







# **The Framed Pavilion**

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Modelling and Producing Complex Systems in Architectural Education

#### **The Framed Pavilion**





#### Code: the Ultimate Way to Control

As a consequence this means that future architects must be trained in designing the "aesthetic surface" as well as **being able to formalize the process**. They need to be programmers (to a certain extend) and know CNC technology with all its constraining and liberating features, so that there is no necessity to "dissect the frog". The designer should be able to "build it" from scratch.

#### Code: the Ultimate Way to Control



In the end of each course second year students (and higher) should **have developed their own** "digital tools" - as we call them - for the realization of their projects. They need to originate their own applications. No preconceived strategies are desired - no predefined output is allowed. Students must design the process and not the result.

#### **Code: the Ultimate Way to Control**

# More Bang for the Buck?

Over the last decade design interests have begun shifting away fro overall forms towards the tessellated worlds of scripted and para defined structures. The blob may be dead, but the challenge of geometries in architecture remains. Blob or pattern – advanced con techniques are becoming indispensable in supporting design, fab process management.

In den vergangenen zehn Jahren hat sich das Entwurfsinteresse weg von den komplexen Gesamtformen hin zu Welten gescripteter und parametrisch definierter Architekturen verschoben. Der Blob ist möglicherweise tot, forderung komplexer Geometrien in der Architektur ist nach wie vor da. Ob Blob oder Pattern – fortgeschritter niken sind aus dem Konstruktions-, Fertigungs- und Proressmanagement nicht mehr wegrudenken.

MARTIN BECHTHOLD

# **Robots: the Ultimate CNC Machines**

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In contrast to this, the scientific approach of the Institute of Architecture and Media is not necessarily based on a problem. We try to take a given tool and explore its capabilities.

Our goal is to get to the bottom of that tool, discover the present limits of its employment and expand the borders of what is possible. And, as we are currently working at the university, we always feel the **need to focus on the process, the research and the education of future architects** rather than on the pure result.

#### **Robots: the Ultimate CNC Machines**



Parametrics/Joints constructed/designed by/in Robots/Wood

Master/Designstudio Winter 2011/12



The Objective: Design a structure and all joints **solely made from timber**, no glue or other fasteners or fixings allowed. For the realization **use the capabilities of a 6-axes robot** on an additional linear axis. Moreover **the entire project must be applied parametrically!** 



Start to **analyze existing and traditional wood joints** and test their possibilities to transform them to digital and parametrical models. Next step is to **improve the parametrical models in consideration of producing all joints with our robot** and the milling environment.





The Studio concluded with **18 individual full**scale algorithmic projects and one completely implemented and built structure: The Framed Pavilion (TFP).





//// 3688 by Stefan Nuncic





Holzspaltung by Stefan Jos





the wooden tree structure **3.0** by Sara Vidacak





Parametric Joint by Karl Pansy







GYRO parametric by Georg Hansemann







#### BretterHaufen by Thomas Bartl



# "the framed pavilion"

SABINE LEHNER



The Framed Pavilion by Sabine Lehner



# The Evolution of TFP



Sabine Lehner's original design intention of was to build **irregular pentagonal frames mutating along an axis**. The implemented algorithmic process enables the user to convert any basic surface that seems appealing.

#### The Evolution of TFP



The Framework for the conceived design to production workflow was Rhinoceros extended by its visual programming language **Grasshopper**.

Due to performance and handling issues of large datasets we decided to split our parametrical process into two components that are linked together:

- 1. **Design Component**: Definition of boundary conditions and design environment for the main structure.
- 2. Joint Detail and Fabrication Component: Elaboration for the joint details with building and fabrication requirements including robot code generation.

# The Evolution of TFP



## **The Design Component**

Evolution from designed shape to finally defined frames and simulating different load situations.



Beside aesthetics, transport dimensions, given wood measurements and other boundary conditions, structural analysis is one of the biggest influences to construct our rigid wood frame structure. In collaboration with the Institute of Structural Design it was possible to define maximum beam length according to its cross section and the crease angle range between each wooden beam **without any external fastener and fixing**.

# **The Design Component**



All drawings, production lists, mounting instructions as well as material nesting results were **generated on the fly**.

# The Design Component





















































































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joint 2 spontpatt-sign 183 log frame 26 beam 2	FRAME 26	joint 1 stassrum t-sup tit og frame 26 beam 2	joint 0 schoot part 1 - ange 102.0 mg frame 28 beam 0	FRAME 28	joint 4 adventure ) - any 1112 au frame 28 beam 0	joint 3 adjoint part 4 angle 10.7 dag frame 29 beam 3	FRAME 29	joint 1 joint 1 ngover.pert.spg frame 29 frame 31 beam 3 beam 1	MI length 233.3 cm	ford 6 point 4 storement of a start of a storement of the store start of a store of the store of	FRAME 32	piet 2 piet 2 spentpet - spentp 2 state - spentpet (state Same 32 frame 34 base 4 bases 2	FRAME 34	biolit [ pint 6] stansarium 1 - segar 112 aug france 24 beam 0	FRAME 37	join sport,mt )- sep 10.1 frame bear
< LEFT joint 3 support just 4 angle HL7 mg frame 26	BEAM 2 million full lenght 276.7 cm	RIGHT > joint 2 separation 11.0 and 11.0 and frame 20	< LEFT joint 1 storerpet2-wys=10.wy frame 28	BEAM 0 an 2017 an full length 263,5 cm	RIGHT > joint 0 squart profession frame 20	< LEFT joint 4 adjournment- unger 1982 mg	BEAM 3 an 755m full lenght 277,4 cm	RIGHT> <left point 3 point 2 separation 2 and set (1.1 mg set), 2 mg set (1.1 mg set), 2 mg</left 	BEAM 1 million full lenght 227 cm	RIGHT> <left juint 1 joint 0 stannet page 101, day transe 31 frame 23</left 	BEAM 4 million full length 284 cm	RIGHT > <left juint 4 juint 7 where the second at the seco</left 	BEAM 2 an 154 m full lenght 122 cm	RIGHT> < LEFT juike 2 juike 1 stansport, angle 154, angle stansport, angle 154, angle frame 34 transport, angle 154, angl	BEAM 0 an Wilson full lenght 183,2 cm	RIGHT join squart and stage 103 frame
beam 3 < LEFT joint 4 stoom jact 1 unge 115 ing	BEAM 3 an 2014 m	beam 3 RIGHT > joint 3 adjust (art 2- angle 10.7 mg	beam 1 < LEFT joint 2 advantpet 3- angle 100 dag	BEAM 1 ans vectors full length 100,5 cm	beam 1 RIGHT > joint 1 steamt, and - ange 112 mg	beam 4 < LEFT joint 0 adjoint just 1 unde 1003 day	BEAM 4 an 200 m full lenght 219,8 cm	beam 4 beam 2 RIGHT > <left joint 5 report junt 1 and 1 a</left 	BEAM 2 an VIC m full lenght 179 cm	beam 2 beam 0 RIGHT> <left joint 2 joint 1 standport, and rith and</left 	BEAM 0 an 2014 m full lenght 213,2 cm	beams 0 beams 3 REGMT> < LEFT joint 0 joint 4 spentjant - sept 10.1 mg	BEAM 3 an 200 m full lenght 313,5 cm	beam 3 beam 1 RIGHT> < LEFT joint 3 joint 2 standpart_antapps 112 aug standpart_antapps 112 aug	BEAM 1 an States full lenght 353,8 cm	bean RIGHT join speed,and - organistic
frame 26 beam 4 < LEFT joint 0 separtpart - argentititing	FRAME 26 BEAM 4 Int TOLEN full length 199,2 cm	frame 24 beam 4 RIGHT > joint 4 scientiant ) - sign 111 au	frame 28 beam 2 < LEFT joint 3 squartpet+ wap 12 mg	FRAME 28 BEAM 2 min 2014 m full length 237,5 cm	frame 28 beam 2 RIGHT > joint 2 adjoint (21 day	frame 50 beam 0 < LEFT joint 1 separature 2 man 10.0 mg	FRAME 30 BEAM 0 min 202 m full length 243,6 cm	frame 30 frame 31 beam 0 beam 3 RIGHT > <left joint 0 joint 4 adjustment and sector part - any stat any</left 	FRAME 31 BEAM 3 sec 201. on full length 290,2 cm	frame 31 teams 33 teams 3 beam 3 team 1 RIGHT> < LETT joint 3 joint 2 steamstart - report - super (20.4 teg	FRAME 33 BEAM 1 millionght 278 cm	frame 33 frame 34 bases 1 bases 4 RIGHT > < LEFT joint 1 joint 0 statestant-sept 105.0 ag	FRAME 34 BEAM 4 sm 300 m full length 200,4 cm	frame 34 frame 37 beam 6 beam 2 RIGHT> <left joint 4 joint 3 stansport - support and stansport - support (20.7 day</left 	FRAME 37 BEAM 2 an Tot on full lenght \$2,3 cm	frame bean RIGHT join sdoort.art 1-args 104
trame 37 beam 3 < LEFT joint 4	FRAME 37 BEAM 3	frame 37 beam 3 RIGHT > joint 3	frame 29 beam 1 < LEFT joint 2	FRAME 39 BEAM 1	frame 39 Beam 1 RIGHT > joint 1	frame 40 beam 4 < LEFT joint 0	FRAME 40 BEAM 4	frame 40 frame 42 beam 4 beam 2 RIGHT > <left joint 4 joint 3</left 	FRAME 42 BEAM 2	frame 42 frame 44 beam 2 frame 44 RIGHT> <left joint 2 joint 1</left 	FRAME 44 BEAM 0	frame 44 frame 45 bears 0 bears 1 RIGHT> < LEFT junt 0 juint 4	FRAME 45 BEAM 3	frame 45 trame 47 beam 3 beam 1 RIGHT> < LEFT joint 3 plots 2	FRAME 47 BEAM 1	frame Bear RiGHT juin
frame 37 beam 4 < LEFT	FRAME 37 BEAM 4	frame 37 beam 4 RIGHT >	frame 39 beam 2 < LEFT joint 3	FRAME 39 BEAM 2	report professional frame 30 beam 2 RIGHT >	frame 41 beam 0 < LEFT	FRAME 41 BEAM 0	report part 1 - sign (12.5 g) effect (and 1 - sign (12.5 g)) frame 41 frame 42 beam 3 RIGHT > <left juice 4</left 	FRAME DEAM 3	representation of the second s	FRAME 44 DEAM 1	spectral to age 102 ag barne 64 barn 1 barne 65 barn 1 barne 66 barn 1 barne 67 barne 67 barne 68 barn 1 barne 69	FRAME 45 BEAM 4	epontant)- up ttt / ag frame 45 frame 47 beam 4 beam 2 R(347 + <1 FFT cont 4 w	FRAME 47 BEAM	Right Right
ngenergent - ange 1073 ang frame 38 beam 0 < LEFT	full lenght 333,8 cm FRAME 38 BEAM 0	pund 4 ndecer(pet)-angle 153 mg frame 38 beam 0 RSGHT >	spectart and the set	full lenght 154,8 cm FRAME 39 BEAM 3	prof 2 adjust (241 - angle 173 og frame 39 beam 3 RIGHT >	Name 41 bean 1 < LEFT	full lenght 177,1 cm FRAME 41 BEAM 1	specification of the second se	full lenght 206,3 cm FRAME 42 BEAM 4	view w12 mere w spectrants mitting beams 4 RIGHT> <left< td=""><td>A Mg UNA KANG CRA BEAM 2</td><td>an and a man 4 been 2 RIGHT&gt; <left< td=""><td>FR //E 41 BEAM 0</td><td>New 1- 00.7 m - 00 - 01 - 01 - 10 New 2 - 00 - 01 - 01 - 01 NGHT&gt; <left< td=""><td>FR //E 4. BEAM 3</td><td>per advertanti-argin tits brane bran RIGHT</td></left<></td></left<></td></left<>	A Mg UNA KANG CRA BEAM 2	an and a man 4 been 2 RIGHT> <left< td=""><td>FR //E 41 BEAM 0</td><td>New 1- 00.7 m - 00 - 01 - 01 - 10 New 2 - 00 - 01 - 01 - 01 NGHT&gt; <left< td=""><td>FR //E 4. BEAM 3</td><td>per advertanti-argin tits brane bran RIGHT</td></left<></td></left<>	FR //E 41 BEAM 0	New 1- 00.7 m - 00 - 01 - 01 - 10 New 2 - 00 - 01 - 01 - 01 NGHT> <left< td=""><td>FR //E 4. BEAM 3</td><td>per advertanti-argin tits brane bran RIGHT</td></left<>	FR //E 4. BEAM 3	per advertanti-argin tits brane bran RIGHT
joint 1 separat part 2-ange 105.8 ang frame 38 beam 1	FRAME 38	joint 6 alportjant 4 - angle 1813 ang framo 38 beam 1	joint 4 adventanti- urgn 11.5 mg frame 39 beam 4	FRAME 39	joint 3 separat part 2 - angle 118,5 day frame 20 beam 4	joint 2 adjoint (and ) - angle 114,0 mg frame 41 beam 2	FRAME 41	joint 1 joint 0 nipuntjant)-mije 107,5 mj frame 41 frame 43 beam 0	Millionghi 253,3 cm	joint 4 joint 3 alpont(an1)-aujo (c) aug frame 43 frame 44 beam 0 beam 3	FRAME 44	joint 2 joint 1 separatus 1 angle 11 dag frame 64 beam 3 beam 1	FRAME 46	joint 0 joint 4 advertigent 4 ange 102 ang frame 46 frame 47 beam 6	In 201 m full lenght 222,5 cm FRAME 47 DE AM 4	join sportpit 2- opril;1 frame bean
< LEFT joint 2 sport(set) - sept 10.0 kg	full lenght 337,6 cm	RIGHT > joint 1 squart,set1 - squart 11.1 mg	< LEFT joint 0 adjust just 1 augu 100.1 dag	full lenght 300,8 cm	RIGHT > joint 4 states(and ) - style 10.1 mg	< LEFT joint 3 adjust(jat(4) angle (14,2 ang	torcAM Z an ULL m full lenght 143,3 cm	RIGHT > < LEFT joint 2 joint 1 squarture 1-angle 118.2 day squarture 2-angle 118.7 day	full lenght 174,3 cm	RIGHT> < LEFT joint 0 joint 4 stport just 4 - stport just 1, stop	In Soften full lenght 246.3 cm	RIGHT> <left joint 3 joint 2 separatual 2- separatus and separatus 1- separatus 2- separatus and</left 	full lenght 194,3 cm	RIGHT> < LEFT joint 1 joint 0 eleverjant - anja 112, anja sejeverjant - anja 123, anja	Nil lenght 175,8 cm	RIGHT joir stasser.pet 1- man th





#### Parametric joint design



Different machining operations and milling path creation.



For the parametrically generation of all machining operations and tool paths following input parameters were considered:

- 1. Milling head for 6-axis robot with different cylindrical tool definitions.
- 2. Robot geometry including additional linear axis for reachability simulations.
- 3. Fastening structure for beams during milling.
- 4. **Tolerance optimization** between easy manual assembling and best values for friction and rigidity inside the joint.
- 5. **Milling parameters** like cut levels, path offset distances, point step density and additional tolerances to avoid collisions.
- 6. Optimization of tool paths and strategies to reduce production time



Mounting and the restrictions.

Based on all these conditions the necessary machining operations were specifically developed to generate automated production data.





Different machining operations and milling path creation.



To keep different robotic production environments and robot manufacturer in mind we developed two gateways to communicate with the output devices.

- 1. Our component is able to **export apt milling files** which are standard in exchanging milling information as example for robot post processors like Pi-Path for ABB robots.
- The second output format creates the possibility to directly write and simulate entire ABB RAPID code in real-time without intermediate steps between design environment and production – the Java or Grasshopper-based simulation, code generator and live controller for ABB robots Boot The Bot.



The positioned wooden beams and **robot milling head during the production** of the two parts.









**Assembling** pentagonal frames.

**Combined to transportable units** with wooden plugs driven in at the predefined **skew drill holes** and rolled into the upright position.











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# Acknowledgements



# **The Framed Pavilion**