Web Based Configuration And CNC Production

Project Description: Endless Space Generated by individual sections Pavilion (ESG_Pav)

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Abstract

The ESG_Pav project demonstrates the advantages of computer aided design, collaboration, and production technologies. The parti-concept for this project was the design and programming of a parametrically driven architecture that could be designed by “users” of a web based configurator. The underlying technology relies on a logical and parametric geometry structure which was developed, programmed and implemented by the postgraduate students of the CAAD-NDS study program. The pavilion has since been the instigation of a number of projects that use this concept of the 'digital production chain'. This methodology is conceived for every stage of the work; from the design to the production of architecture, and still allows for the creation of highly individualized solutions within the mind-set of mass-production methods.

Keywords

Mass Customization, Design Collaboration, Research, Education, Digital Chain

Organization of the postgraduate study

Ideology of the professorship

The chair for CAAD at the department of architecture ETH Zurich, researches the use of current information technologies as an augmentation of the concept of architecture. This extended definition covers “design support” through means of digital media, program assisted design, fabrication & building with computer controlled machines, and intelligent building services.

Aim of the postgraduate studies

The postgraduate studies in CAAD are open to university graduates with professional experience from the field of architecture and adjacent disciplines. The main focus of the course is computer based architectural design and automatic production technologies. Throughout the studies the participants expand their proficiencies in computational geometry modeling, computer based design, construction, production and multimedia presentation. These skills augment their capabilities as architects, incorporate new fields of activities in their skill set, and help to expand the definition of architecture as a whole.

The year long course of study is divided in different modules, each focusing on specific themes. After eight months the students start with their final project, which is divided into two parts; an individual thesis, and a group thesis. The individual and theoretical part provides the possibility to focus and specialize on the students own interests and is put in practice by the group work.

Concept and idea of the ESG_pav

The ESG pavilion was the group thesis work of the CAAD NDS 2003. The ESG pavilion is a linear assembly of different, independently designed sections. The sections are a linear extrusion of a 2d outline which is designed by collaborative users on an internet configurator. Each extruded section can be conceived as an abstract space within the lengths of the pavilion for a specific use. Customization of the profile of each section is up to the whims of the user. By manipulating the section geometries it is possible to create furnishing such as seating or table surfaces.

Each user designed section is autonomous and unrelated to the next section. The ESG-computer program is then programmed to “bridge” one section to the next by generating “adapting geometry” sections. By aligning the user defined sections and adapting sections, one after the other in a linear arrangement, a pavilion of continuous linear space is created.

The Digital Chain

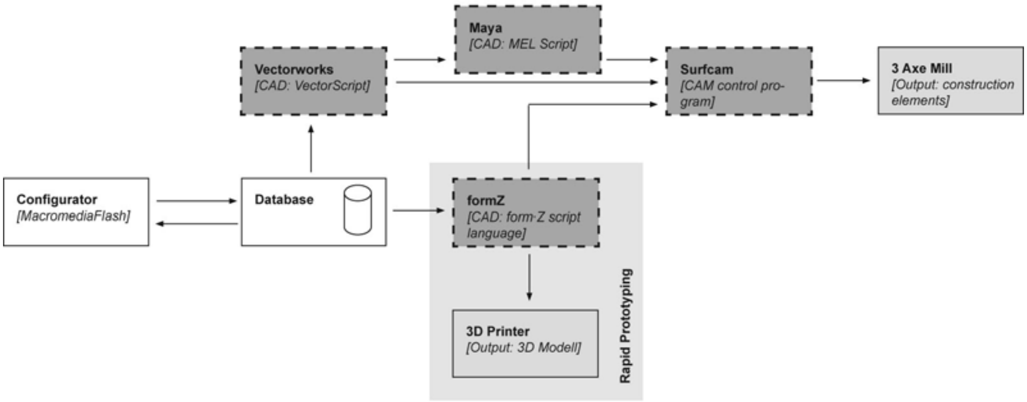


Figure 1. Processing steps of the digital chain related to the ESG_pav

The procedural flow developed during this project is part of the ongoing research work into digital design and fabrication methodology at the CAAD chair. This process is referred to as the “Digital Chain.” The digital chain is a design and production sequence with no analog steps, the process offers high flexibility in terms of design and production [1]. Due to the parametric relationship among the different process steps, and a high degree of programmed automation, each change can be validated quickly and with ease. Computer Aided Manufacturing (CAM) solutions, as the technological backbone of the digital chain, permit changes up to the last minute before production. The speed and facility of using these machines requires a disciplined and controlled flow of design & production data, however this can be automated within the digital chain programming.

The initial effort for set up and testing a digital chain is higher than creating a single “one-off” pavilion, however when factoring in the desire for customization and mass production, the additional effort remunerates the additional investment of effort.

Design

The overall ESG project consists of an internet configurator, a geometry database, and a set of post processing applications.

The configurator is the front-end of this digital chain; it is used to define all necessary parameters for each piece, which are then stored in a database. Once the geometry is defined there are three different CAAD procedures used to transform the individual geometry data of each piece into specific production data sets. The output from these processes is the construction data to fabricate the pavilion on a 3 axe mill, and the file needed to print out a small scale model on a rapid prototyping 3D printer.

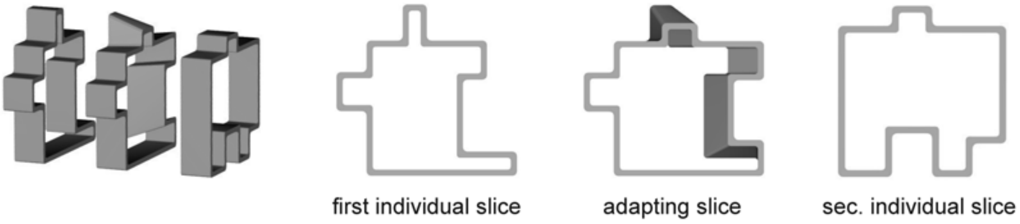
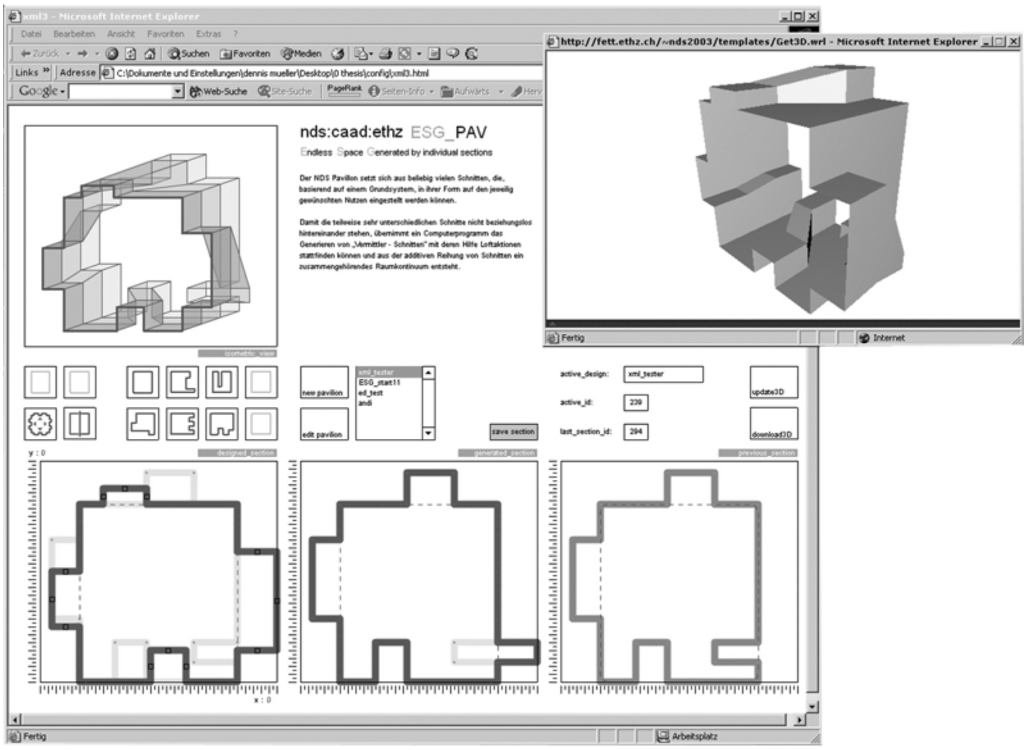


Figure 2. Creation of Space flow

The user designed sections were defined by a manipulated rectangular section. Each section could be manipulated and formed based on a unit grid; segments are straight and perpendicular to each other while corners are automatically rounded. The maximum outer limits of a segment are defined by a rectangle 3 m wide and 2.85 m high. The proportion of the area taken up by such protrusions and recesses between the two rectangles is limited only by design and the program. This system allows for various designed configurations within an abstracted notion of ’furnishing contours’.

To design a section the user can begin with a rectangle or load an existing section from the database. Within the interface the user can then shift the control points to create their desired sectional profile. Through indentations and protrusions of various depths, the external enclosure can be shaped and the interior formed to create seating, tables, shelving, or other functional forms. Each designed section once finalized is then extruded to 60 cm wide. For the concept, every second section is designed [2]. The geometry of the intermediary segments is generated by the program itself. This “lofting” system ensures that the edges and corners of the various sections designed by one user can be linked with that of the next.

Configurator



nds:caad:ethz ESG_PAV

Endless Space Generated by individual sections

Der NDS Pavillon setzt sich aus beliebig vielen Schnitten, die, basierend auf einem Grundsystem, in ihrer Form auf den jeweilig gewünschten Nutzen eingestellt werden können.

Damit die teilweise sehr unterschiedlichen Schnitte nicht beziehungslos hintereinander stehen, übernimmt ein Computerprogramm das Generieren von „Vermittler - Schnitten" mit deren Hilfe Loftaktionen stattfinden können und aus der additiven Reihung von Schnitten ein zusammengehörendes Raumkontinuum entsteht.

active_design: xml_tester
active_id: 239
last_section_id: 294

Figure 3. Screenshot of the configurator (http://www.esg-pav.com/: Jan 2003).

The configurator is the on-line design program which allows user input. The user can access previous section designs, see the status of a pavilion, and add to the existing work. In the interface's top left corner [3] the last set of developed sections, including the current one, are rendered as isometric view. The three views along the lower half illustrate, from the right to left; the previous designed section, the generated section and the actual design section of the pavilion.

In this lower left viewport the control points of the section can be manipulated. There are a number of design tools programmed for the interface. Upon completion of the design a 3D VRML view is generated for visualization of the 3D geometry

The computer generated section

The geometry for each section is defined by a maximum of 36 control points. These control points describe the deformation of the perimeter. If the section is a rectangle, the points will be arranged equally on the four corners; if there have been manipulations the points are distributed to the corner deflection points.

From the example in Figure 4: A user configures the new section "designed 03". The program creates the extrusion based on an offset of the points [21, 22, 23, 24] perpendicular to the XY plane and compares their absolute positions to the last XY position from “designed 01”. The perimeters generated in "generated 02.1 & 02.2" are the result of the designed perimeters with the programmed bridging logic applied. The resulting “bridging section” is a lofted surface between the profiles of “generated 02.1 & generated 02.2”.

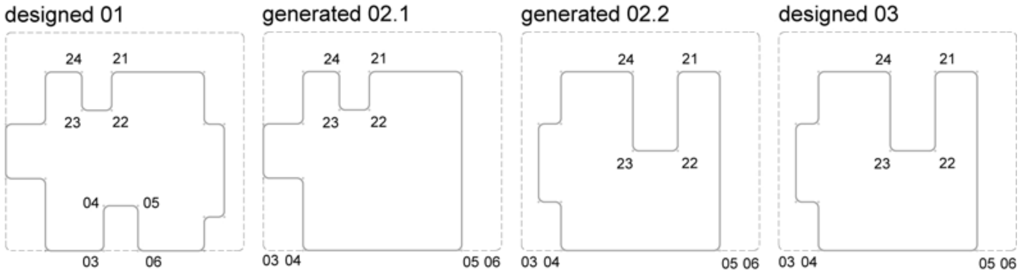


Figure 4. Generation rules for the intermediate section

The upper profile is a continuous extension of the sectional topology. Because the control points are proximal from one section to the next the surface is angled to bridge the distance. In contrast, the lower segment of the profiles (points [03, 04, 05, 06]) does not maintain a common arrangement of control points. As such the configurator is programmed to “step-over” the opening, in favor of the most recent designed section. The lofting is programmed with a set of logical operators which determine that the geometry is extruded only from “inside to inside” or outside to outside”. In this way, the generated geometry is limited to ruled surfaces. Following these principle all points are compared with each corresponding point, and then the application can provide a generated section to mediate from one user configured sections to another.

Once a design is complete and submitted, the parameters (all points of the generated and designed section, design name, and actual section number) are stored in a database. An XML file then describes the geometry of the pavilion, and is stored on a web folder to allow ease of access to a number of different software platforms.

The Database Storage

The Database is one of the foundations of the digital chain. All important data is stored and retrieved from one single source. The database provides services and data to the on-line Interface, such as generating the VRML model, and coordinating the data for different user requests.

The database consists of three tables. A ‘design table’ administers the names of the different pavilions and their dedicated identification names. The ‘section table’ holds the list of stored sections connected with the ID of the parent section, it manages the data for dedicated design tables, and has an index of their developments (designed and generated). Finally, the ‘points table’ manages a list of the geometry point data, with x-, y-, and z-coordinates, as well as the assigned section ID.

The Database operates in real time over the internet. With each change in the configurator the point coordinates modified and the data-set is updated. A server-side perl script operates as the integrator between the Flash “front-end” and the database engine. The big advantage of this so called ‘three tier system’ is the independency between the design of the front-end (interface) business logic and data storage.

Generation of rapid prototyping data

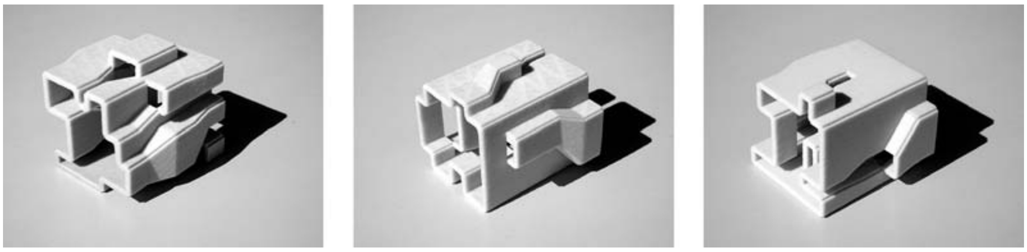


Figure 5. Plaster models created by printer to a scale of 1:100

While users are on-line creating new design sections, all of the geometry is immediately saved as a real-time 3D model for visual control. This VRML model is shown within the window of the configurator. The VRML file is also subsequently used to provide information to a Zcorp – rapid prototyping 3D printer, through which one can immediately ‘print out’ a plaster model version of a set of sections as a pavilion [5]. The VRML file is processed by the control software into a set of 2d sections a tenth of a millimeter thick. Plaster layers are set one upon each other to build up a layered model of the chosen sections. This method permits reproduction with a fair degree of accuracy, and allows for a scaled understanding of the complex spatial forms. In 2003, the preparation for printing the generated VRML model was done by hand in FormZ, however in the latest version of FormZ (vers. 5) there is the introduction of the ‘form Z Script Language’. It is now possible to automate this step.

Generation of digital production data

The goal for the project was to construct a “proof of concept” prototype at the 1:1 scale, using machines similar to those found in local industry.

A plug-in for VectorWorks was programmed to enable the .xml geometry files (all 36 x, y, z coordinates for the corner points of each individual section) to be accessed as CAD data. This plug-in reads the geometry, creates the outlines for structure, and generates the construction data-set. The output from the plug-in is a set of cutting lines for the wooden elements. The plug-in also generates all of the connection joint detailing. The plug-in works with a wide range of local and global settings and parameters, which can be used to fine-tune the desired construction. The parameters that can be set include settings for the number of secondary beams, size and shape of the ‘puzzle’ connectors, allowances for the different tools of the CNC machine, and specifications about the dimensions and physical characteristics of the material.

Figure 6. a) Alternating sequence of designed sections and intermediate segments generated by the plug-in; b) sequence of elements of a generated section calculated by Maya; c) milling paths in SurfCAM

Limitations in the working method of the machines also needed to be understood and compensated for. The limitations of undercutting and the need for “rounded inside angles” from a CNC milling machine also dictated their own design considerations. As a result the connections were developed in such a way that they can be manufactured with a cylindrical cutting tool. The resulting puzzle connection is a transformation of the traditional dove tail joint, adapted for the constraints and capabilities of a 3 axis CNC mill.

A final crucial aspect of production is the ability to subdivide the sections into components that fit onto the CNC equipment. The size limits of the manufacturing machines were also included in the parameters of the plug-in, and the resulting component pieces were optimized for both fabrication layout and structural concerns.

Processing of the geometry, structure, and skins were done using different applications to benefit from their unique competences. Programming 2D geometry in vector script is quite easy, more complex 3D lofting is easier in Maya. A standardized format of data, made it possible to choose the software platform that was best suited to the task at hand. Also the calculating of the glass fiber reinforced plastic geometry is done in FormZ, because it provides specialist tools for unfolding the skin.

CAM – Computer Aided Manufacturing

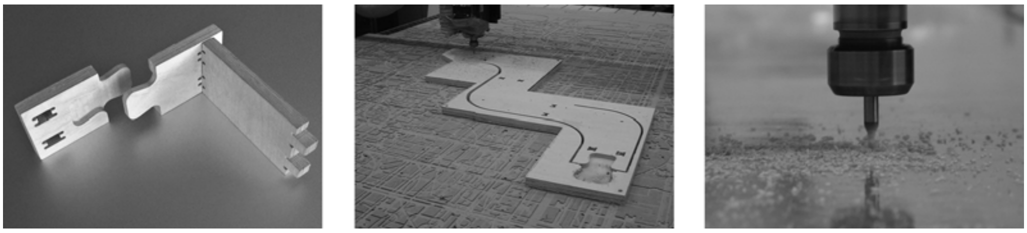


Figure 7. a) CNC-generated dovetail joint and plug-in connection; b) milling of a designed section segment; c) milling of the GRP

The production data outputted from the plug-in was then passed to two different production streams. One set of data, for the “unfolded” Scobalit skins was processed in FormZ and then fed directly to a G-code generating software (SurfCAM) where the cutting paths were processed. The structural data was concurrently imported into the software Maya, where it was pre-processed for fabrication by a MEL script program, and then exported for G-code processing.

The digital chain should be regarded as a single methodology. For this project, we developed the digital production method beyond the strict conceptual and logistical design, and as such the entire process was created to be adaptable for both the advantages and constraints of its different components. [7] The specific constraints of the software platforms, the fabrication machines, and even the physical qualities of the chosen materials, were factored as parameters into the entire procedure.

All the preparation, set up, and operation of the CNC machines was executed by the postgraduate students.

The Pavilion: Materialization, Static and Mounting

Figure 8. a) The edges of the milled plywood had to be chamfered manually; b) Mounted construction without the GRP; c) Toothed abutment of adhesive-fixed GRP sheeting

The load-bearing structure of the prototype consists of birch plywood. [8] The structural framing was based on ridged corners and joints so as to transmit the vertical loading, and to absorb moments and torsion from use and inhabitation. Bracing is provided by secondary “joists” that connect the two main structural rings of a segment. The joists are T-jointed by means of a CNC milled mortice-and-tenon joint.

A translucent material, Scobalit, was chosen for the outer enclosing skin, so that the load-bearing structure would remain visible. [8] This surface lining consists of GRP (glass fiber reinforced plastic) sheeting, which also serves to stiffen the section. The toothed ends of the individual sheets of the GRP lining prevent the connections from opening. This specially made sheeting material (1.5 and 2 mm) is sufficiently pliable to fit round the curved end faces of the beams and still withstand user loading. The skins are bonded to the structural sections using a special adhesive tape.

Every section consists of a number of assemblies connected with the ’puzzle’ dovetailed joints. In order to minimize the weight and dimensions of the individual segments of the pavilion for transport and assembly, each element can be divided into two parts, which interlock with each other by means of a jigsaw-like dovetail joint. The joined halves are then reversibly connected with four to five dowels. The stability of the pavilion prototype has been demonstrated even without adhesive fixings.

Conclusion

The ’digital chain’, conceived for every stage of the work from design to production of the pavilion, allows the creation of highly individualized solutions without significantly greater costs in comparison with conventional mass-production methods. The digital chain concept allows for the development of the disparate components of the system while the configurator assures that they would all be compatible [9].

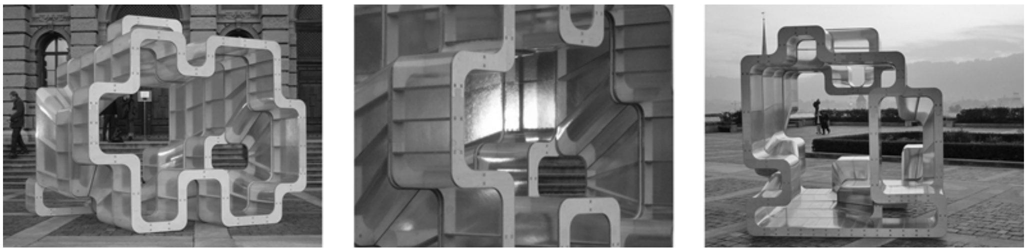


Figure 9. ESG_Pav – Endless Space Generated by individual Sections Pavilion

The development of a collaborative platform for design provided the project with the possibility to create an infinitely variable pavilion in a very short time. The digital programs that processed the design data create a full set of prototyping scales and parameters. The concept of a configurator driven design process, permits large variation while still providing the data required for "push of a button" processing to CNC fabrication.

This project was conducted in the summer of 2003, since that time there have been a number of developments in software and digital programming which, today, would allow us to refine and optimize the procedure still. The main form of “analogue” or manual work took place during the assembly procedures. This could be reduced with additional expenditure in machines and automatization of the assembly process.

The ESG_Pav is one example in a series of pavilions from the preceding and the subsequent years, as developed by the students of CAAD.

Further development has been carried on within the research activities of the CAAD chair. The Swissbau pavilion, developed in late 2004/early 2005 is a pavilion and “proof of concept” of further programming and optimization of building in architecture. The pavilion was designed, optimized and generated with the help of computer programming, allowing for the designer to specify its form and apertures, and then the program calculated all of the structural elements and generated all of the CNC fabrication instructions. The final output was manufactured and assembled by a professional carpenter's workshop according to the data sent by e-mail. This pavilion was manufactured and assembled by specialized workers under realistic economic conditions, and is the basis for yet more research and development of the digital chain.

Acknowledgement

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http://www.caad.arch.ethz.ch
http://www.esg-pav.com

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Participants in ESG Pavilion project:
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