicate in English, which was none of the students' mother tongue. Naturally, postgraduate students are always expected to be independent and creative in their work. But perhaps with some moderation of the discussion, the initial phase of the work would have been shorter and there would have been more time for "real work".

Architects' wishes in digital design process

Mostly because of the already mentioned time limitations, it cannot be claimed that the results of the research can be used instantly in the real building process. Nevertheless, the elaborated digital design work schema seems to be satisfying. So is the fact that the group of architects – neither qualified programmers, nor constructors – was able to design, program, produce and build such a structure in quite a short time seems to be significant.

Other observation about the digital design process was that it turned out that there is always a strong wish to change the computer-generated structure manually, to give the "human touch" to the soulless effect of machine creation. That wish resulted in the creation of special tools – scripts which enabled additions and changes in the structure during and after calculations. One of them could be used to add manually a construction frame or to change its position and then add its coordinates to the mathematical description of whole structure. Every "human" architect who looked at the model claimed that he/she would be able to add or change the structure immediately and easily so that it would better meet the expectations. But after a short 'battle' almost everyone gave up because movements and adjusting in one joint made the situation worse on the others. The final structure, however, is a result of computer generation and optimization as well as human addition and adjustment.

Conclusions

Generally speaking, the final version of the structure built should be regarded only as an instance of an endless variety of possible solutions offered by the computer. Accordingly, the work presented should be perceived as an exemplary extended use of still uncommon architectural design method, where the computer is present at every stage of the process and where it exerts a big influence on the final visual form of a project. Moreover, if it wasn't for computers, the creation and execution of such an idea would be impossible, at least in such a short time.

What is more, it can be said that in the presented project not only do digital tools had an influence on the final design, but it was also the designer who influenced digital tools. The presented project is then not an example of how CAD/CAM technologies are taking over the role of architect/engineer, but how the computers and human minds, machines and handicraft could be combined together, and cooperate in order to achieve the best possible result.

The author of this paper, as one of the students, was responsible for generation of the wire frame model of this grid and its optimization with regard to diverse aesthetic, manufacturing and material features. She also cooperated in joints and assembly process programming.

Acknowledgements

The project presented in this paper was a group work of postgraduates studies at ETH in 2003/2004 at the CAAD Chair by professor Ludger Hovestadt. The students were: If Ebnöther, Jörg Grabfelder, Anna Jach, Jae Hwan Jung, Alexandre Kapellos, Irena Logara, Michelangelo Ribaudo, Hanne Sommer, Agnieszka Sowa, Detlef Wingerath, Thomas Wirsing, Li-Hsuen Yeh. The author would like to thank them all for all their work, help, cooperation and company during this year. She would also like to express her gratitude to the CAAD chair staff (especially Karsten Droste, Markus Braach, Russell Loveridge and the NDS coordinator Philipp Schaerer).

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