

# Optimalisatie van textielgevormde betonconstructies Optimisation of fabric formed concrete structures

ir. Diederik Veenendaal, TEKTONIEK, TU Delft, 07.04.2015

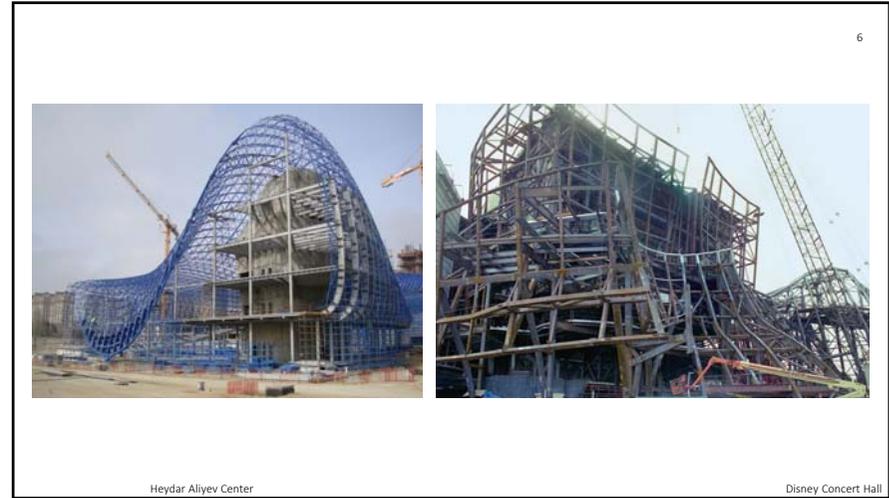
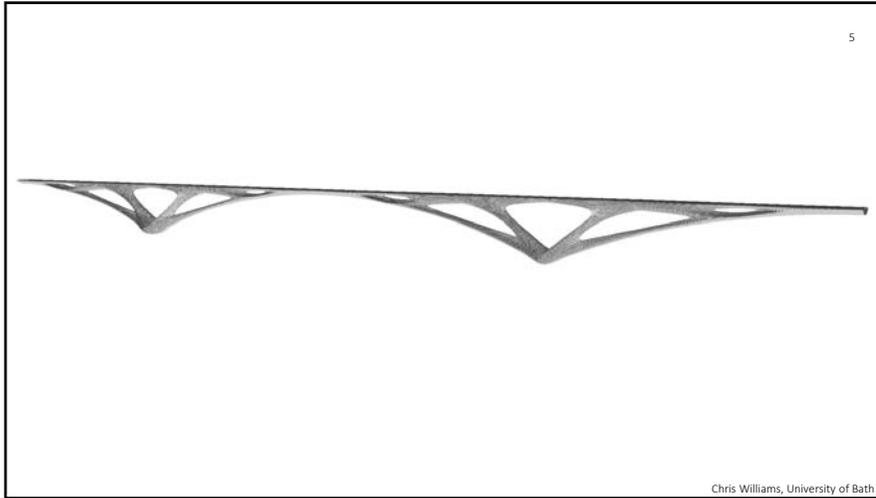


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- (Structural) optimization and form finding
- NEST HiLo floor system
- Bi-directional evolutionary structural optimization (BESO)
- Genetic algorithms
- Fabric formworks
- Fabric formed shells
- NEST HiLo roof





(Structural) optimization and form finding

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What is optimal?

Mathematically speaking:

Minimize a function  $f$  of  $n$  variables  $\mathbf{x}$ ,  
subject to  $m+p$  constraints  $g$  and  $h$ .

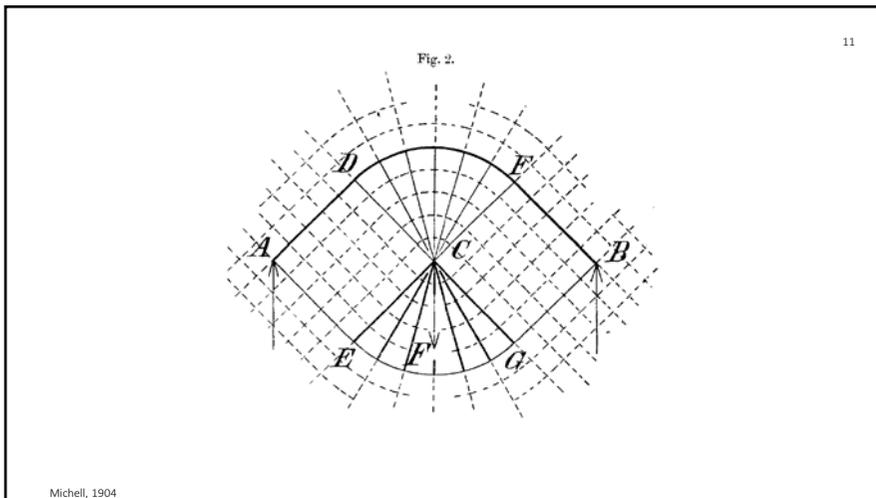
$$\begin{aligned} & \text{minimize } f(\mathbf{x}) \\ & \text{subject to } \begin{cases} g_i(\mathbf{x}) \geq 0, & i = 1, \dots, m \\ h_j(\mathbf{x}) = 0, & j = 1, \dots, p \\ x_i \in \mathbf{x}, & i = 1, \dots, n \end{cases} \end{aligned}$$

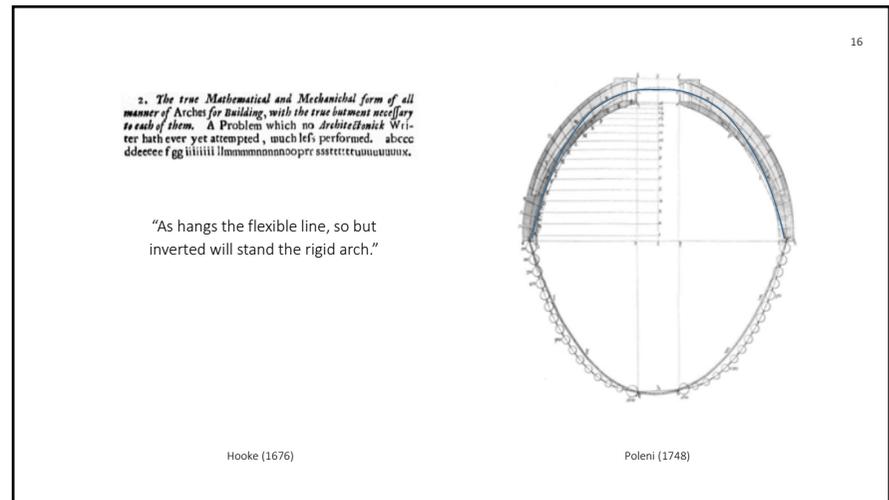
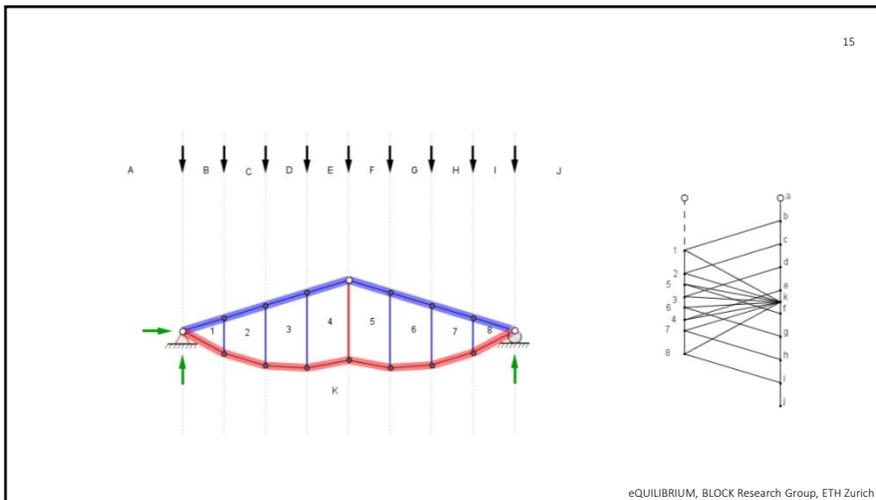
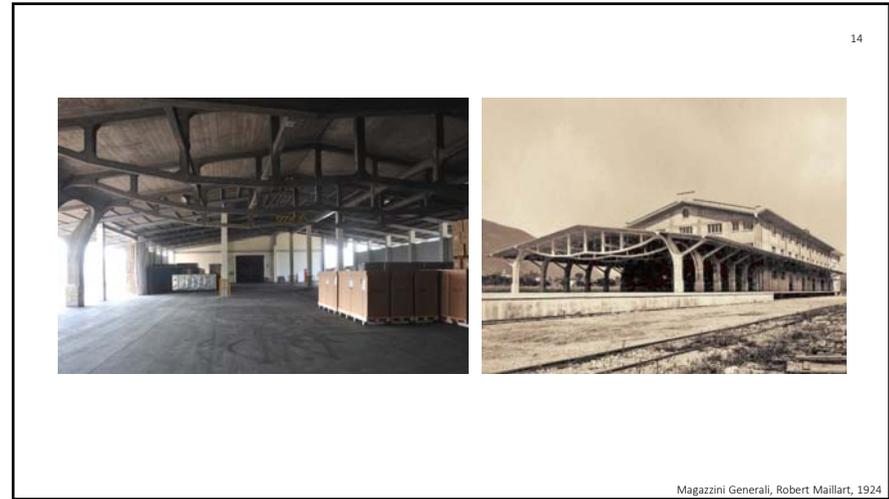
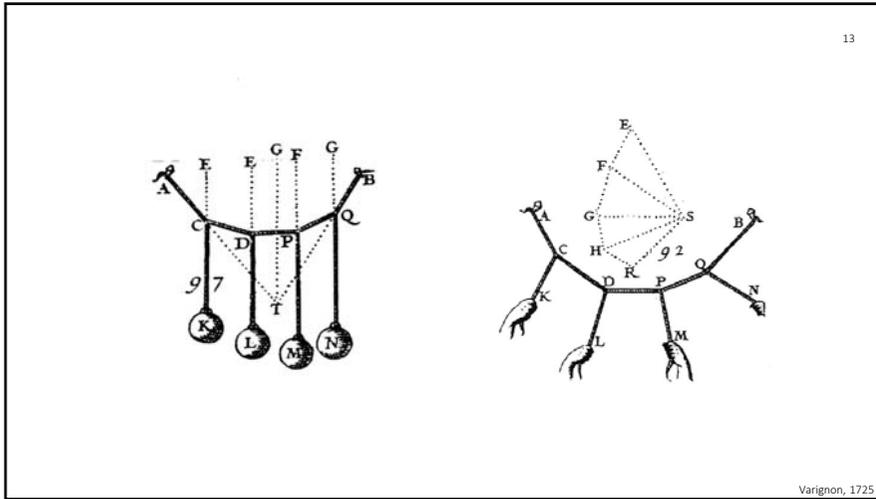
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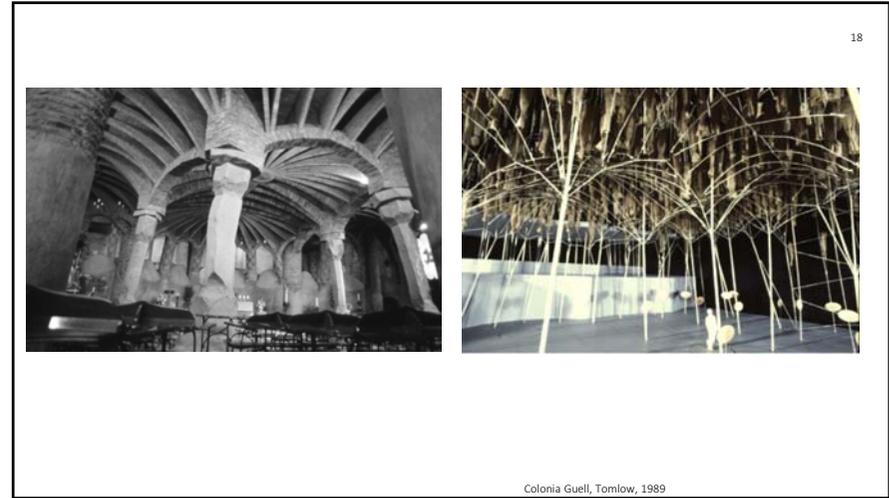
What do we minimize?

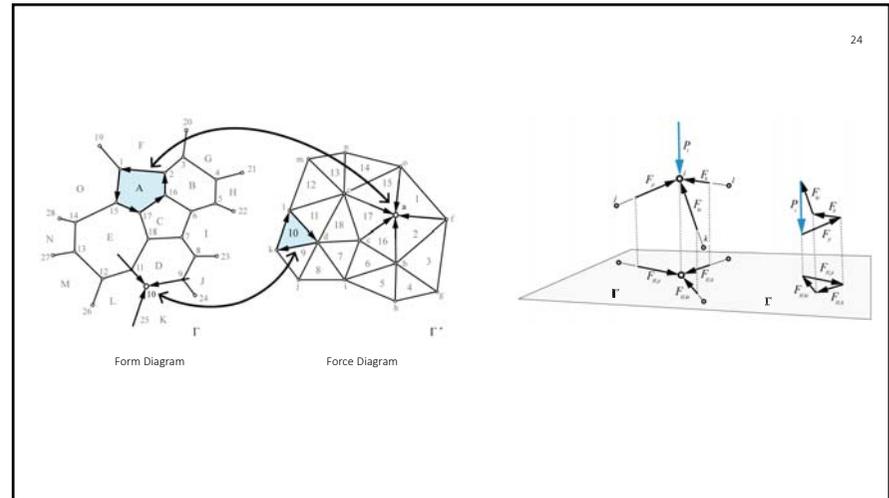
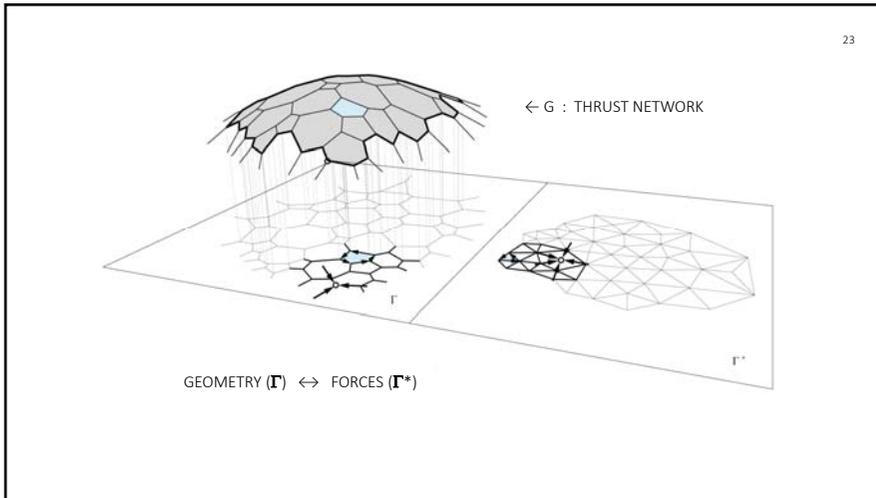
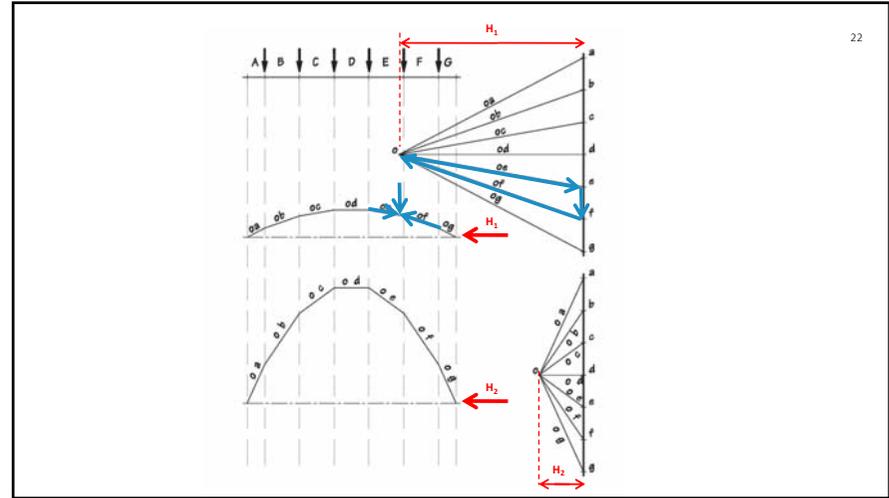
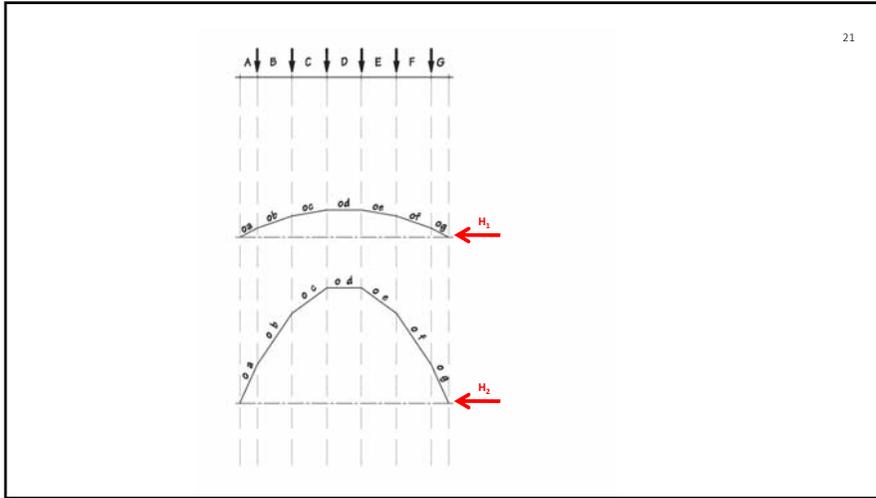
Structural engineer might say:

- material / weight
- deflections / vibrations
- 'compliance' (maximize stiffness)
- buckling
- ... etc.

$$\begin{aligned} & \text{minimize } f(\mathbf{x}) \\ & \text{subject to } \begin{cases} g_i(\mathbf{x}) \geq 0, & i = 1, \dots, m \\ h_j(\mathbf{x}) = 0, & j = 1, \dots, p \\ x_i \in \mathbf{x}, & i = 1, \dots, n \end{cases} \end{aligned}$$








RhinoVAULT (video removed from presentation):  
<http://player.vimeo.com/video/75312554>  
<http://www.block.arch.ethz.ch/brg/tools/rhinovault>

**NEST HiLo – Research & Innovation Unit**  
 EMPA, Döbendorf, Switzerland, 2013 - present

**BLOCK Research Group, ETHZ**  
 Prof. Dr. Philippe Block  
 Diederik Veenendaal  
 Dr. Tom Van Mele  
 David López López  
 Dr. Tomás Méndez Echenagucia

**Collaborators**  
 supermanoeuvre  
 ZJA Zwarts & Jansma Architects

**SuAT, ETHZ**  
 Prof. Dr. Arno Schlüter  
 Gearoid Lydon  
 Dr. Zoltan Nagy  
 Anja Willman  
 Johannes Hofer  
 Bratislav Svetozarevic  
 Prageeth Jayathissa

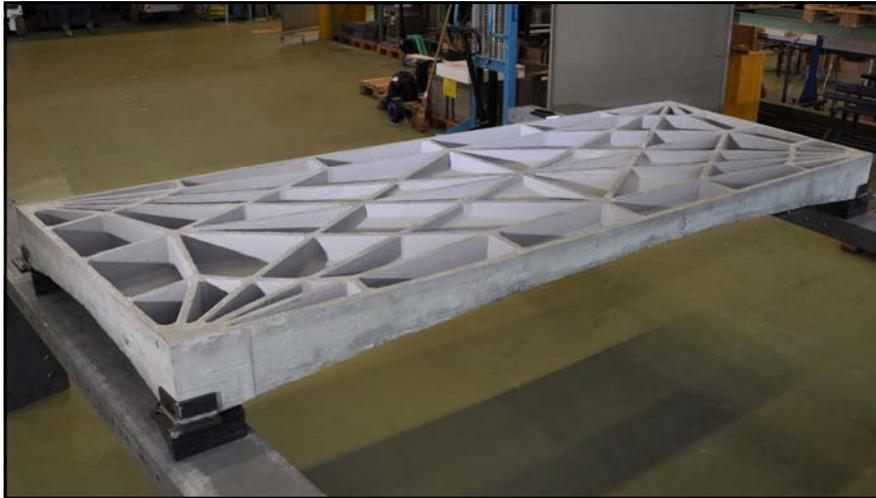
**Consultants**  
 Gruner Roschi, HHM  
 Hämmerle + Partner, HSP  
 Reflexion, Wichser Akustik  
 Bollinger+Grohmann Ingenieure



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**Main innovations**

- Integrated, multifunctional shell
- Lightweight, flexible formwork system
- Ultra-lightweight, integrated funicular floor
- Adaptive solar façade system
- Intelligent building control

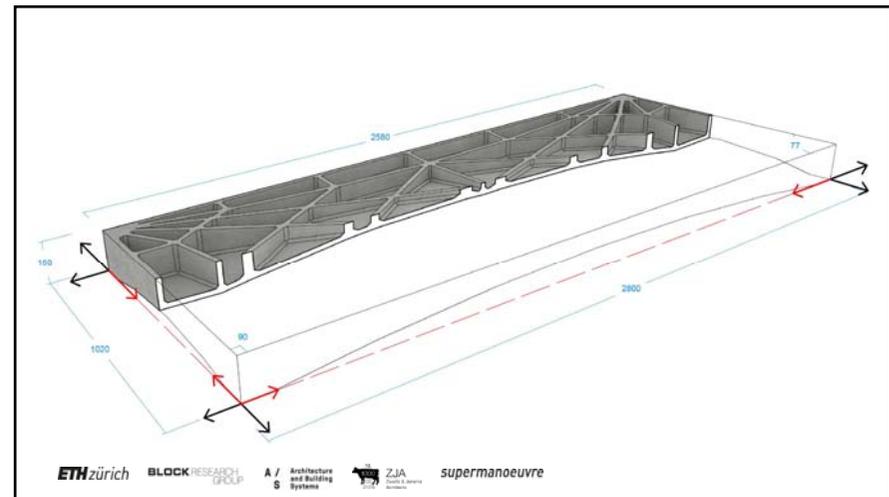
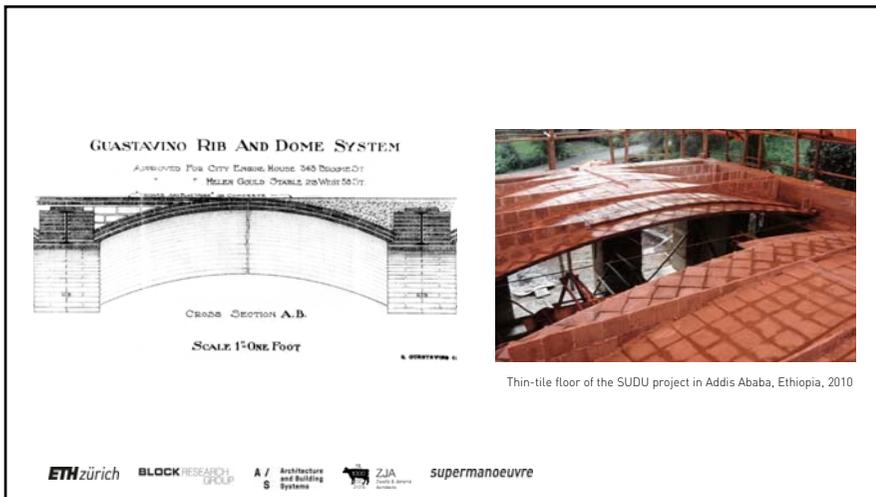


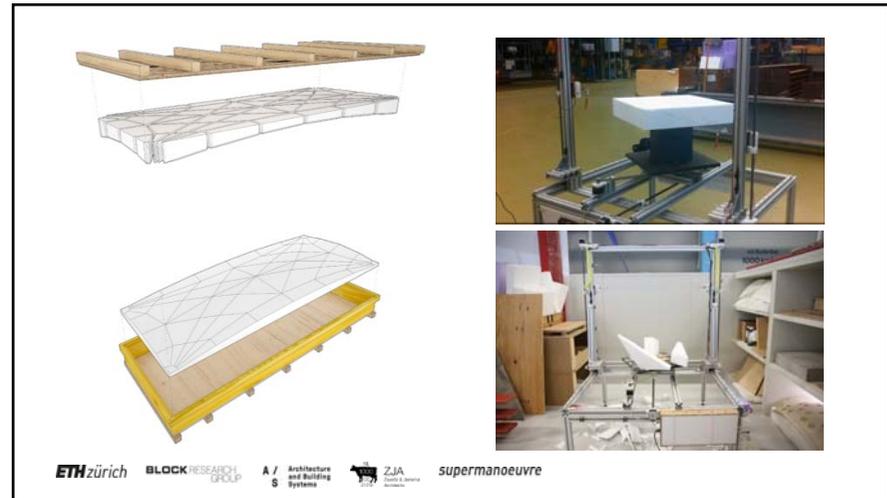
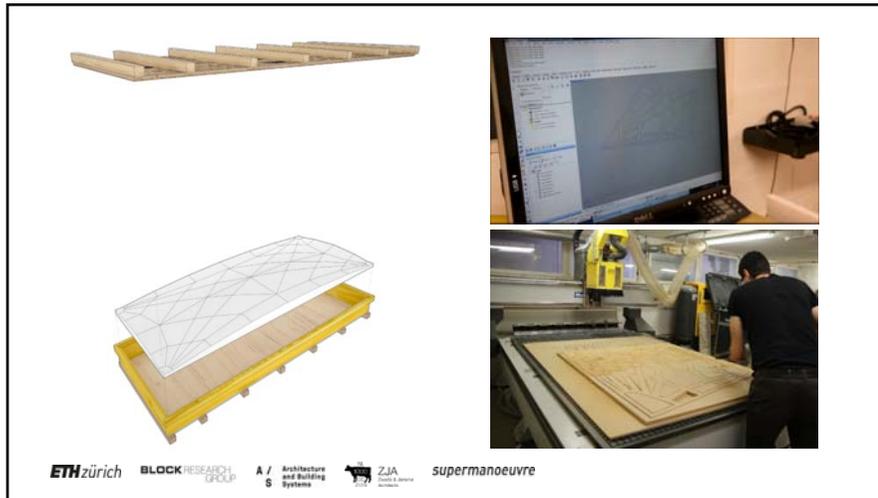
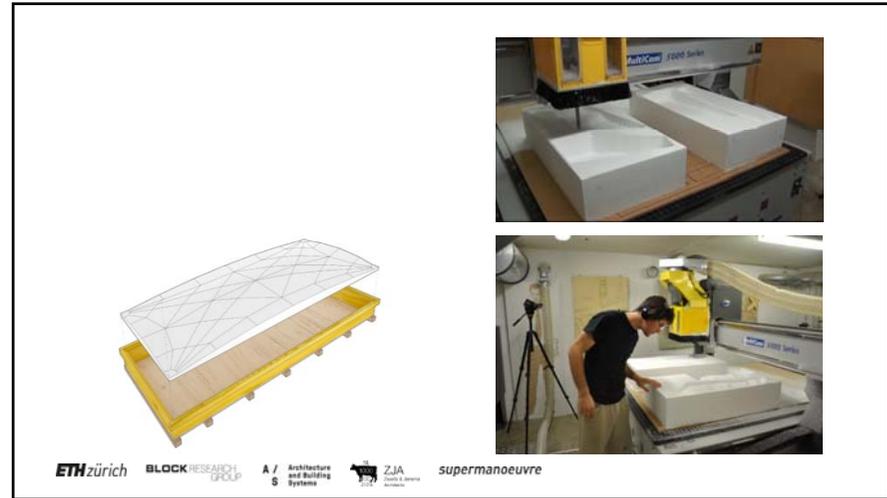
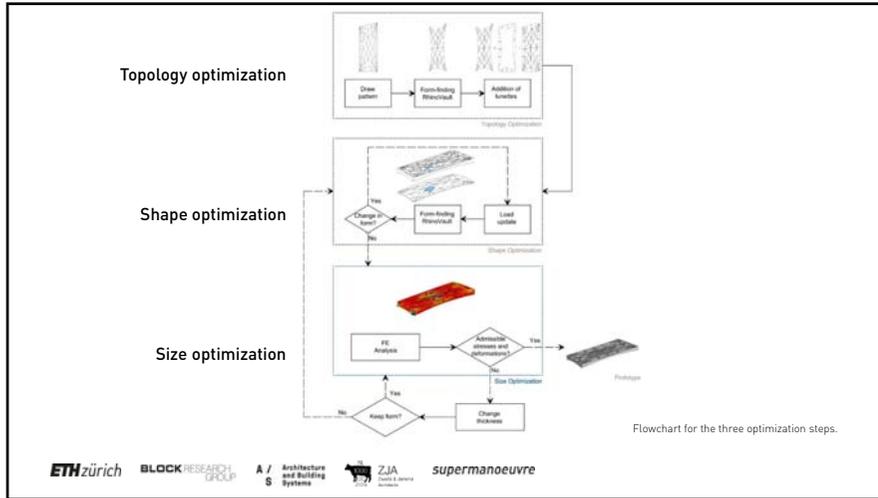
### Floor system

- funicular (= compression-only) 2cm shell
- stiffened by diaphragm 2cm ribs
- unreinforced concrete
- 70% saving of material
- according to SIA building codes

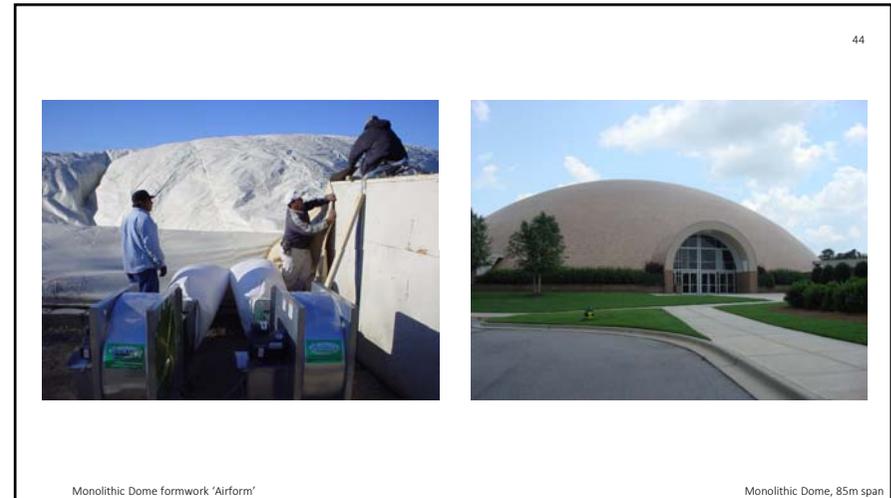
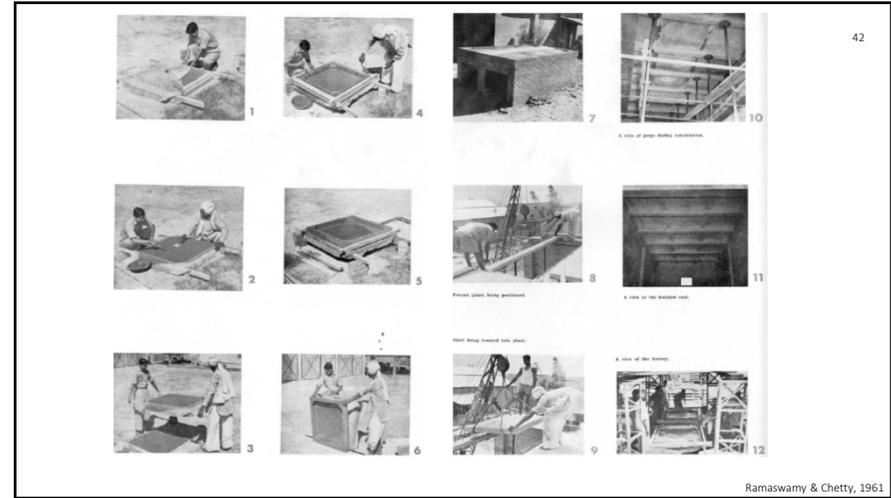


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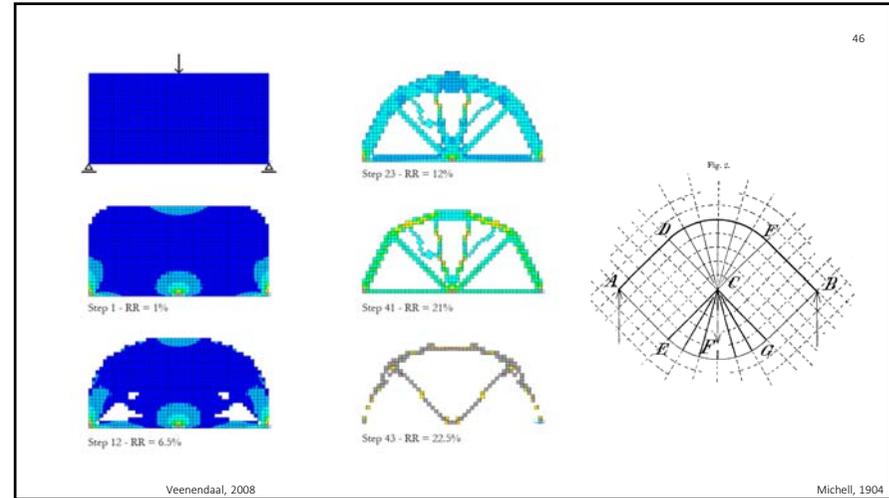




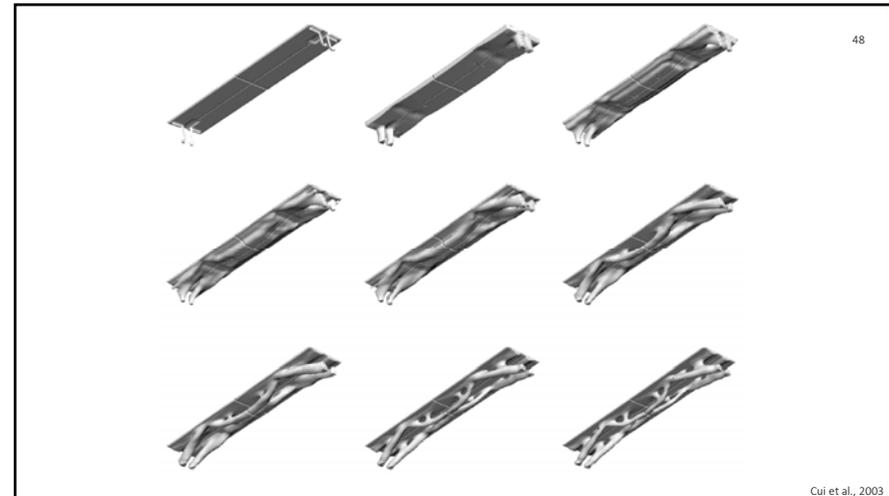




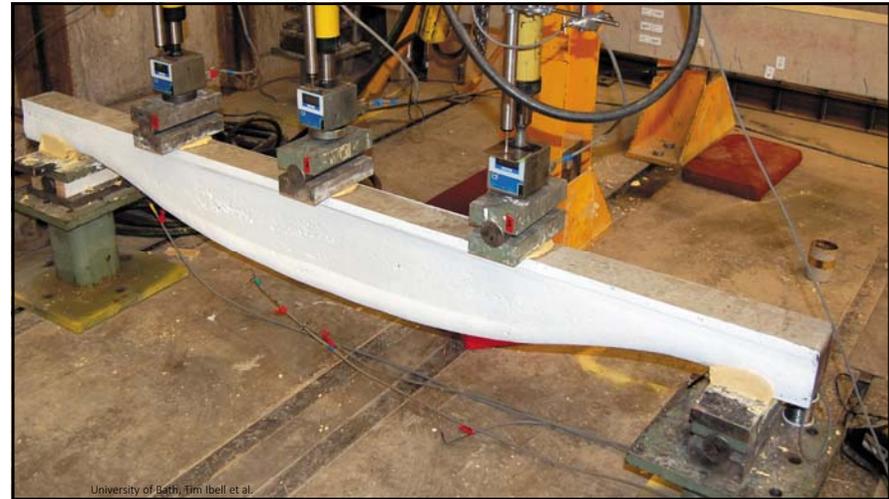
# Bi-directional Evolutionary Structural Optimisation (BESO)



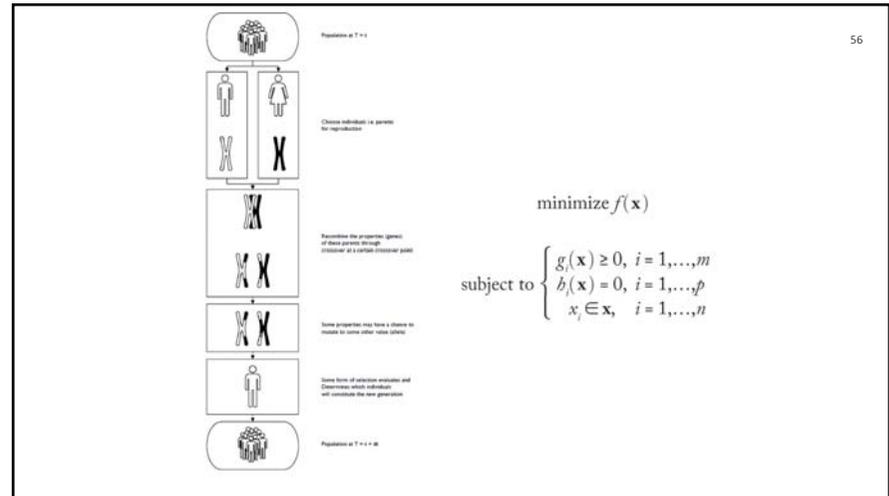
BESO in ANSYS (video removed from presentation):  
<https://youtu.be/J9cyYP-mzBA>  
<https://youtu.be/LkTam7bev14>

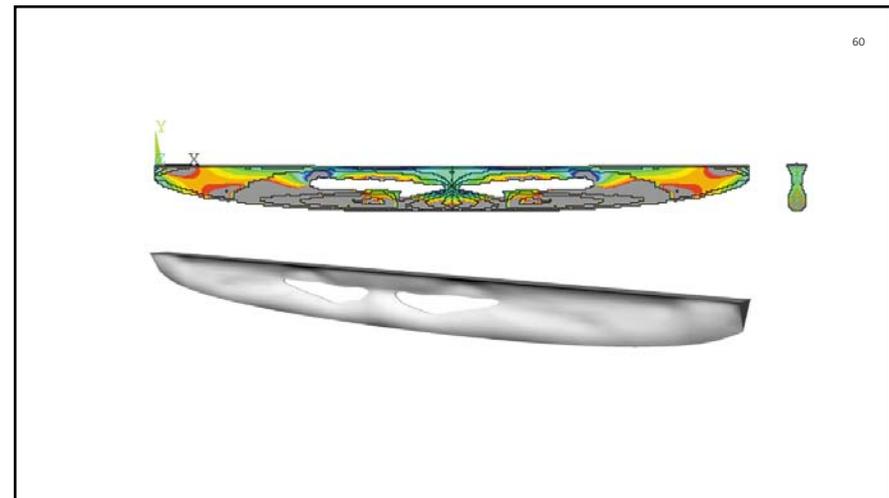
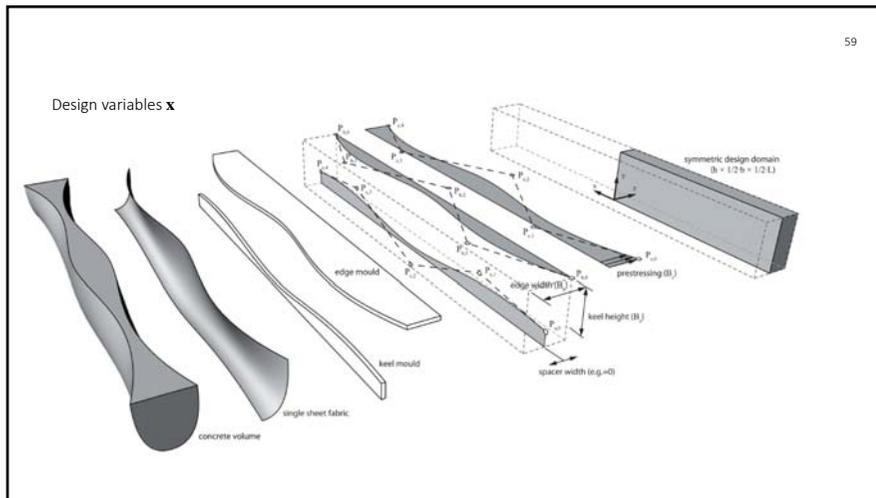
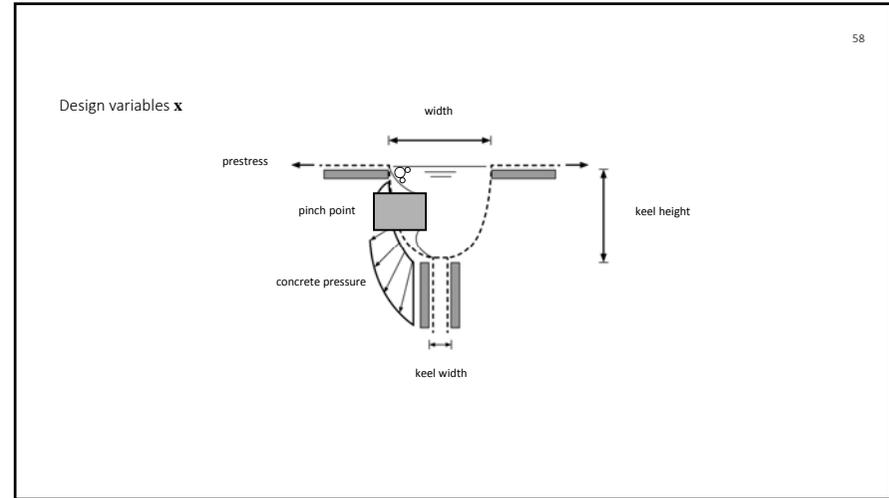
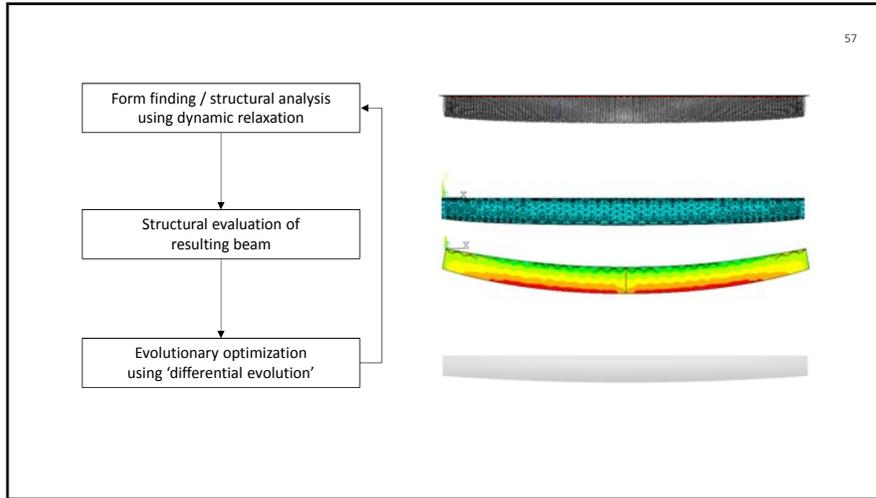






Genetic algorithms





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Comparison with rectangular beam

same volume, same w/h ratio  
91% less deflection

same volume, same height  
78% less deflection

same height, same deflection  
58% less volume

deflection

w

h

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**Structural analysis, optimisation, form finding**

- Kangaroo
- Karamba
- Millipede
- Bullant
- Donkey
- Dodo
- etc.

**Genetic algorithms**

- Galapagos
- Octopus

Fabric formwork

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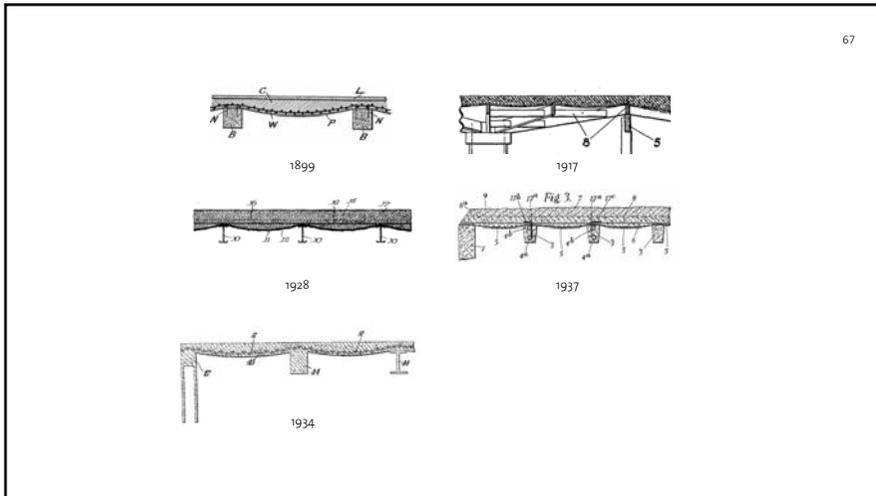
Schnitt in Deckentraverse

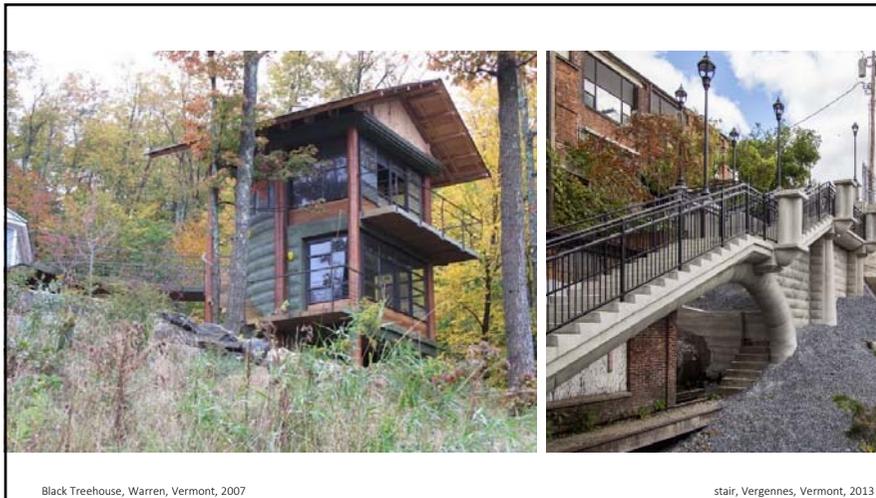
Querschnitt Lastträger

Deckentraverse

Trifflische Lastfläche

Gustav Lilienthal, Berlin, Germany

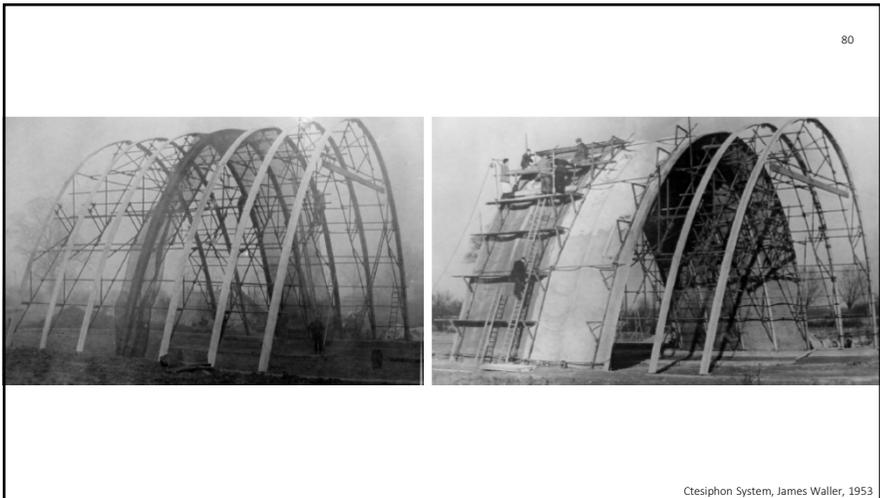
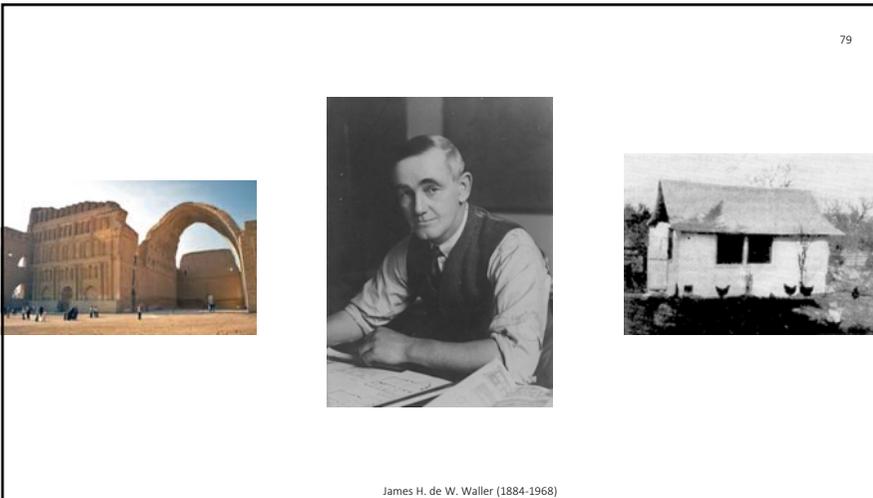




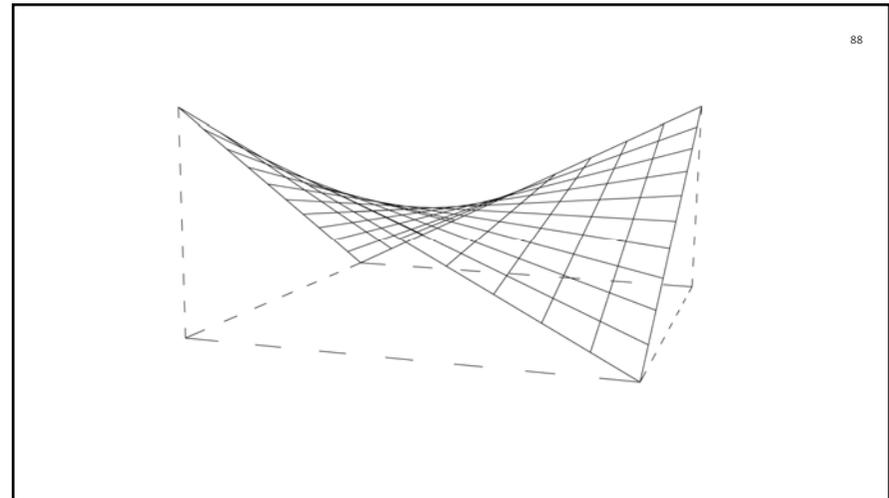
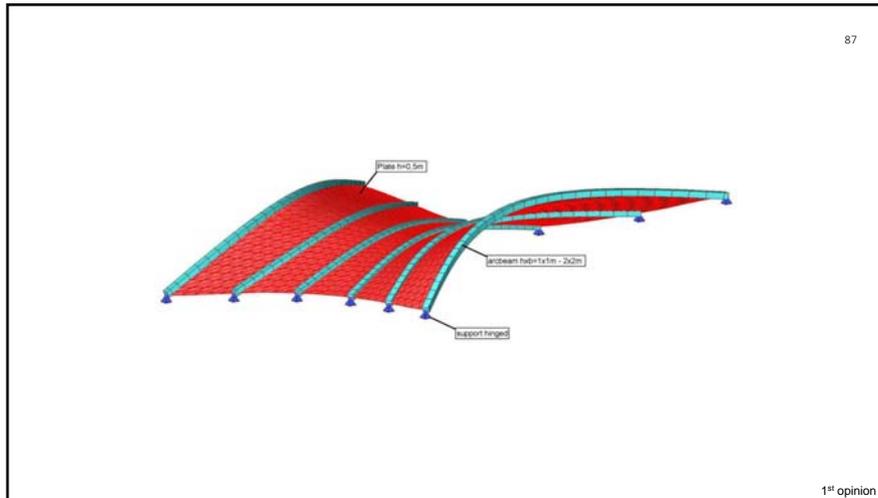


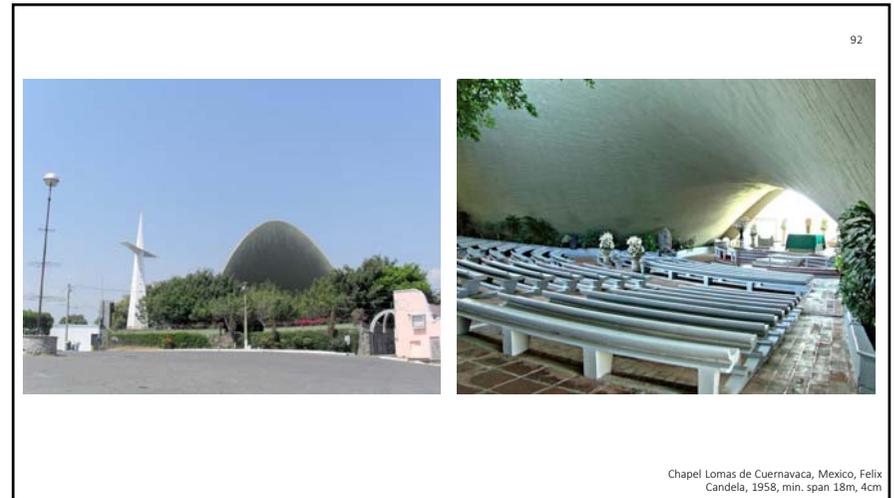


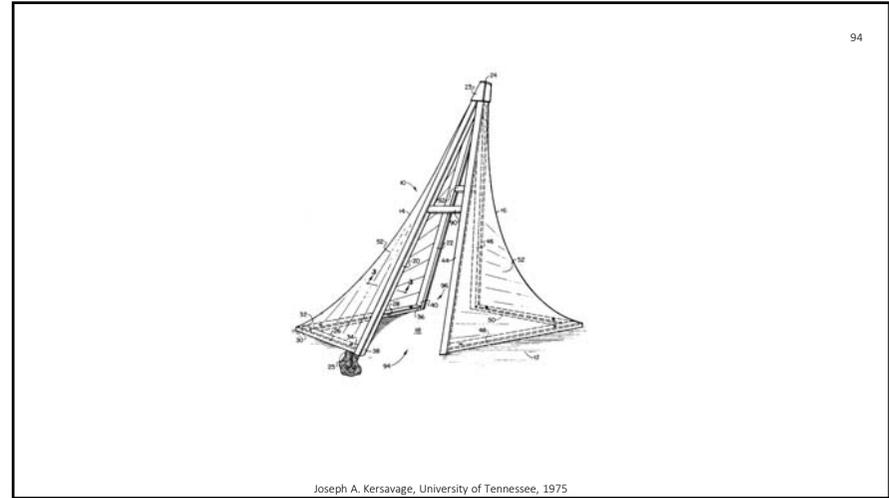
Fabric formed shells



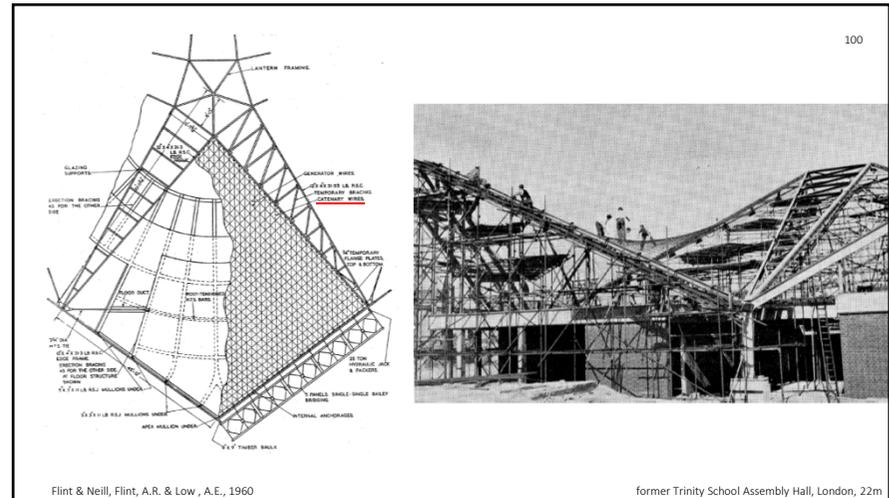
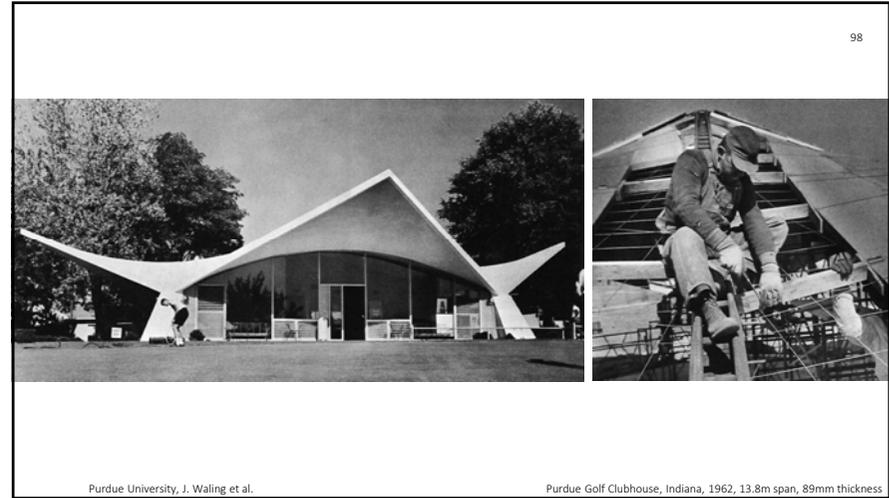






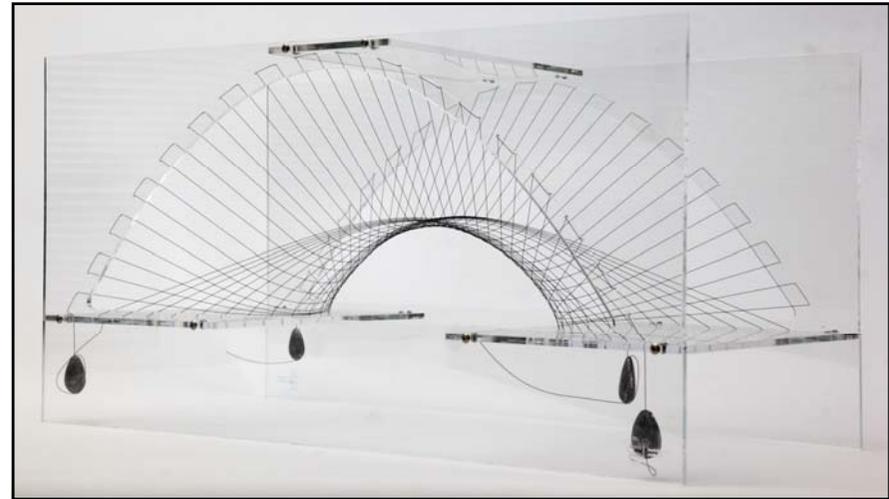
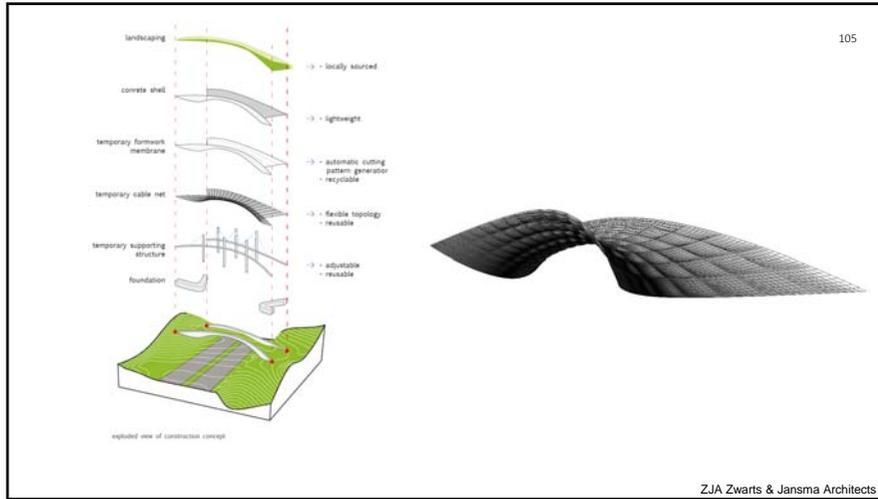


Cable-net formworks





Hybrid cable-net and fabric formwork

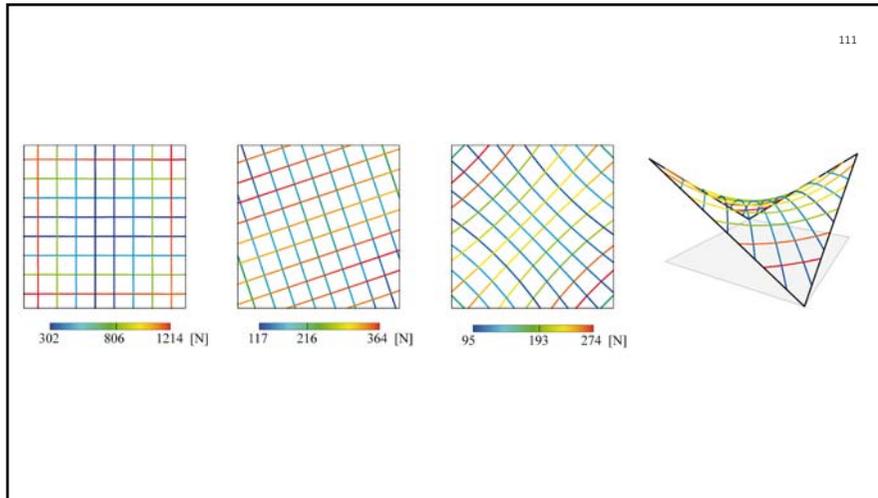
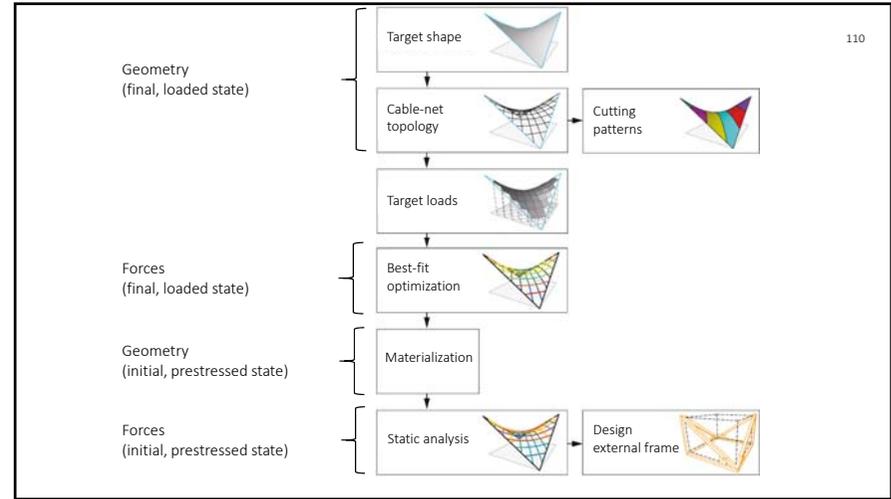
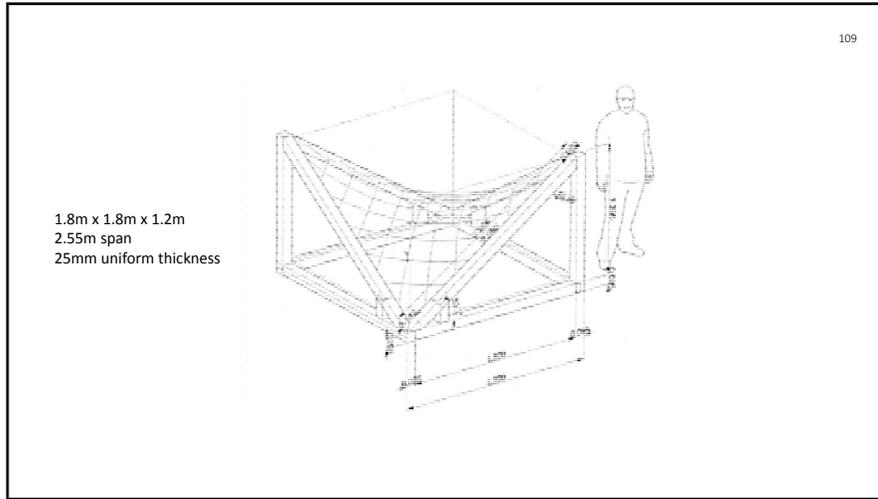


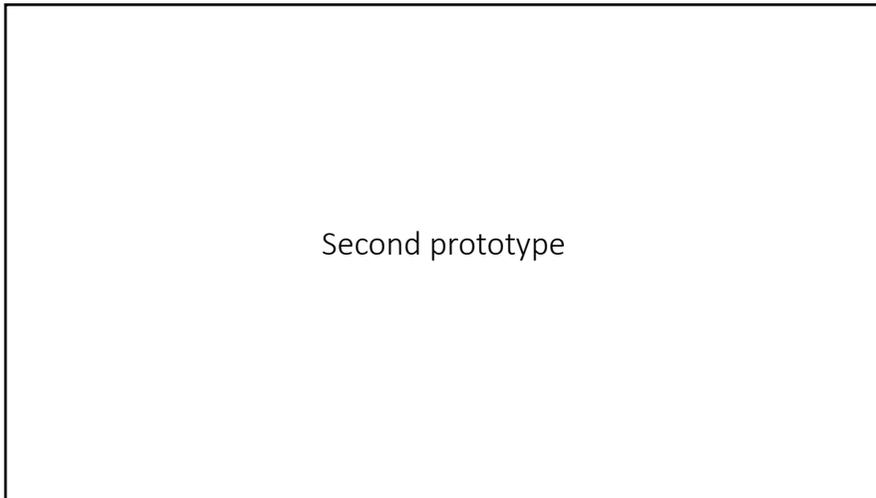
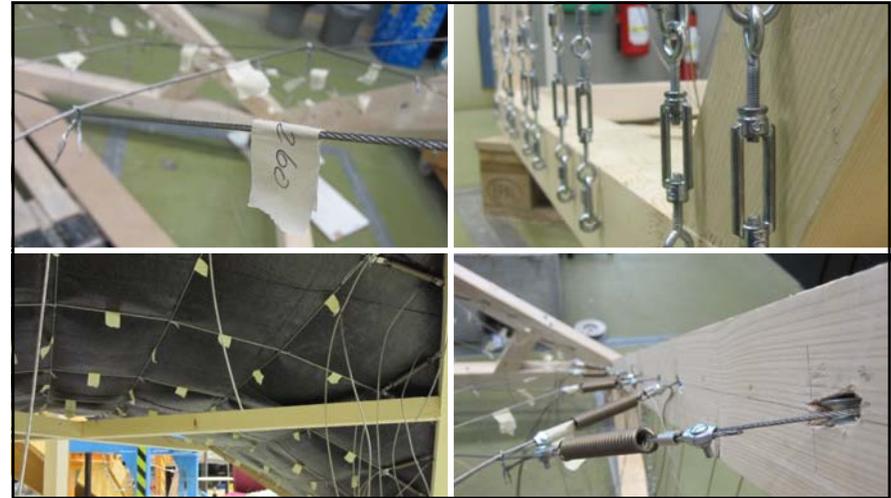
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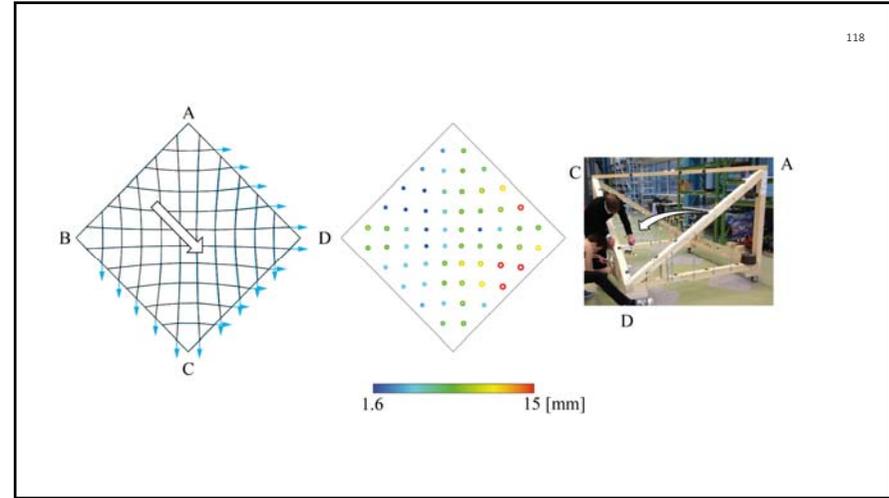
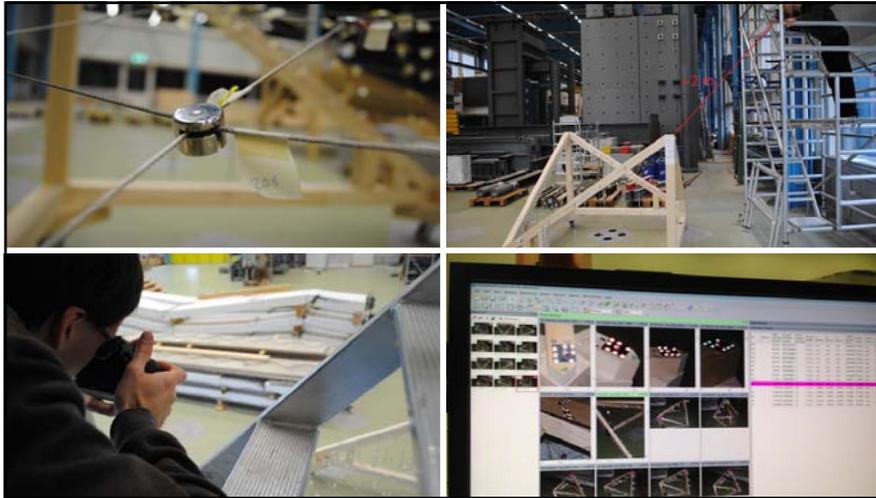
**Concept**

- Cable-net falsework with fabric shuttering
- Lightweight and compact
- Non-uniform prestress distribution
- 'Freeform', anti-clastic shell design
- Large-span, affordable formwork
- No scaffolding directly underneath
- Construction tolerances?

First prototype





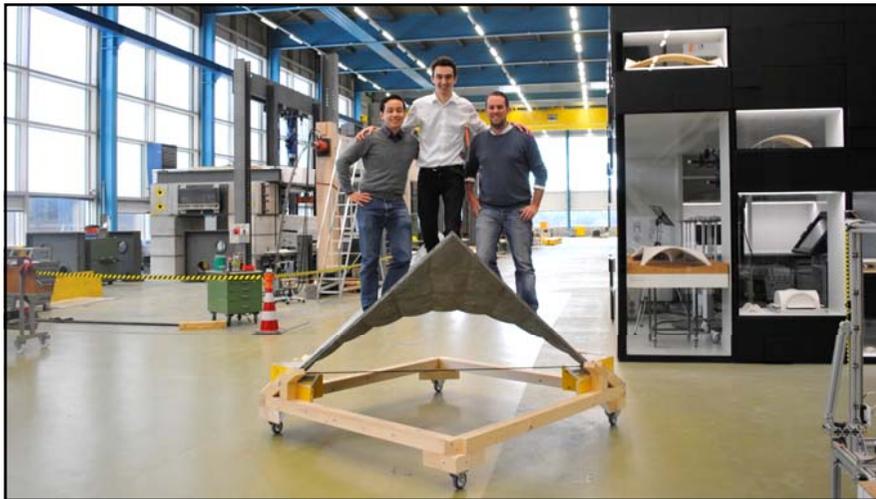


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	Unloaded state	Loaded state
Initial comparison	7.8 ±2.5	10.0 ±2.6
(1) Remapped boundaries	7.0 ±3.1	7.0 ±3.3
(2) Perpendicular to surface	2.6 ±1.4	2.0 ±1.5
(3) Recomputed digital model		1.3 ±0.8

mean deviation ±standard deviation [mm]





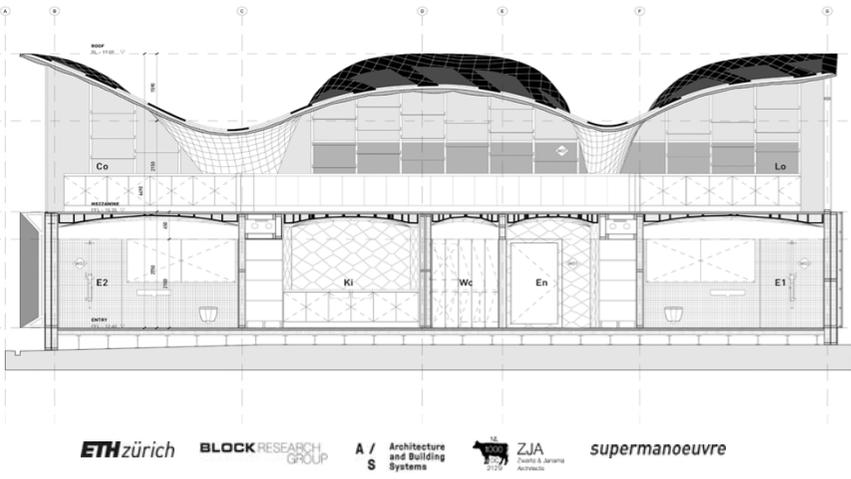
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**Main innovations**

- Integrated, multifunctional shell
- Lightweight, flexible formwork system
- Ultra-lightweight, integrated funicular floor
- Adaptive solar façade system
- Intelligent building control

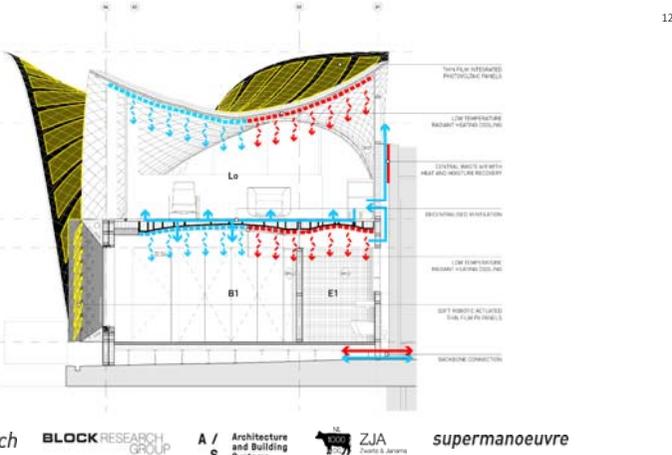


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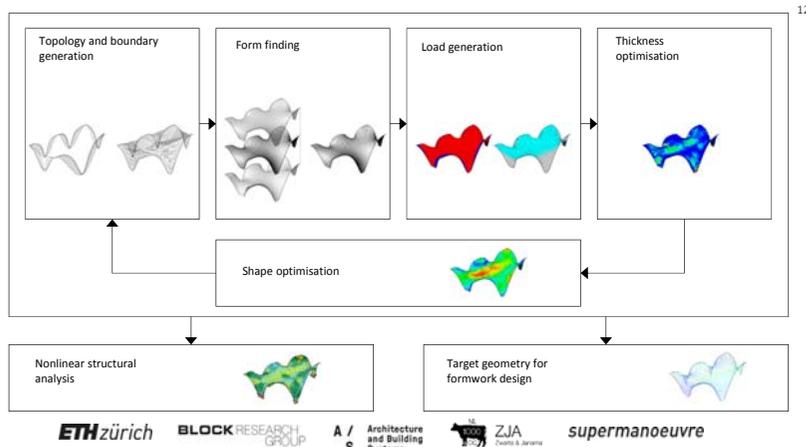
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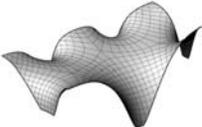
**Shell design process**

Swiss code for loads, ACI code for ferrocement, IASS recommendations for shell

Optimise thickness for stresses < 20 MPa, deflections >  $L/500 = 18\text{mm}$

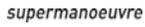
Four objectives: internal elastic energy vs buckling load; head clearance vs glazing area

Current shape: 9m max. span; 6-11cm average concrete thickness; 20-45 metric tonnes





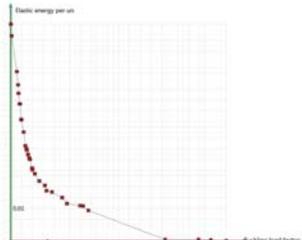




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**Shell design process**

Buckling versus weight



Clearance versus glazing

