designto**production** – we realize complexity



Digitally optimized production chains

How the "impossible" is getting feasible

The production effort for objects with complex free form becomes
thanks to automized planning processes comparable to a serial production.

date documentation projects 2005

abstract designtoproduction is a consultancy for digital production of complex design. Innovative concepts and knowledge about digital production characterize our work. As geometrical consultants we try to realize our clients' complex architectonical ideas with efficient algorithms. designtoproduction develop digital production chains for demanding construction projects to improve efficiency, planning flexibility and quality assurance in the realization phase.

company designtoproduction
consultancy for digital production of complex design
www.designtoproduction.com

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designtoproduction is a spin-off company from ETH Zurich (Swiss Federal Insitute of Technology)
Chair of CAAD, Prof. Dr. Ludger Hovestadt
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in collaboration with project-orientated partners

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Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

designto**production**

Initial position
In contemporary architecture a strong movement towards organic, non-orthogonal, "free" shapes is observable. Architects as well as their clients seem to be fascinated by the opportunity to burst the bonds of regular grids and modules in order to create landmark designs. Thanks to advanced 3D-CAD-software, planners face fewer and fewer technical difficulties to develop such complex shapes in the design stage of the project. They are, however, often confronted with unexpected problems during realization, since free forms usually are constructed from a large number of different parts. While modern manufacturing technologies allow "one-of-a-kind" production at almost the cost of serial production, for non-regular structures the preceding planning effort is no longer reducible through serialization. This leads to the effect, that production costs of regular and non-regular structures are almost the same, but planning costs rise with the number of dissimilar parts in the structure. Sometimes it is possible to play tricks and generate forms that seem to be non-regular, but consist only of few different pieces. However, in most cases the formal need to build a free form leads to increasing planning and realization costs and a high error rate in production.

designtoproduction
designtoproduction addresses the issue of complex design by algorithmically automating planning- and production-processes and thus making non-regular designs economically feasible and geometrically controllable. designtoproduction offers consulting services to architects and planners, applying current academic research from the field of digital production chains to demanding building projects. designtoproduction was established as a research group in 2005 by Fabian Scheurer (computer scientist) and Christoph Schindler (architect) at the Chair of CAAD at the Swiss Federal Institute of Technology, ETH Zurich. Innovative programming techniques, experience with CNC-machines and close collaboration with industrial partners characterizes the work of designtoproduction.

Digital Chain
A "digital chain" is a continuous digital process from design (determination of shape and structure) to engineering (detailing) and production (CNC-manufacturing). Digital tools at all process stages are linked together in order to ensure the uninterrupted flow of information. Within this digital chain, innovative optimization techniques are used to extend the role of the computer from a passive digital drawing board to a tool that actively supports the design. The involved architects, engineers, and fabrication experts provide rules, interrelations, and objectives, which the computer is able to match in many variations due to its computing power. The role of the architect shifts from form designer to process designer. The result of the digital chain is the so called "G-Code" to control the CNC-machine.

Three exemplary wooden constructions
To demonstrate the potential of the "digital chain", three different wooden constructions were realized within the research at the ETH Zurich:

Inventioneering Architecture (p.5)
Libeskind's Futuropolis (p.9)
Swissbau Pavilion (p.13)

All three projects were manufactured on the 5-axis CNC-Router of our manufacturing partner Bach Heiden AG.

Process Analysis
Together with the manufacturing specialists we analyzed the production processes of the three projects. In comparison to a "conventional" realization with manual machine programming, three essential improvements became clear:

Efficiency
Detailed calculations for all three examples provided by the manufacturing partner impressively showed the difference between the conventional approach and the digital chain. To realize the projects with the same CNC-machine but without a digital chain delivering the machine-ready data would have been up to five times more expensive: the reduction of manufacturing cost ranges from 72% in the Futuropolis project to 83% in the Swissbau project. Primary cost factor in the conventional CNC-process is the creation of the G-Code and the optimization for production, which were completely taken off the manufacturer's shoulders and done much more efficiently by the use of parametric CAD-models. In case of the Futuropolis project the client solicited two other offers from manufacturers in Switzerland and China that confirm the figures calculated by Bach Heiden.

The digital chain:
After developing the constructive details and the production process together with the designer, the client and the manufacturer (1) designtoproduction establishes a continuously digital process on the base of a parametric model (2). The result is a machine code (3) that directly controls the CNC-machines at the production company (4).

Flexibility
Since the whole process relies on a parametric digital model, it responds very well to changes. Late design alterations as well as other changes are no problem as long as they lie within the boundaries of the model. In the Futuropolis project, the delivered material turned out to be two millimeters thicker than ordered, which changed the geometry for all 2164 parts. The new G-Codes for the CNC-router could be generated virtually overnight, so the production schedule was not influenced.

Quality management
With CNC manufacturing it is possible to achieve a level of exactitude that is not within the reach of manual work at this project scale. By implementing a digital chain, this quality can be maintained throughout the whole process, which only now permits the creation of structures from a few thousand individually shaped parts that fit to a tenth of a millimeter at every joint. The tolerances of the CNC-machines are very reliable and the material tolerances (especially when working with wood) are much more challenging. Since the algorithmic generation of geometries and fabrication codes leads to either entirely correct or systematically flawed results, mistakes can be located rather easily.

```
N200 ( Unterprogrammaufruf Liebeskind )
N202 ( Parameter werden auf Null gesetzt )
N204  M28.400900
N206 ( Parameter werden eingelesen )
N208 P520:30; P521:0 (PLATTENBREITE JETZT AUF 0.0 !!!);
N210 ( Paramter Tisch links G54= 1, oder Tisch rechts G55= 2 )
N212 P530:1;
N214 ( Anwahl Tisch links G54 )
N216 P530<> P1.38;
N218 M28.400040
N220 G54
N222 M23.(N‰CHSTER NC- SATZ)
N224 ( OP 1   BOHREN   WERKZEUG 90   6 MM )
N226 ( WERKZEUGDURCHMESSER 6, BOHRUNGSDURCHMESSER 5 )
N228 G47 T90 M6 (6 MM)
N230 T90 M16 (6 MM)
N232 T90 M6 M8
N234 T24
N236 G0 G54 G49 X272.250 Y145.
N238 G0 G54 G49 Z33.
N240 G0 G49 X272.250 Y145. A0. B0.
N242 Z10.
N244 G48
N246 G81 X272.250 Y145. Z-29. R10. M04 F3000
N248  X88.547 Y145.
N250  X88.547 Y428.722
N252  X88.547 Y481.983
N254  X272.250 Y481.983
N256  X272.250 Y428.722
N258  X272.250 Y1079.428
N260  X272.250 Y1132.689
N262  X88.547 Y1132.689
N264  X88.547 Y1079.428
N266  X272.250 Y1556.798
N268  X88.547 Y1602.822
N270 G80
N272 G0 Z10.
N274 G0 G47 Z:P799;
N276 G0 M0 Y3950
N278 ( TEILE ANSCHRAUBEN )
N280 ( POSITIONSLOECHER )
N282 G0 G54 G49 X150. Y100.
N284 G0 G54 G49 Z33.
N286 G0 G49 X150. Y100. A0. B0.
N288 Z10.
N290 G48
N292 G81 X150. Y100. Z-32. R10. M04 F3000
N294  X150. Y1660.
N296 G80
N298 G0 Z10.
N300 G0 G47 Z:P799;
N302 ( SCHNEIDEN DER SEITEN )
N304 G47 T33 M6 (3.5 MM D 350)
N306 T33 M16 (3.5 MM D 350)
N308 T33 M06 M09
N310 T25
N312 G0 G54 G49 X427.566 Y-82.500
N314 G0 G54 G49 Z183.750
N316 G0 G49 X427.566 Y-82.500 A-90. B57.501
N318  Z183.750
N320 G48
N322 G1 G42 X-75.000 Y129.031 Z-261.886 F8000
N324  X-1685.
N326 G40 X-1842.500 Y384.698
N328 G0 G54 G49 Z183.750
N330 G0 G49 X-268.506 Y1842.500 A90. B32.499
N332  Z183.750
N334 G48
N336 G1 G42 X1685. Y-78.148 Z10.713 F8000
N338  X75.
N340 G40 X-82.500 Y325.184
N342 G0 G54 G49 Z183.750
N344 G0 G49 X176.611 Y-82.500 A-90. B57.501
N346  Z183.750
N348 G48
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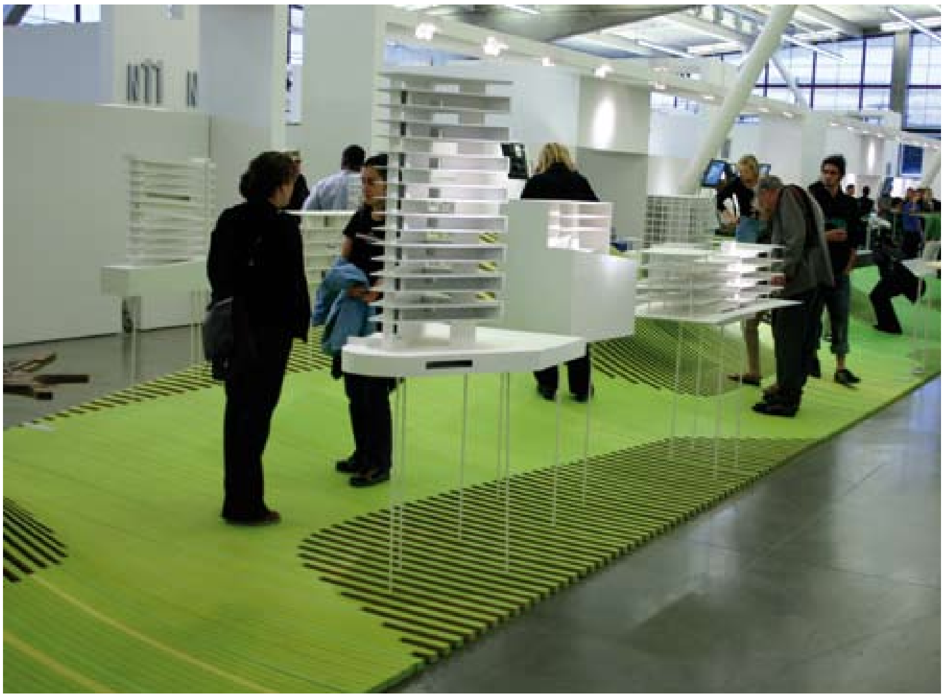
The final result delivered by designtoproduction is pure code for the CNC-machine.



Inventioneering Architecture
California College of Arts and Crafts, San Francisco
exhibition architecture
2005

organisation and design
Instant Architekten, Zürich / Berlin
Dirk Hebel, Jörg Stollmann, Sascha Delz

geometry consulting and engineering
caad.designtoproduction, ETH Zürich
Fabian Scheurer, Christoph Schindler, Markus Braach

client
ETH Zürich Executive Board,
Prof. Dr. Gerhard Schmitt, Prof. Dr. Marc Angélil

CNC-production
Bach Heiden AG, Heiden

Opening on October 4th 2005 at the California College of Arts and Crafts in San Francisco (Image: Instant Architekten)

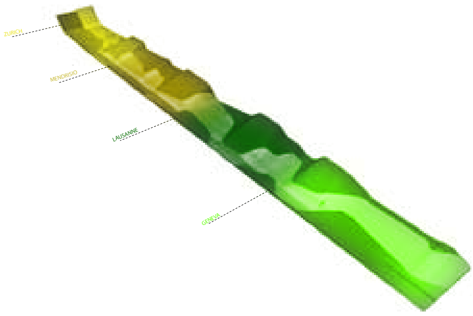
Inventioneering Architecture

“Inventioneering Architecture” is a traveling exhibition of the four Swiss architecture schools (Zurich, Lausanne, Geneva and Mendrisio) that was first shown at the California College for Arts and Crafts (CCAC) in San Francisco and is now touring the world. For this project the Zurich office Instant Architekten designed a stage that resembles an abstract crosscut through Swiss topography. This doubly curved platform measures 40 by 3 meters with varying heights up to 1.5 meters. A footpath meanders along the surface, passing the exhibits.

In order to meet the budget requirements, we proposed to assemble the hilly platform from 1000 individually curved rafters that were milled out of medium density fiberboard (MDF). They are assembled in comb-shape, so that their overlapping sections form the closed surface of the path while the exhibition area is marked by gaps. By choosing a rather cheap material and implementing a continuous digital chain from the definition of the surface geometry in the CAD software Maya until the control of the five-axis CNC-mill that the parts are manufactured with, production costs could be lowered significantly.

The detailing was developed to fit the capabilities of a five-axis router. The platform is divided into 40 millimeter wide sections, each describing the upper surface of one rafter. The milling tool follows the center path of the section and rotates around it at the same time, cutting out a so called “ruled surface” that follows the topography of the platform both along and across the section. Thus it is possible to manufacture a three-dimensional, doubly curved surface from two-dimensional sheet material at very low cost. The rafters are connected by dowels and supported by perpendicular boards.

Since the structure consists of roughly 1100 individually shaped parts, the crucial point was to automate the translation of the platform geometry into the geometry of the single parts and finally into the code controlling the CNC mill. This was accomplished by a set of scripts in the CAD-package Vectorworks. The first script imports the original design defined as a NURBS-surface from the modeling software Maya, reads the coordinates of the platform’s cross-sections for every rafter and determines the angles of bank.



The platform is colored in four different greens, marking the four Swiss architecture schools in Zurich, Lausanne, Geneva and Mendrisio. (Image: Instant Architekten)

A second script translates this information into the milling paths for all 1000 rafters, also including all drillings for the dowels. A third script arranges and optimizes the rafters on the MDF-boards and generates the so called G-Code, the programs which control the five-axis CNC-router. 120 MDF-boards sized 1.0 by 4.2 meters were used to fabricate all rafters within roughly 50 milling hours.

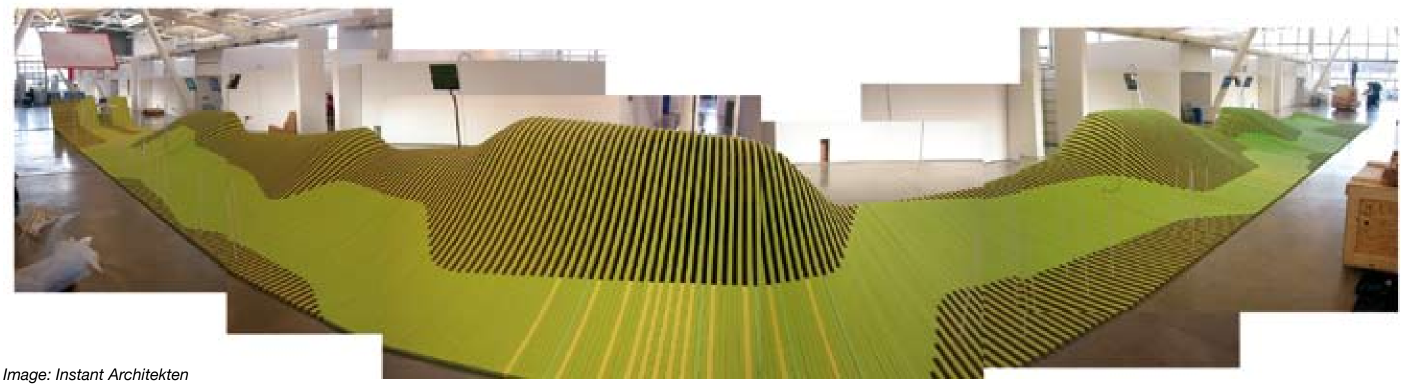
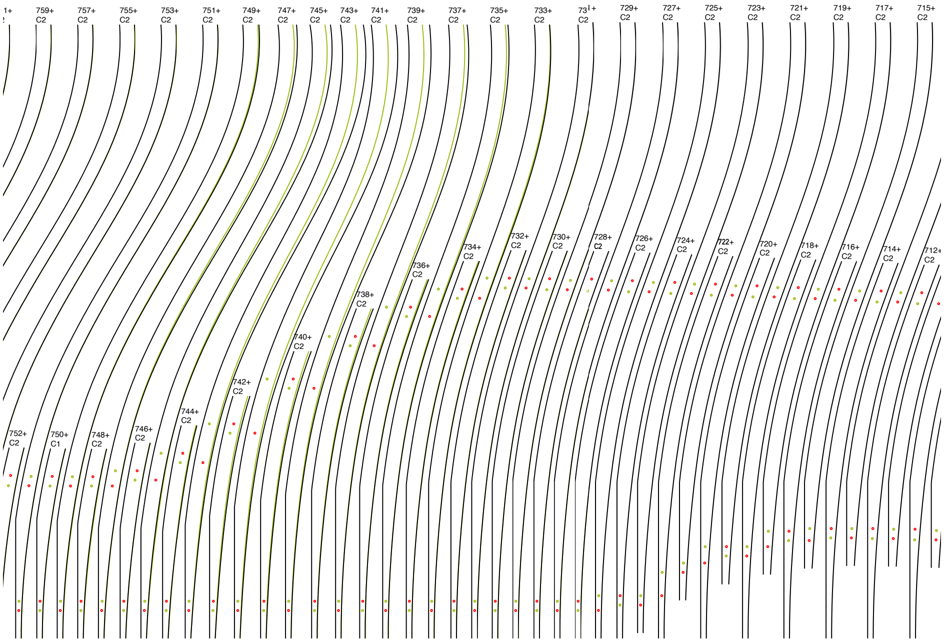
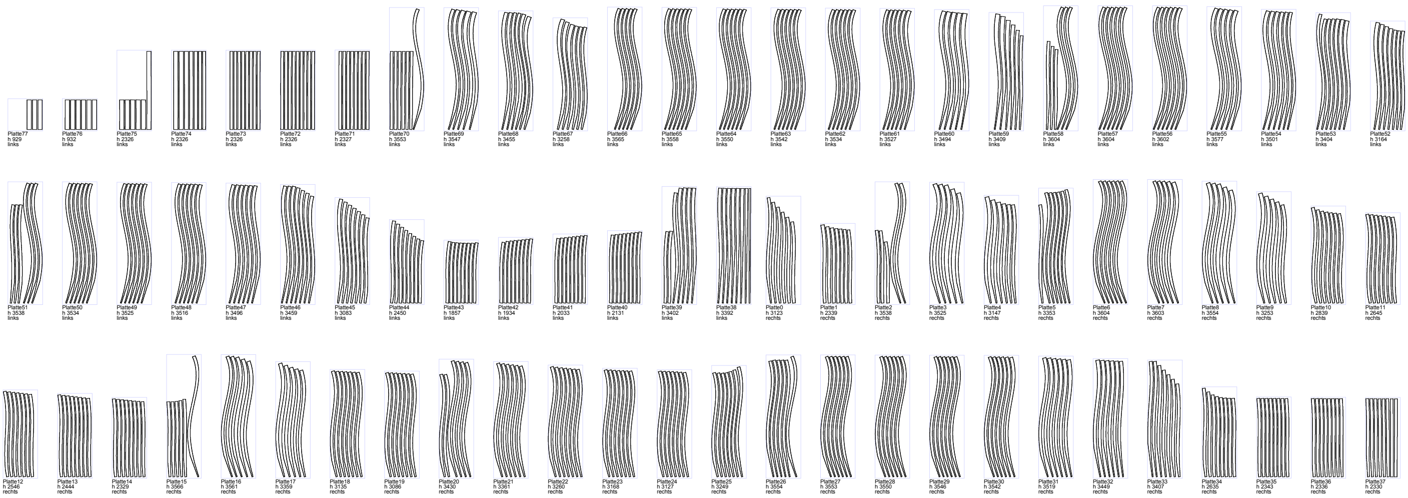


Image: Instant Architekten

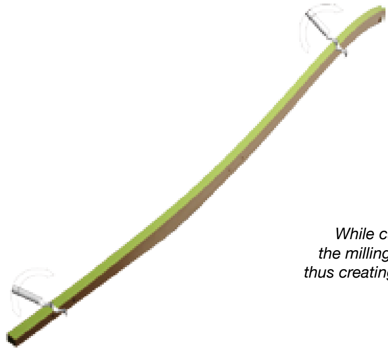


A selection of the platform's milling paths, as generated by VectorScript. The rafters are defined by Spline-curves, but since the CNC-router only uses straight lines and radii, the curvature had to be approximated by polygons with a point distance of 9.0 mm.



The platform's 1000 rafters are automatically arranged and optimized on 152 MDF-boards. One G-Code for the 5-axis router is generated per board.

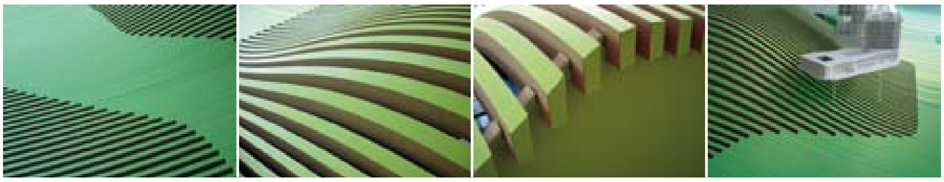
The code for the 5-axis mill is directly fed into the machine without manual revision.
The three CNC-fabrication steps are:
Drilling: crating dowel holes for the connections
Roughing: pre-cutting the form of the rafters
Finishing: smoothing the surfaces



While cutting the upper surface of the rafter, the milling tool rotates around the milling path, thus creating a doubly-curved surface in one go.

Every rafter has a different profile.

Inventioneering Architecture



INVENTIONEERING ARCHITECTURE
Statement of costs with and without designtoproduction

			time [in minutes]	time [in hours]	time [in weeks]	price CHF / h	estimated cost without digital optimization CHF	effective cost with optimization by designtoproduction CHF
number of single parts ca.		1100						
number of raw boards (1.0 x 4.0m)		120						
project management and detailing etc.	flat rate			131	3.1	CHF 95.00	CHF 12'445	CHF 3'500
arranging and optimizing the single beams on boards of1000x4020mm	min. per board	135	16200	270	6.4	CHF 95.00	CHF 25'650	CHF 0
programming the 1100 beams from existing geometries, milling of 3D-surfaces, milling the edges, drilling the holes etc	min. per part	39	42900	715	16.8	CHF 95.00	CHF 67'925	CHF 0
creating stickers for labeling	flat rate	1	1100	18	0.4	CHF 95.00	CHF 1'742	CHF 0
test "dry" milling of 120 boards	min. per board	10	1200	20	0.5	CHF 195.00	CHF 3'900	CHF 1'150
milling 120 boards	min. per board	30	3600	60	1.4	CHF 195.00	CHF 11'700	CHF 9'080
postprocessing of the beams	min. per part	10	11000	183	4.3	CHF 97.00	CHF 17'783	CHF 13'000
painting	min. per part	8	8800	147	3.5	CHF 65.00	CHF 9'533	CHF 9'000
assembly of the 1100 beams	min. per part	10	11000	183	4.3	CHF 65.00	CHF 11'917	CHF 9'050
material cost							CHF 28'000	CHF 25'000
total cost							CHF 190'595	CHF 69'780
							100%	37%
risk supplement	40%						CHF 76'238	CHF 0
total cost including risk							CHF 266'834	CHF 69'780

Futuropolis at the St. Gallen Concert Hall in October 2005

Libeskind's Futuropolis
Concert Hall St. Gallen
piece of art from 98 single sculptures
2005

project leader freshmen week
HSG: Holm Keller, Dr. Timon Beyes

design
Daniel Libeskind, New York
project architect: Thore Garbers

technical realization and programming
caad.designtoproduction, ETH Zürich
Fabian Scheurer, Christoph Schindler, Markus Braach

client
Universität St. Gallen HSG
with McKinsey & Company, Düsseldorf

CNC-production
Bach Heiden AG, Heiden

Libeskind's Futuropolis

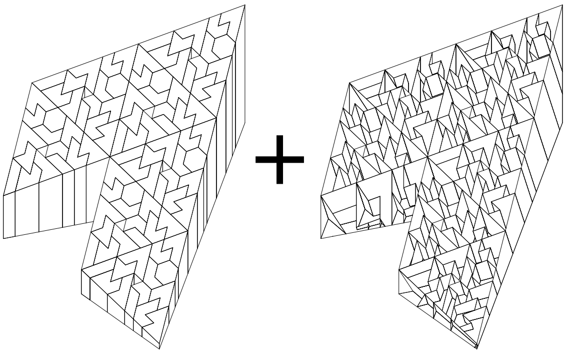
"Futuropolis" is a wooden sculpture designed by New York architect Daniel Libeskind for a workshop he held at the University of St. Gallen (HSG) in October 2005. HSG, a renowned business school, introduces its new students with a freshman week every year. In 2005 the objective for the 5-day workshop was to conceptualize a "City of the future" and visualize the ideas by help of the intricately shaped towers of the Futuropolis sculpture.
The design is based on a triangular grid, where a 98 tightly packed prismatic towers form an ascending volume of up to 3.8 meters height. The towers are constructed from roughly 600 wooden boards, arranged in the same pattern as the footprints of the towers and penetrating the sculpture at an angle of 25 degrees. Thus, the boards are cut into almost 2000 wooden polygons by the perpendicular faces of the towers. Since the realization of this design within the given time and budget was not possible by means of traditional craftsmanship, a complete digital production chain was set up.

The first challenge was to find an appropriate solution for connecting the parts of each tower. Maximum structural integrity had to be guaranteed at minimum production and assembly costs. By using aluminum dovetail-connectors, it was possible to reduce the number of connection details to only six variants with eleven subtypes, whose miters and notches can be milled by a CNC-router.

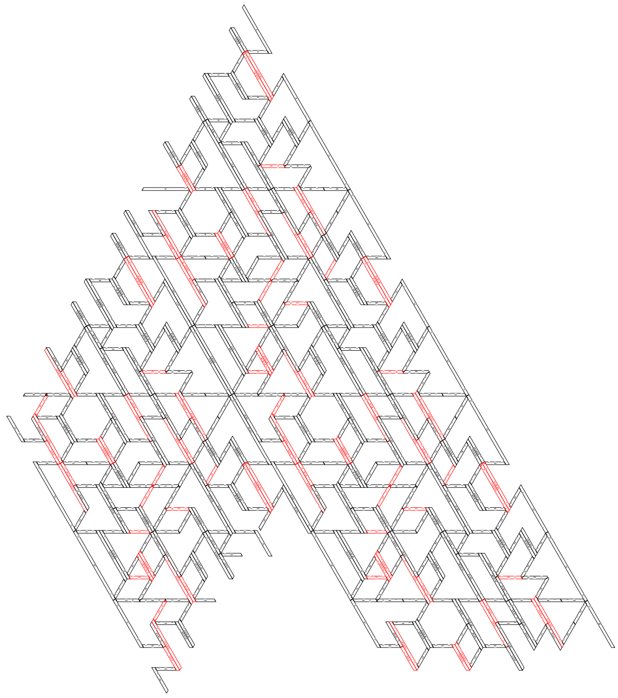
The second challenge was to generate the exact geometry of all 2164 parts, including the bases where the towers stand on.
A completely parametric CAD-model of the sculpture was programmed in Vectorworks, which calculated the outline of all parts by closely following the algorithmic design rules given by the architect. The appropriate connection details where automatically assigned to the edges, the parts were numbered and arranged on boards.

The third step was to translate this geometry information into the code for controlling the CNC-machine. Since the boards had to be turned around in the middle of the production process, two G-Code programs per board had to be generated by a script. For calculating the material costs and preparing the raw boards, the exact widths and lengths of all boards were automatically exported as data-tables. In the end the sculpture consists of 360 square meters of 32 mm thick boards, altogether almost 11.5 cubic meters of birch wood. Total milling time summed up to about 200 hours, the assembly took roughly 500 man-hours.

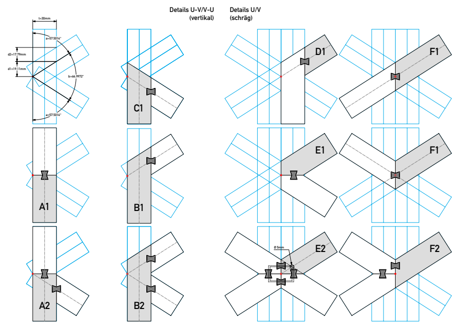
The architect addressing the freshmen during the inauguration.



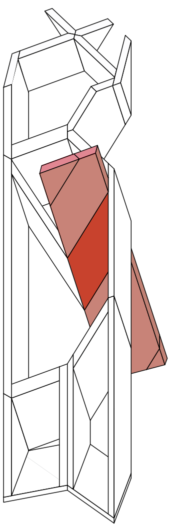
The design by Studio Libeskind: An ensemble of 98 extruded tower volumes is truncated by a sloped layer (left). The cutting edges of this operation are extruded perpendicularly to the section plane (right). The resulting “boards” are again intersected with the 98 tower volumes.



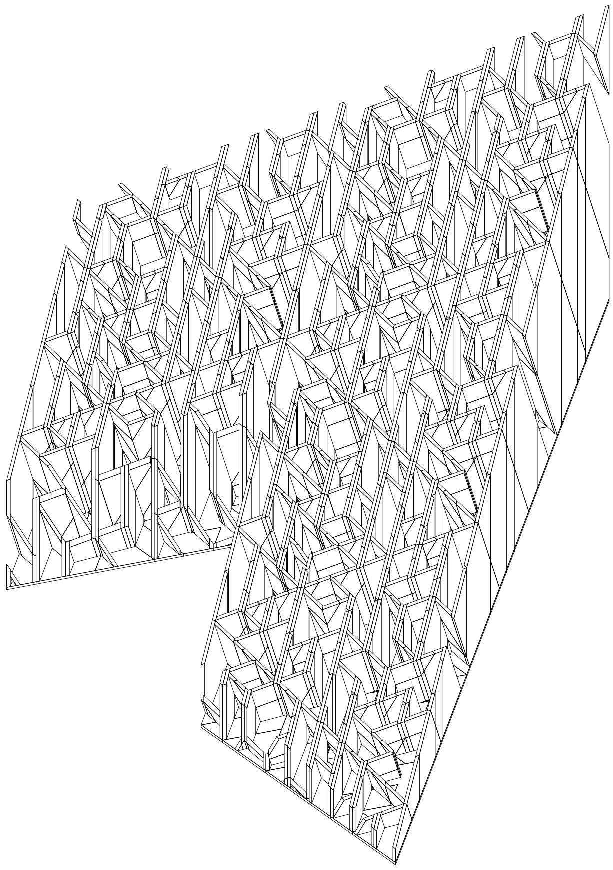
The “stencil” of boards that penetrates the sculpture. To stabilize the resulting towers, designtoproduction inserted structurally necessary boards (marked red).



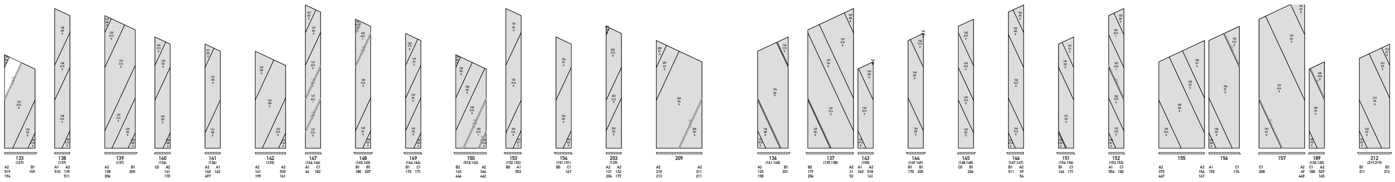
The most important prerequisite for the automated realization was an elegant solution for connecting the single boards. From the numerous variants of two to eight boards meeting at one point, a catalogue of only eleven different details for all possible connections was developed.



Construction principle: Each board intersects several towers. If the towers are closely packed, the grain of the birch wood continuing through the whole structure is clearly visible.



Isometric view of the fully detailed and structurally optimized construction.



Futuropolis consists of altogether 628 boards, each of them penetrating several adjacent towers and thus being cut up by the vertical faces of the towers into several parts. The boards are generated from a parametric model programmed in VectorScript, including the positions and angles for all dividing cuts, miters, notches and fixing holes. As the boards have to be turned around during machining on the 5-axis router, two G-Codes for the router are generated per board.

Production at Bach Heiden:

1) Before machining: the parts on the boards are marked unambiguously with stickers.
2) The 5-axis router is preparing a groove with a saw blade.
3) Change of tools: The groove is cut conical with a special tool to make it fit to the dovetail.
4) Assembly: The elements are glued and connected at the grooves with aluminum dovetails

Some of the parts have extremely acute-angled geometries. In the left image the automatically placed holes are visible, where the parts are fixed during the milling process.

The parts of the sculpture are connected with aluminum dovetails.
Sloped cuts through the dovetails result in interesting geometries.

LIBESKIND'S FUTUROPOLIS
Statement of costs with and without designtoproduction

			time [in minutes]	time [in hours]	time [in weeks]	price CHF/ h	estimated cost without digital optimization CHF	effective production cost with optimization by designtoproduction CHF
number of individual parts ca.		2160						
number of boards ca.		500						
number of towers		98						
project management and detailing etc.	flat rate			135	3.2	CHF 95.00	CHF 12'825	CHF 5'150
arranging and optimizing the parts on boards of different sizes	min. per board	55	27500	458	10.8	CHF 95.00	CHF 43'542	CHF 0
programming the 2160 parts from existing geometries: saw blade, dovetail and drilling of the holes	min. per part	27	58320	972	22.9	CHF 95.00	CHF 92'340	CHF 0
creating stickers for labeling	flat rate	1	2160	36	0.8	CHF 95.00	CHF 3'420	CHF 0
test "dry" milling of 500 boards	min. per board	5	2500	42	1.0	CHF 195.00	CHF 8'125	CHF 3'150
milling 500 boards	min. per board	25	12500	208	4.9	CHF 195.00	CHF 40'625	CHF 37'000
assembly of 98 towers	min. per tower	360	35280	588	13.8	CHF 65.00	CHF 38'220	CHF 36'000
material cost							CHF 40'000	CHF 38'000
total cost							CHF 279'097	CHF 119'300
							100%	43%
risk supplement	55%						CHF 153'503	CHF 0
total cost including risk							CHF 432'601	CHF 119'300
							100%	28%

Swissbau Pavilion
for the special exhibition “Digital Chain”
Swissbau 05 Basel
2005

design and realization
caad:designtoproduction, ETH Zürich
Fabian Scheurer, Christoph Schindler, Markus Braach

organization
I-Catcher GmbH, Basel

CNC-production
Bach Heiden AG, Heiden

windows
Fensterfabrik Albisrieden, Zürich

customized roof sealing
Contec AG, Uetendorf

test assembly at Contec AG in Uetendorf nearby Thun CH

Swissbau Pavilion

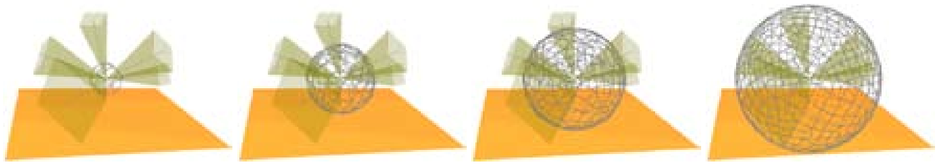
The CAAD Swissbau Pavilion was designed and built to show the potential of the digital chain on the Swissbau 2005 fair in Basel.
It has the form of a sphere with two meters radius and reaches a height of three meters. It is assembled from quadrilateral wooden frames, each consisting of four wooden boards standing perpendicular on the surface of the sphere. But while in a traditional coffered dome a regular structure dictates the placement of openings, here the frames are required to adapt their size and angles to the deliberately asymmetric placement of windows.

To generate this adaptive geometry, an interactive software was programmed in Java that simulates the growth of a quadrilateral mesh on a sphere following simple rules: The edges try to align with the positions of the predefined openings and the floor level, while at the same time every mesh attempts to optimize its size and angles. The simulation of this process is running in real-time and can be influenced directly by the user. Under certain circumstances the structure can locally alter its topology by inserting or deleting meshes until it reaches a stable state. The resulting geometry of nodes and edges is then exported to an XML file and used as the base for the rest of the digital chain.

The subsequent steps are analogue to the first two examples: a script reads the XML file into the CAD-software Vectorworks and generates a 3D-model of the pavilion with the exact geometries of all 320 wooden frames and their 1280 parts. All parts are automatically numbered and a second script arranges them on the raw boards used for milling. The G-Code for controlling the CNC-router is generated automatically for every board and already includes information for drilling the holes and milling the unique part-id into the boards.

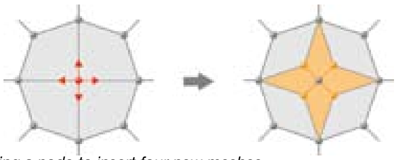
Although the Swissbau Pavilion was the first of the three projects in this booklet, it is the best example for a new approach in computer aided design. The geometry of the other two projects “Inventioneering Architecture” and “Libeskind’s Futuropolis” was determined by the architects and the working process went from the completed design towards the detail scale. Here, the geometry of the Swissbau Pavilion emerges from constructive and functional prerequisites defined on the detail scale. In program development these approaches are called top-down- and bottom-up-design. While the top-down-method (from design sketch to detail) is the working process preferred by most architects, the bottom-up-design allows strategies that are not feasible in a manual design process i.e. optimization of structure by simulation of growth.

All nodes in the structure are different. The four boards forming a frame are connected with plastic dovetails.

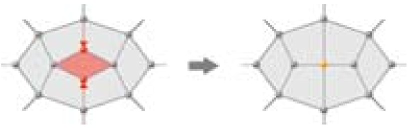


The mesh of the Swissbau sphere is dynamically "growing" in an interactive simulation.
The edges are aligning to the windows (green) and the floor (orange).

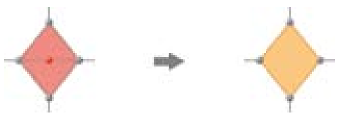
mesh transformations:



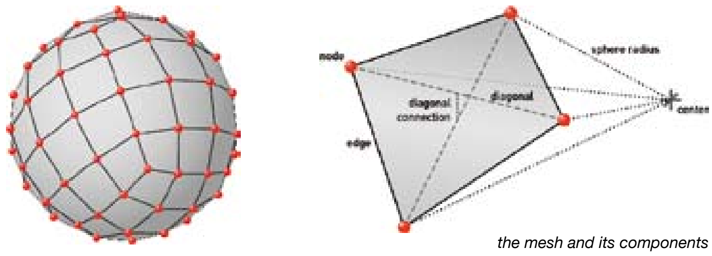
splitting a node to insert four new meshes,



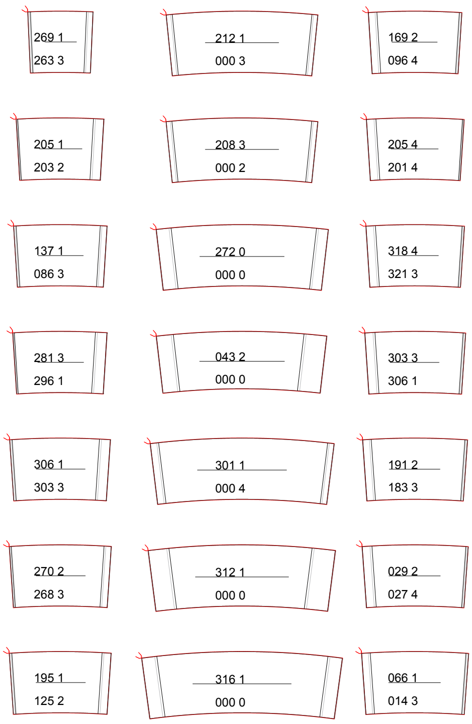
joining two nodes to delete a mesh,



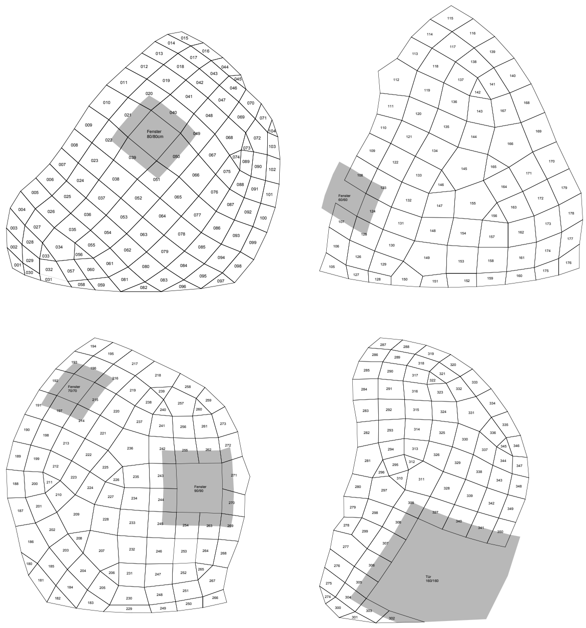
and removing a node to "tidy up" the mesh.



the mesh and its components



For every mesh a quadrilateral frame is generated with Vector-Script. Each of the four frame elements is an arch segment with mitered ends. All elements are automatically numbered, sorted by size and arranged on the raw OSB boards. The numbers are cut into the elements during the production process, the upper number being the ID of the element, the lower number the ID of the adjoining element.



Plans for the exterior skin, which were made from synthetic rubber by a specialist for customized prefabricated roof sealings, Contec AG in Uetendorf. The parts are cut on a CNC water-jet cutter and then vulcanized to form the spherical membrane.

Assembly on site only takes a few hours. The quadrilateral frames of the wooden construction are prefabricated. They are stacked on top of each other like in a brick construction and connected by screws. The roof membrane is delivered in two large pieces and connected on site. Finally the windows are set in.

SWISSBAU PAVILION
Statement of costs for the wooden construction with and without designtoproduction

			time [in minutes]	time [in hours]	time [in weeks]	cost in CHF / h	estimated cost without digital optimization CHF	effective cost with optimization by designtoproduction CHF
number of parts ca.		1280						
number of boards ca.		41						
number of boxes		320						
project management and detailing etc.	flat rate			45	1.1	CHF 95.00	CHF 4'275	CHF 2'100
arranging of the parts on 41 boards to minimize to minimize waste and tool changes	min. per board	115	4715	79	1.8	CHF 95.00	CHF 7'465	CHF 0
programming of the single parts from existing geometry include. Sawing of the slopes, milling the edges, milling the dovetail and drilling the holes	min. per part	23	29440	491	11.5	CHF 95.00	CHF 46'613	CHF 0
creating stickers for labeling	min. per part	5	6400	107	2.5	CHF 95.00	CHF 10'133	CHF 0
test "dry" milling of 41 boards	min. per part	50	2050	34	0.8	CHF 195.00	CHF 6'663	CHF 370
milling of 41 boards	min. per board	60	2460	41	1.0	CHF 195.00	CHF 7'995	CHF 6'500
assembly of 320 boxes	min. per box	15	4800	80	1.9	CHF 65.00	CHF 5'200	CHF 4'600
material cost							CHF 8'000	CHF 7'500
total cost							CHF 96'345	CHF 21'070
							100%	22%
risk supplement	30%						CHF 28'903	
total cost including risk							CHF 125'249	CHF 21'070
							100%	17%