Structural Design VI

Philippe Block · Joseph Schwartz

Lead tutors:

Dr. Tomás Méndez Echenagucia
Dr. Matthias Rippmann

Structural Design VI: Computational Methods

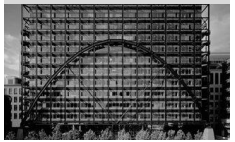
Introduction

Computational Methods in Structural Design

Parametric Design

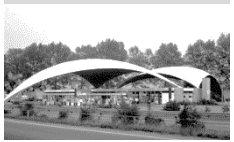
Fabrication-aware Structural Design

Parametric Graphic Statics

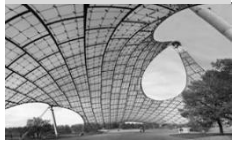


Digital Fabrication Of Structures

Form Finding



Construction and Panelisation of Shells and Tensile Structures



Advanced topics

Optimisation

Design to Production

Computational Methods in the Architectural Practice

Structural Design VI: Computational Methods

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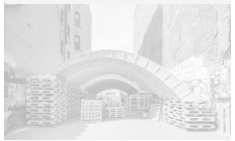

Parametric Graphic Statics

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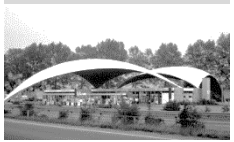

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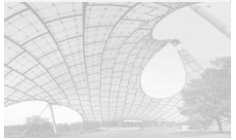

Advanced topics

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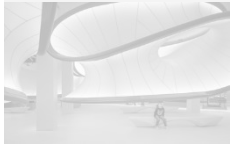

Lecture overview

Definition of Form Finding

Why Form Finding?

Physical Form Finding Models

Computational Form Finding

Computational Tools

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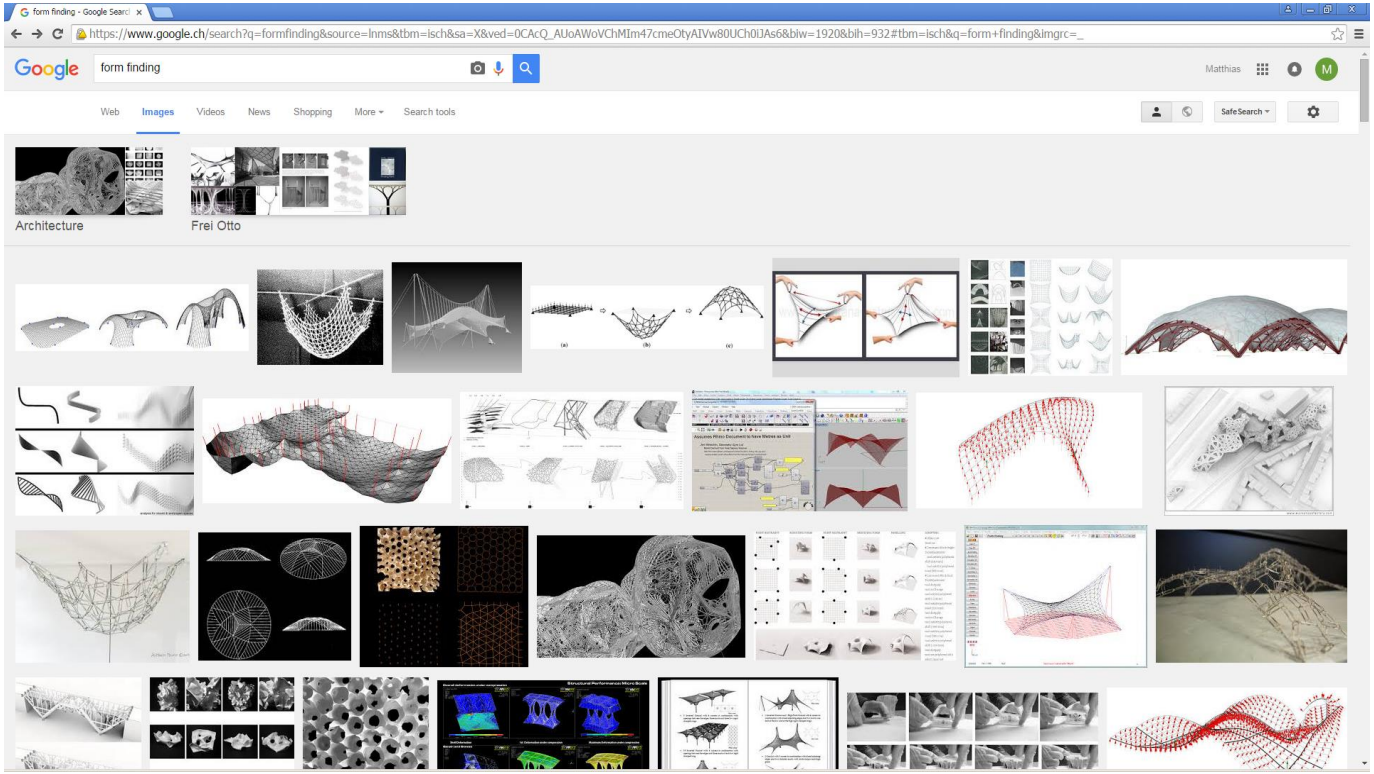
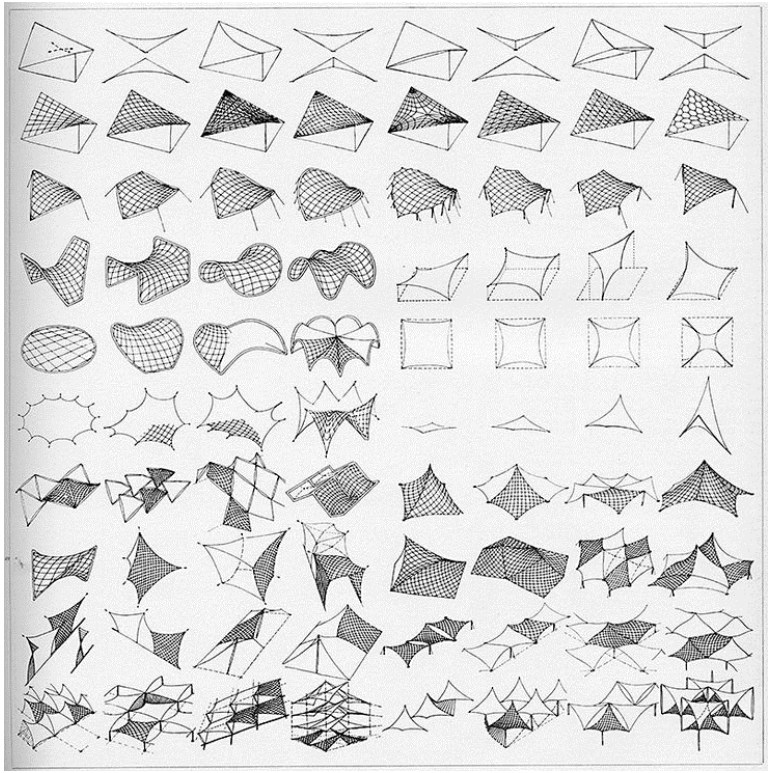
Form Finding != Form Finding

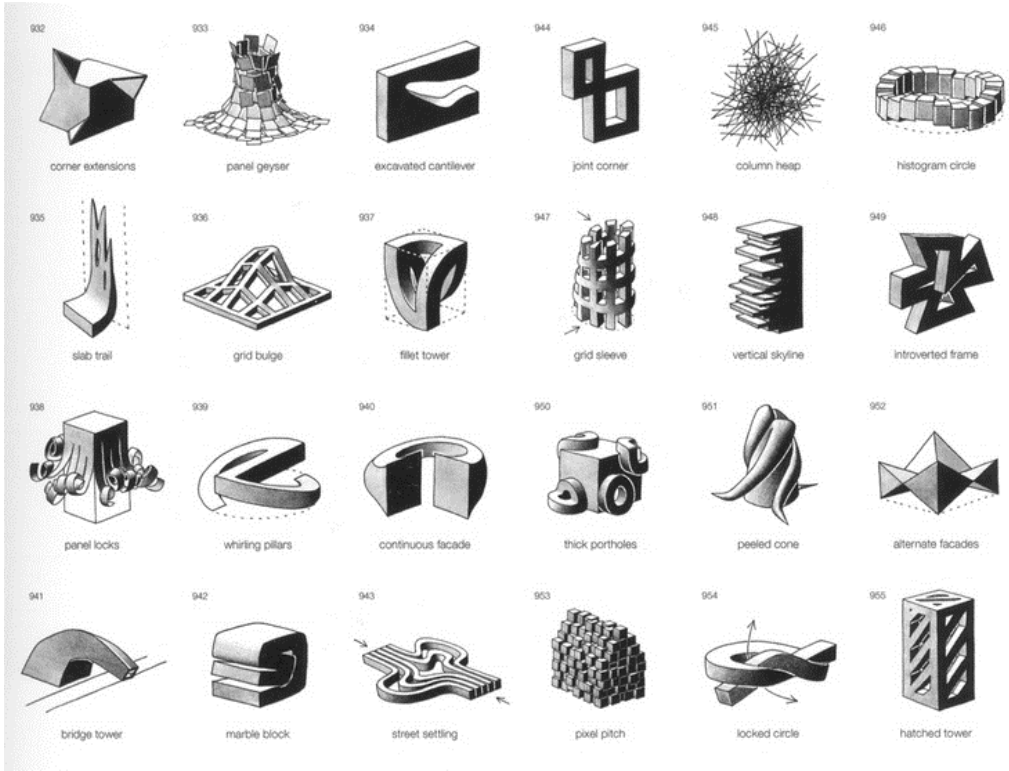


Google search “form finding”

Form Finding != Form Finding



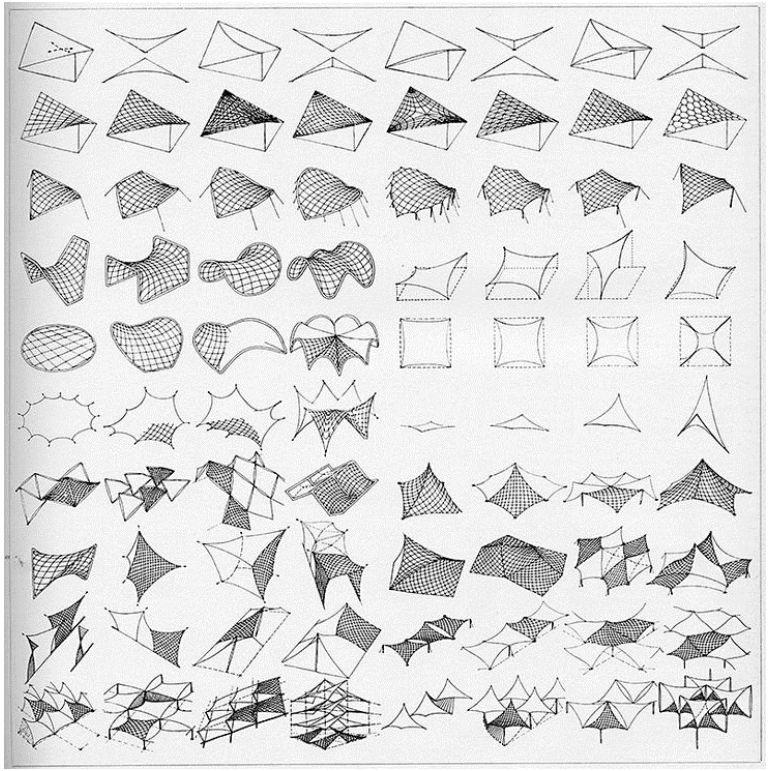
Frei Otto. Casabella 301 1966: 35



Freehand diagrams of architecture | Francois Blanciak | 2008

Definition of Form Finding

Form finding can be defined as the **“forward process in which parameters are explicitly/directly controlled to find an ’optimal’ geometry of a structure which is in static equilibrium with a design loading”** (Adriaenssens et al., 2014).



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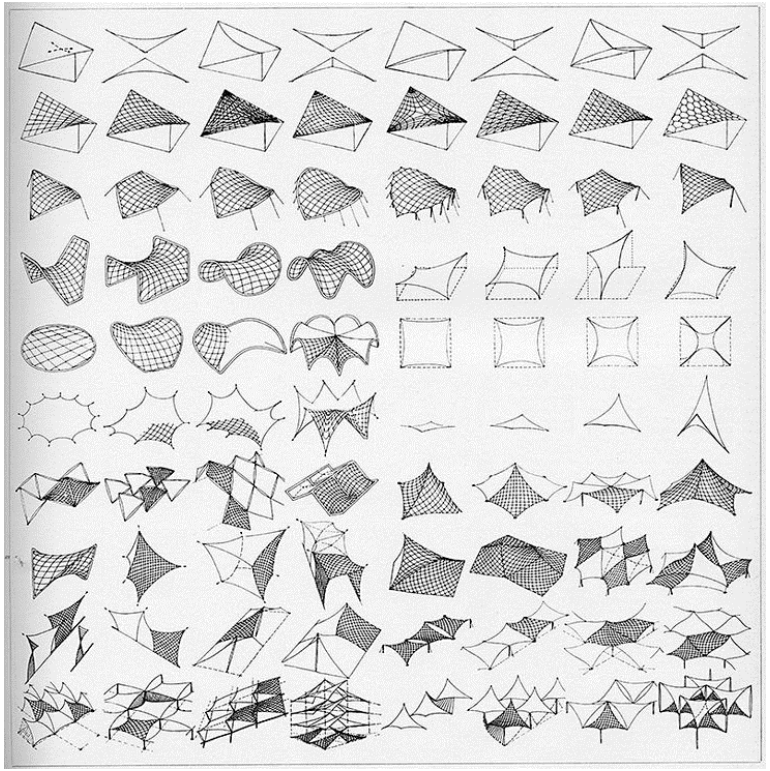
- **Defined boundary conditions**
- **Defined design load**
- **Defined state of self-stress**



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Definition of Form Finding

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Schlaich Bergermann Partner, Lodzer Steg Stuttgart, 1992

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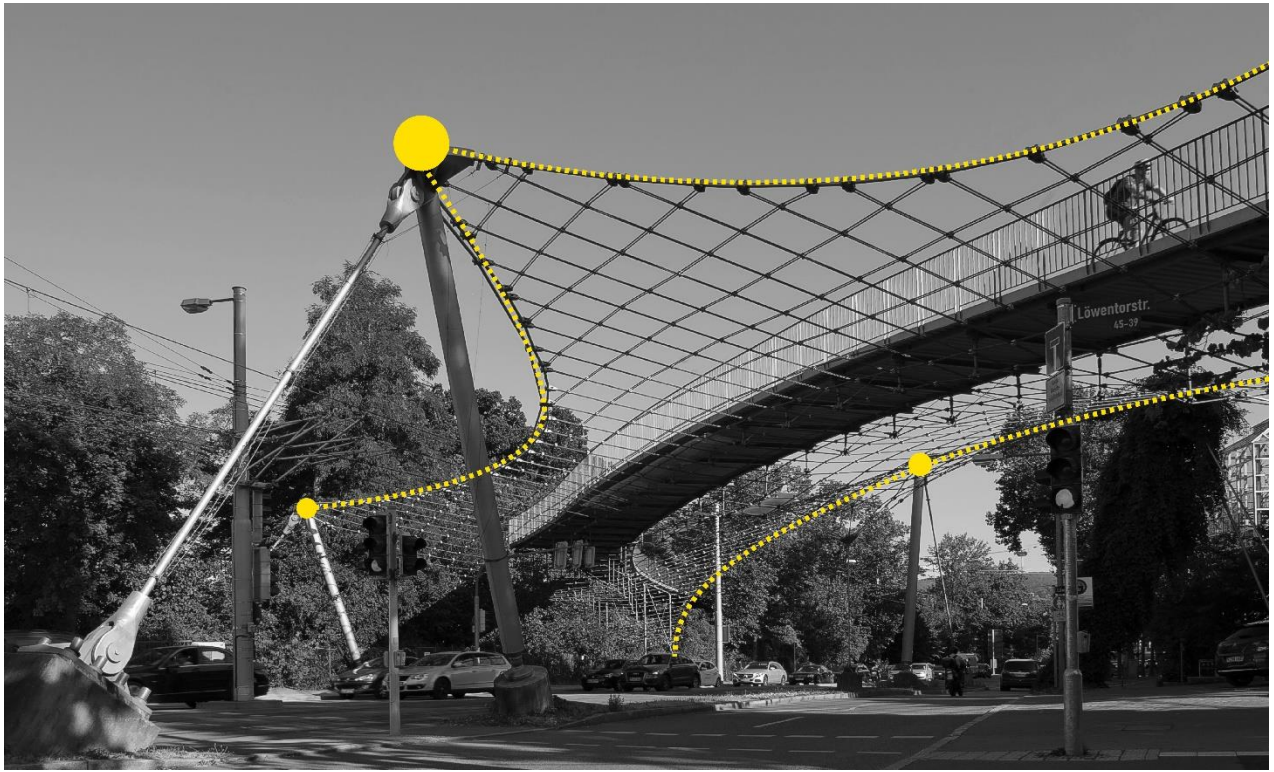

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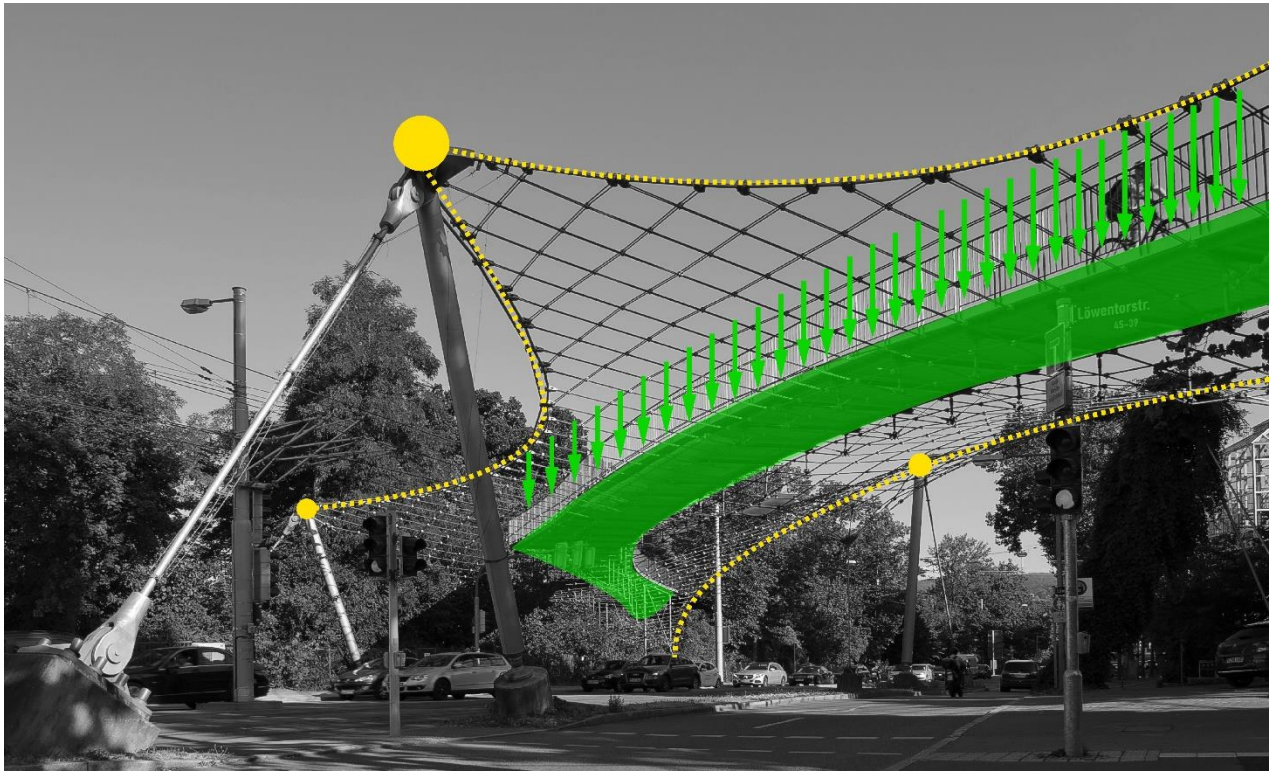

Schlaich Bergermann Partner, Lodzer Steg Stuttgart, 1992

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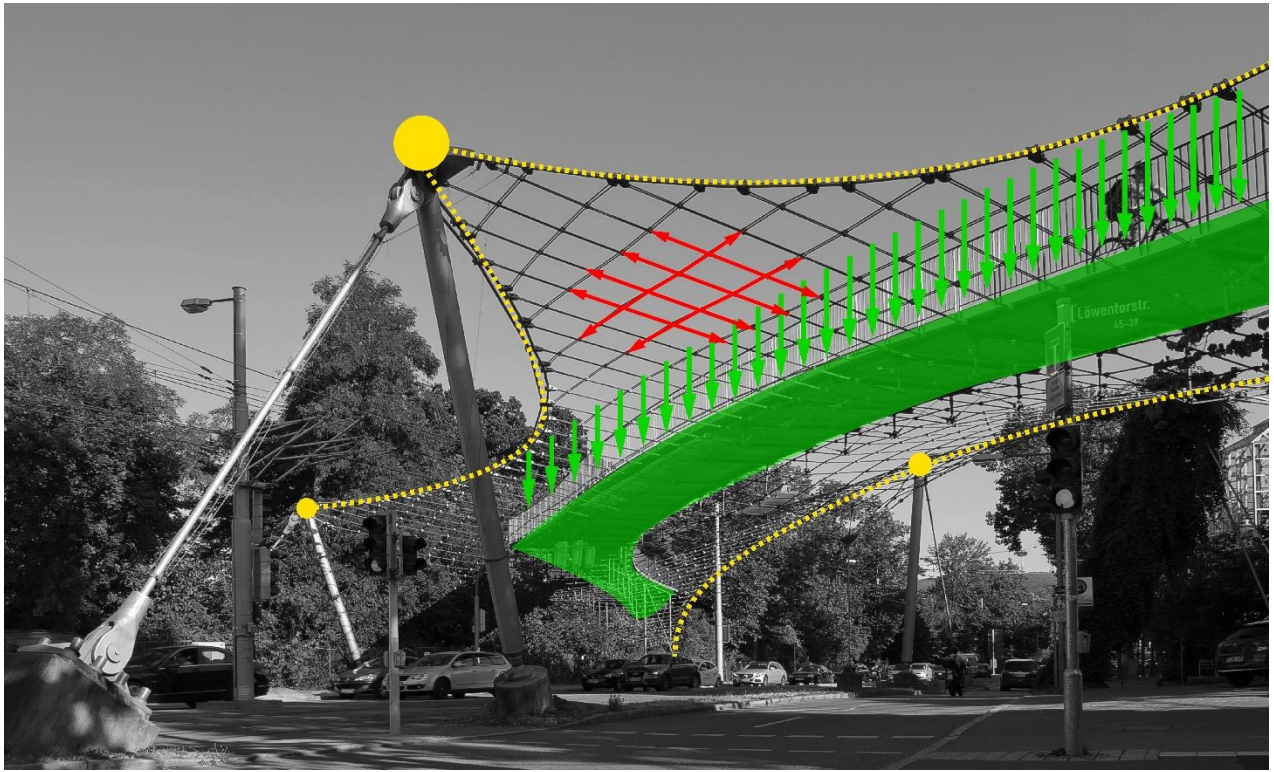


Schlaich Bergermann Partner, Lodzer Steg Stuttgart, 1992

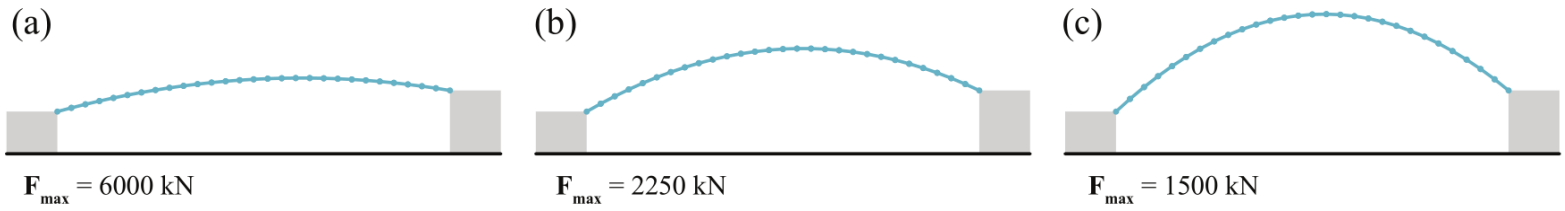
Definition of Form Finding

Why Form Finding?

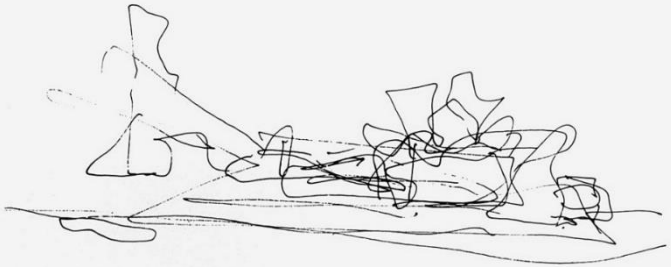
Physical Form Finding Models

Computational Form Finding

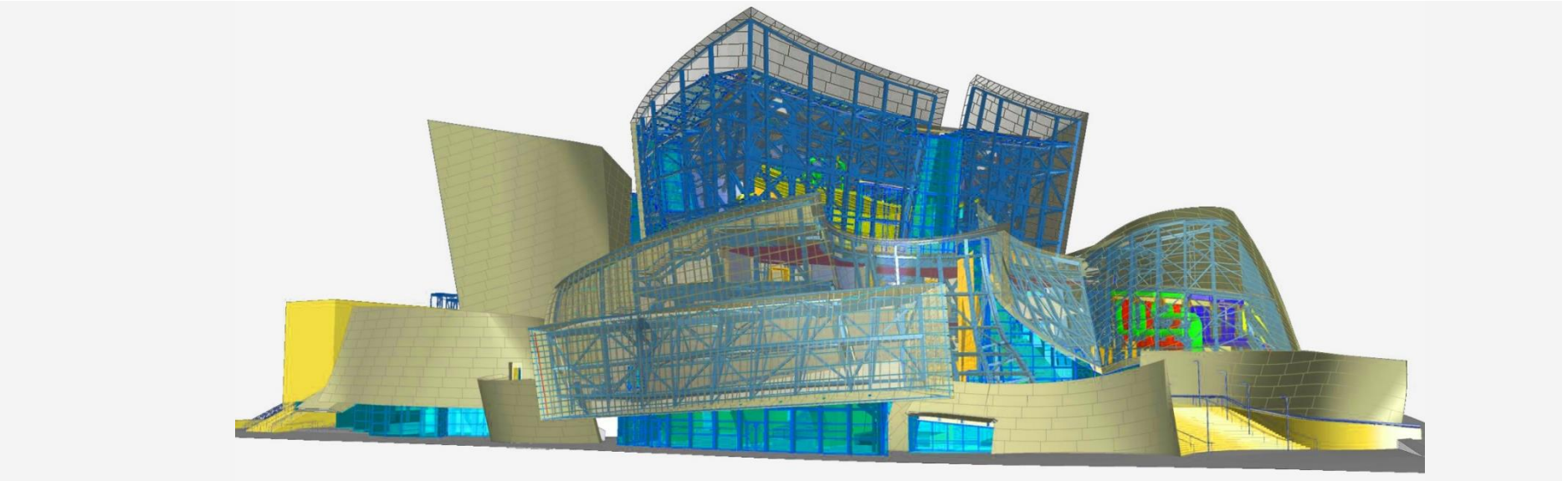
Computational Tools

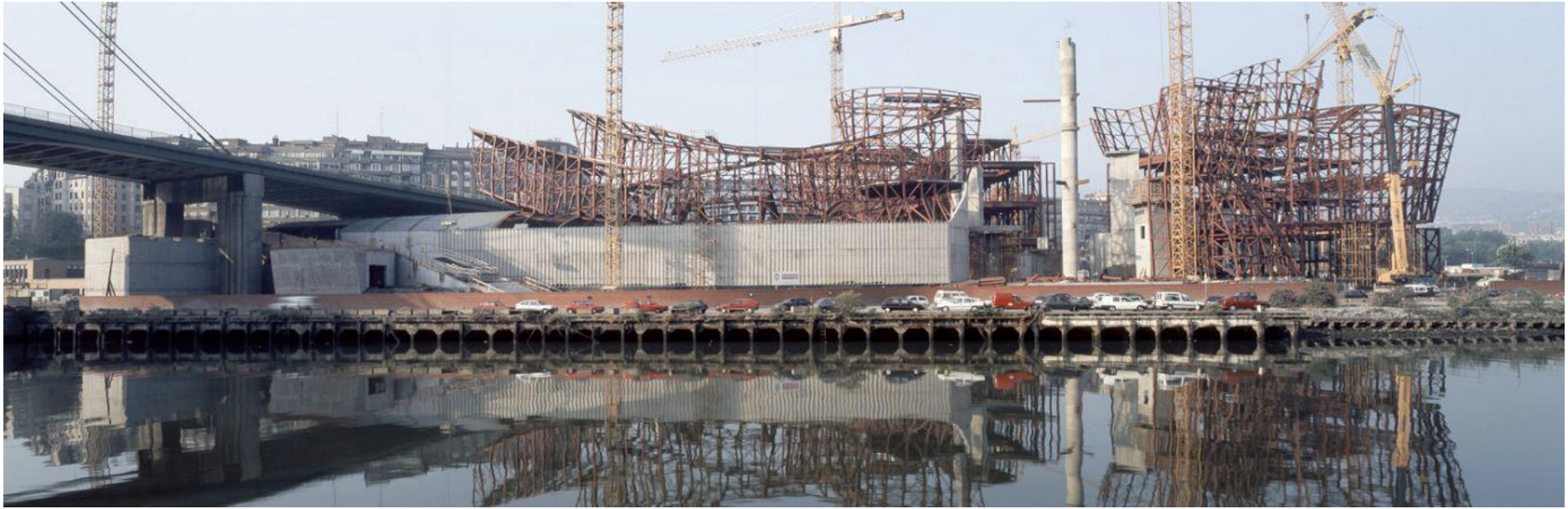

(a)
F_{max} = 6000 kN
(b)
F_{max} = 2250 kN
(c)
F_{max} = 1500 kN

Charles De Gaulle Airport Terminal 2E Collapse, 2004

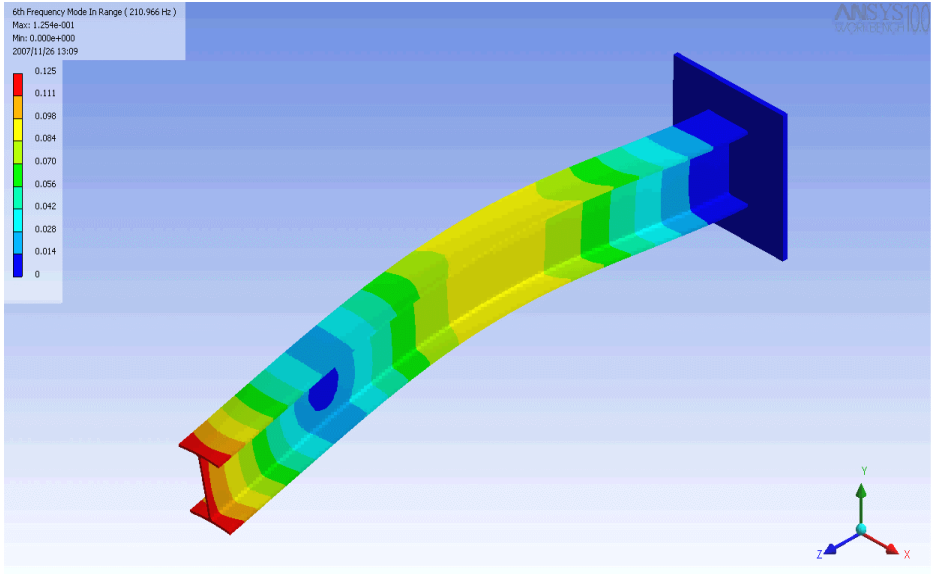


Guggenheim Museum, Bilbao, Spain, 1997 | Frank Gehry



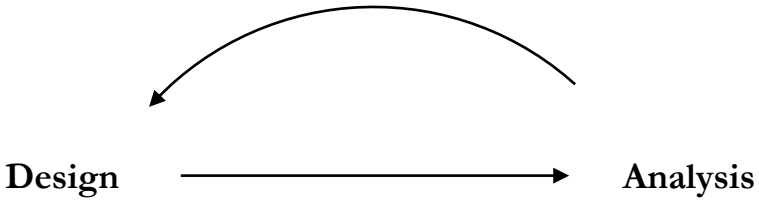


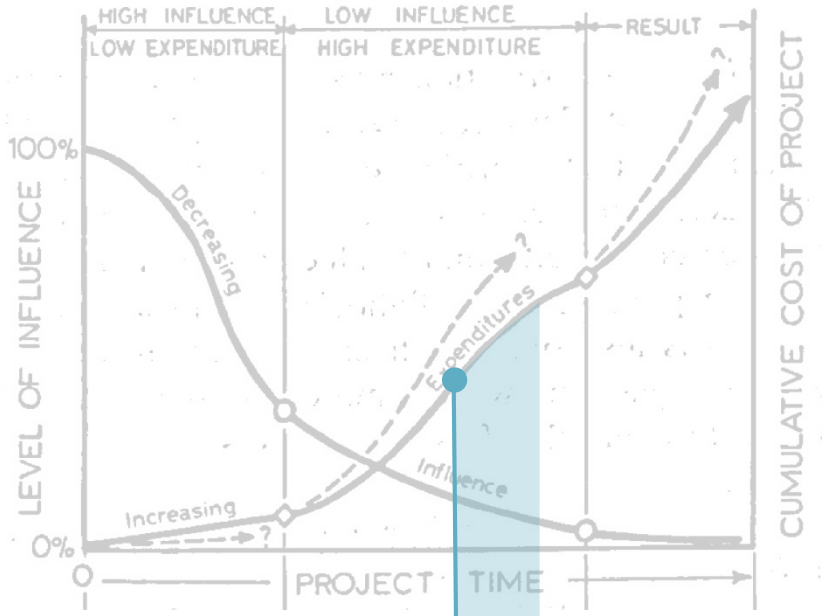
Guggenheim Museum, Bilbao, Spain, 1997 | Frank Gehry



Guggenheim Museum, Bilbao, Spain, 1997 | Frank Gehry

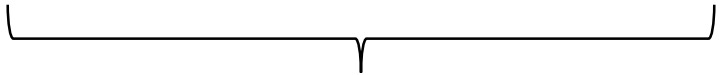
Design → **Analysis**


Design
Analysis

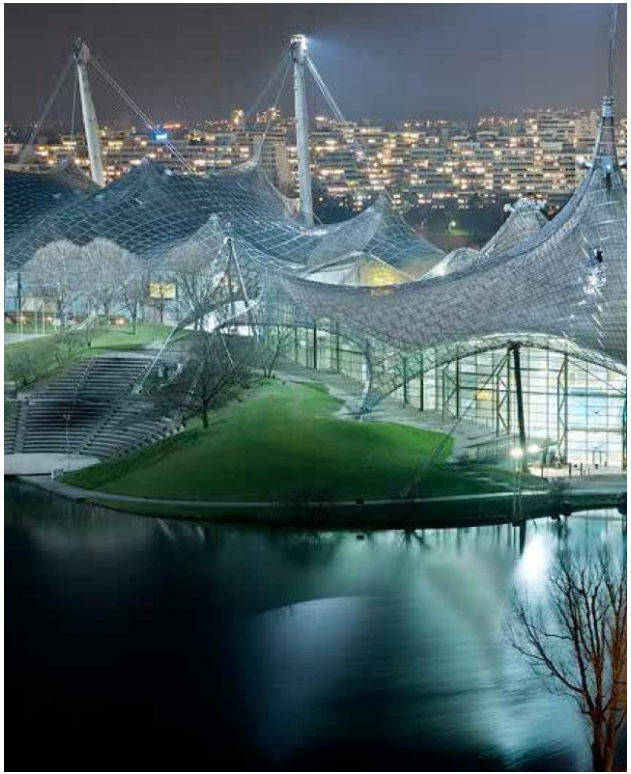


Paulson Jr., 1976

Design **Analysis**



Form Finding



Günter Behnisch, Frei Otto: Olympic stadium, Munich, 1972

Marqués de Riscal , La Rioja, Spain, 2007 | Frank Gehry

Definition of Form Finding

Why Form Finding?

Physical Form Finding Models

Computational Form Finding

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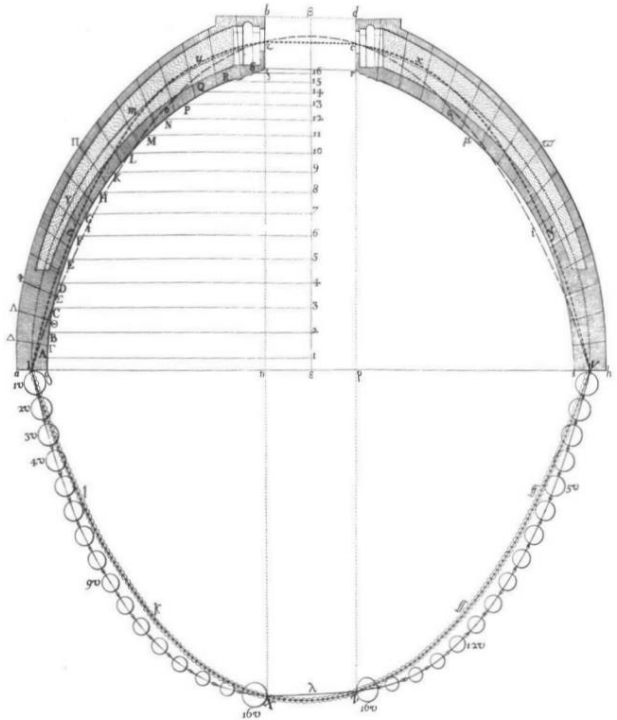
Physical Form Finding Models

Analysis

«As hangs the flexible line,
so but inverted will stand the rigid arch.»

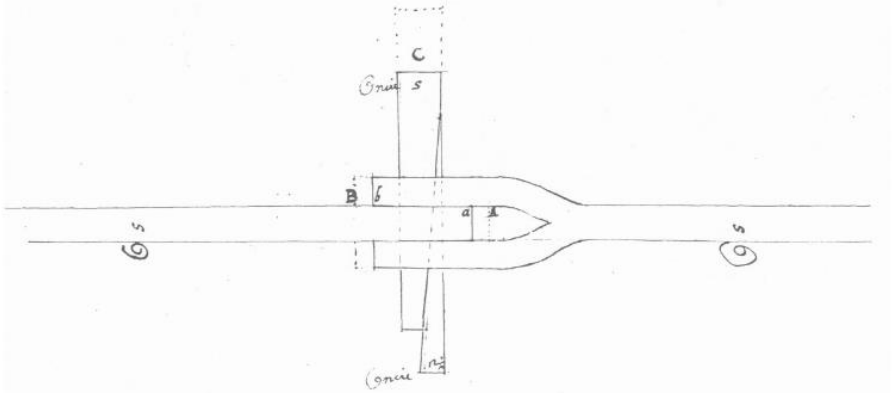


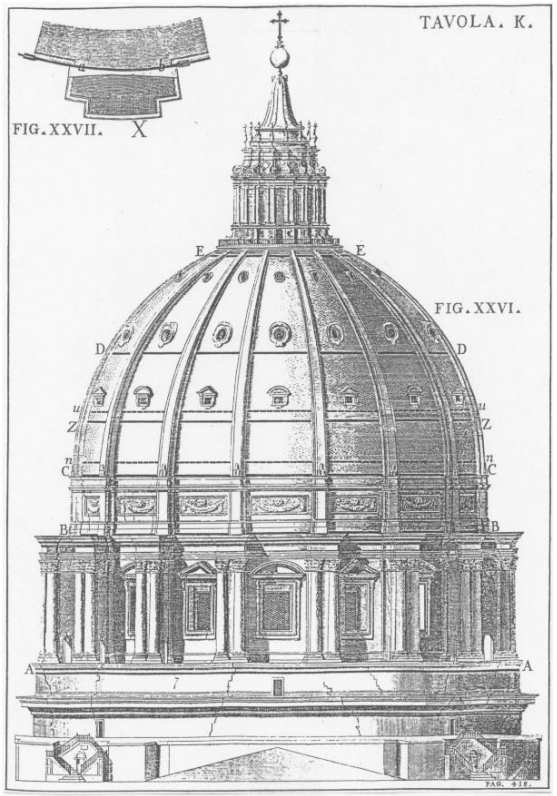
Hooke (1676)

Poleni (1748)

Physical Form Finding Models

Analysis

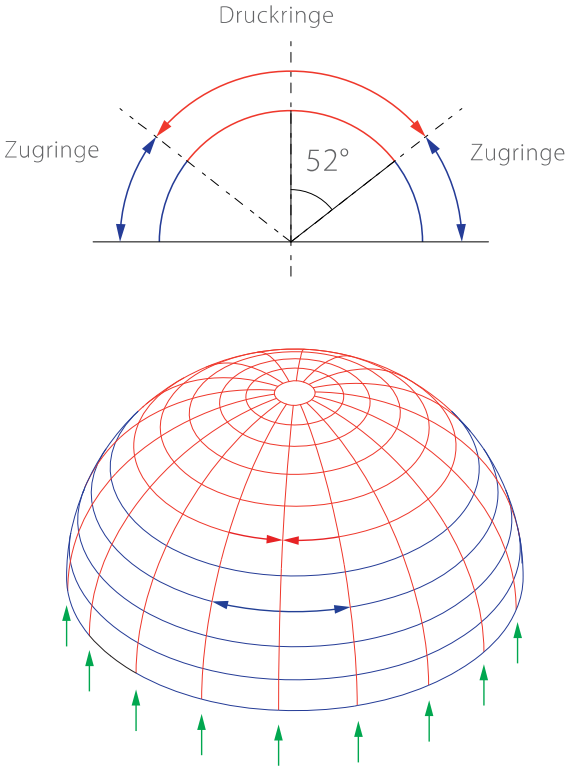


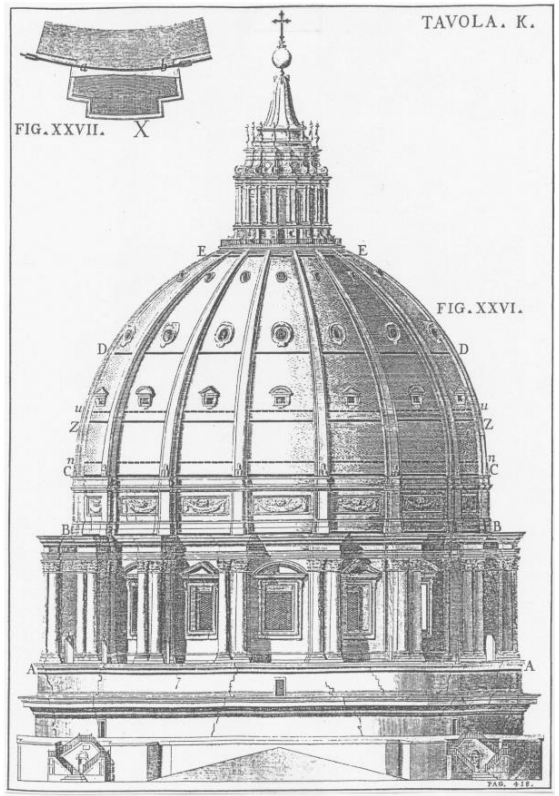


Poleni´s Manuscripts about the Dome of Saint Pete's (López, 2006)

Physical Form Finding Models

Analysis





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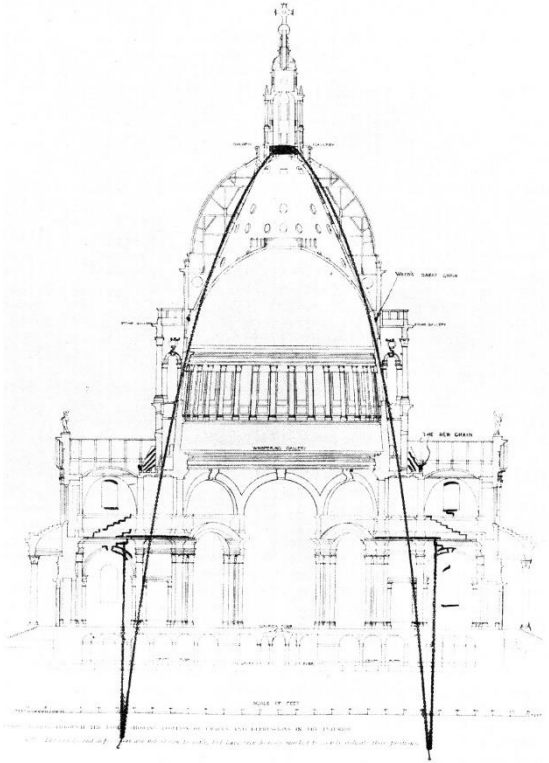
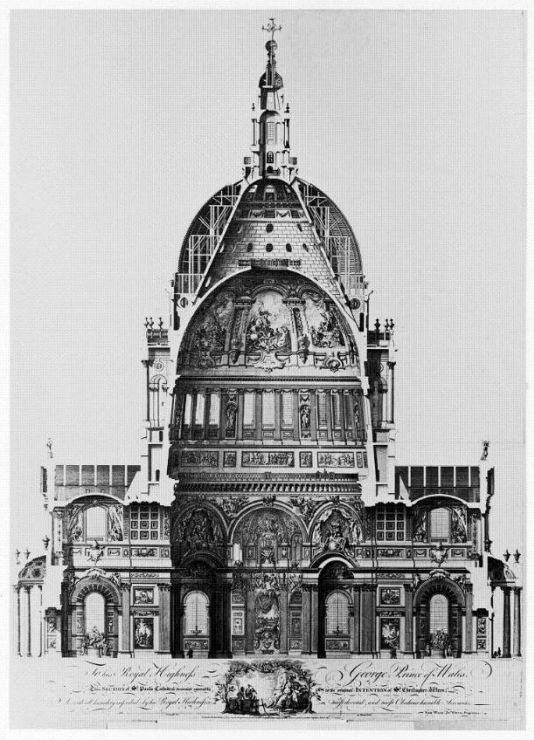


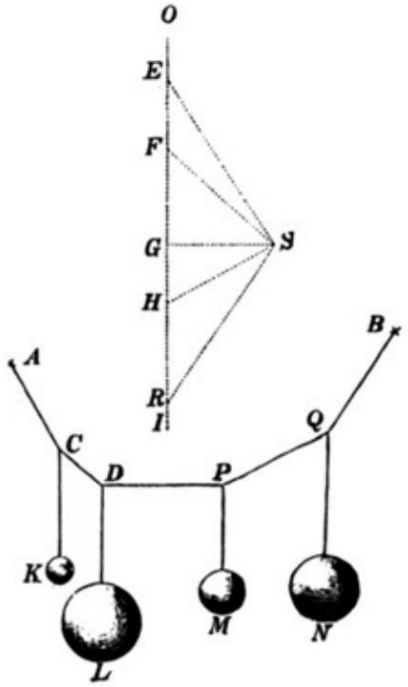


St Paul's Cathedral, London, UK, 1675-1720 | Christopher Wren

Physical Form Finding Models

Design

(a)



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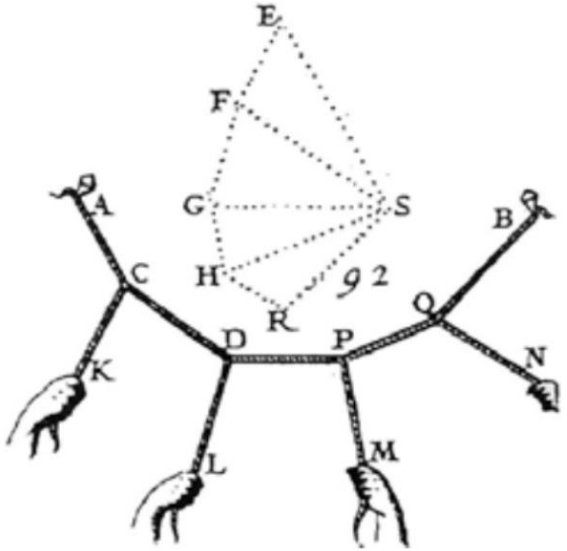
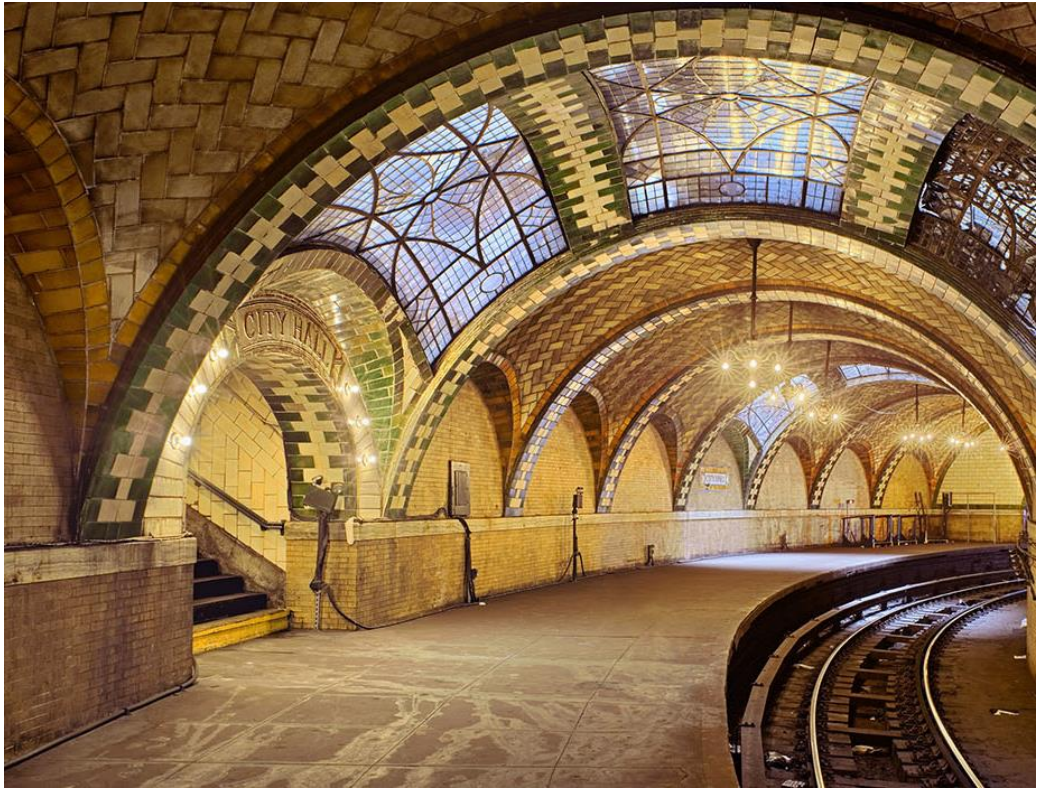
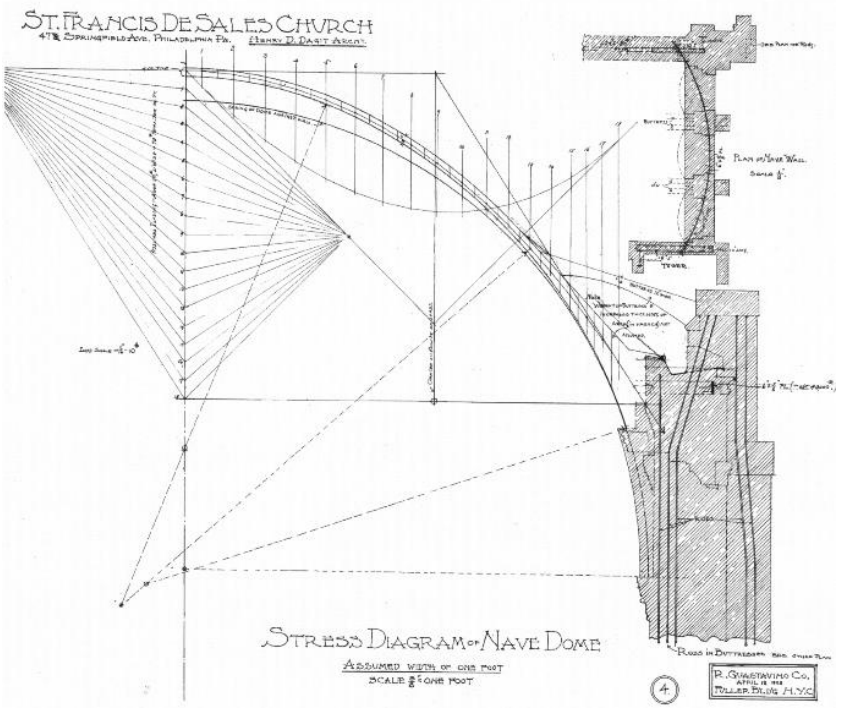


Varignon, 1725

Physical Form Finding Models

Design





Guastavino's graphical analysis. (Ochsendorf and Freeman, 2013)

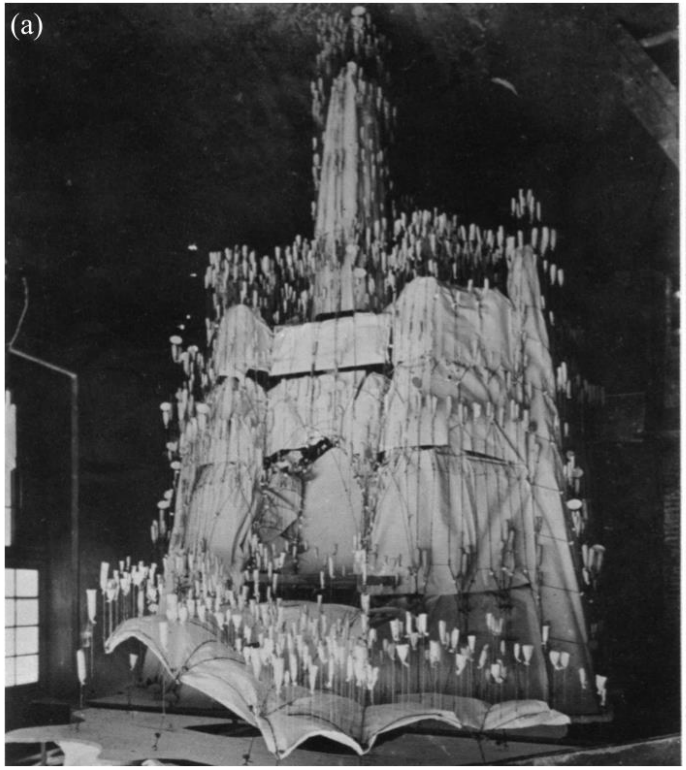
Physical Form Finding Models

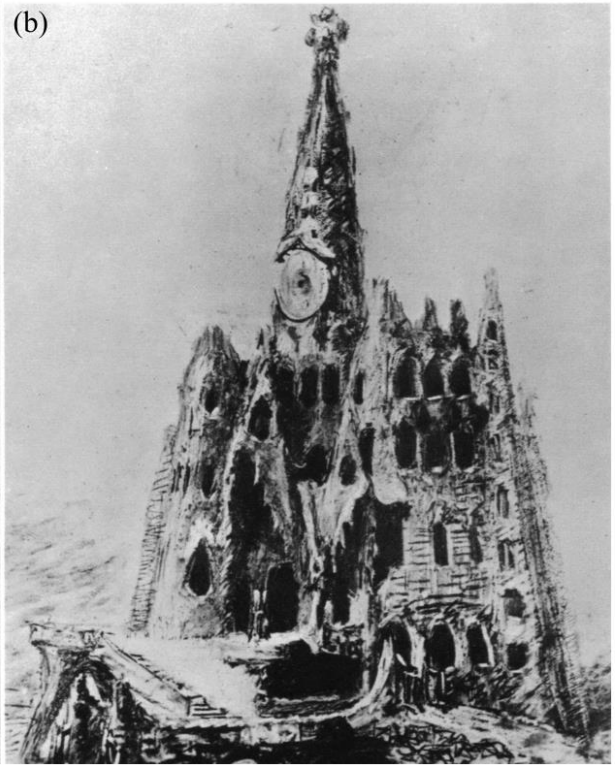
Three-dimensional hanging models

Antoni Gaudí (1852 – 1926)

Physical Form Finding Models

Three-dimensional hanging models

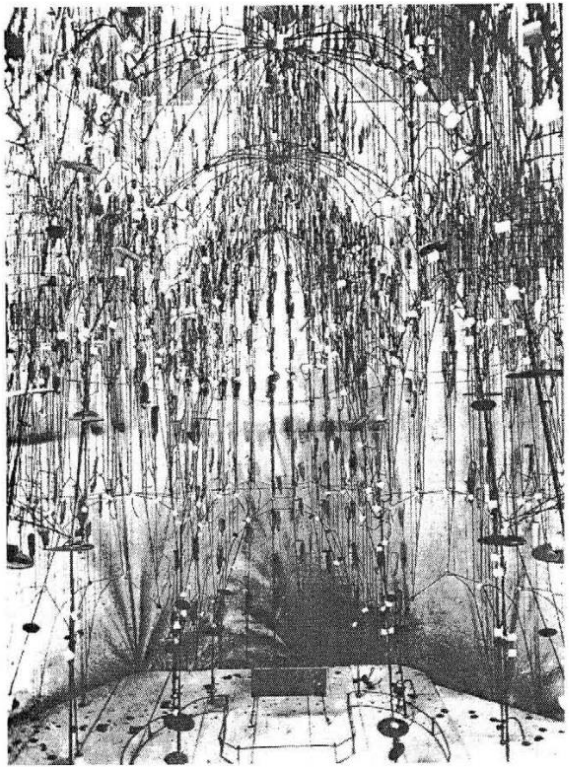


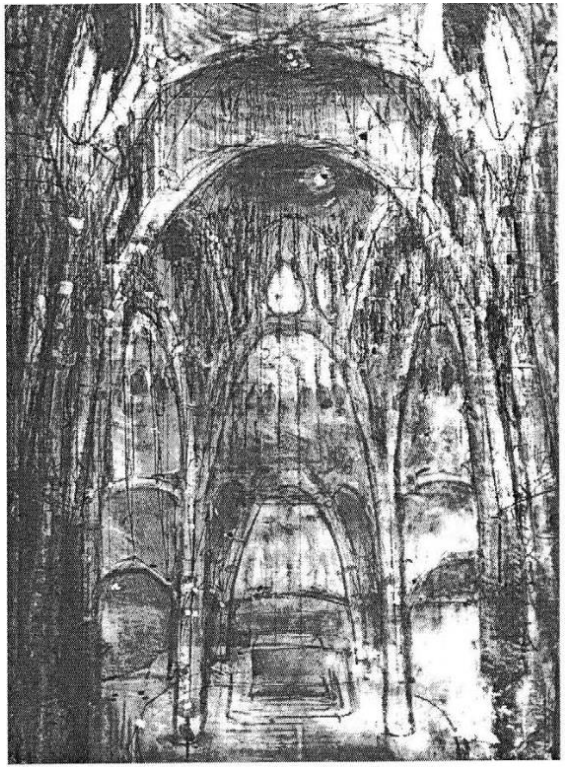


Gaudí's design of its exterior directly sketched on the inverted photograph of the hanging model | Images: Collins, 1963

Physical Form Finding Models

Three-dimensional hanging models

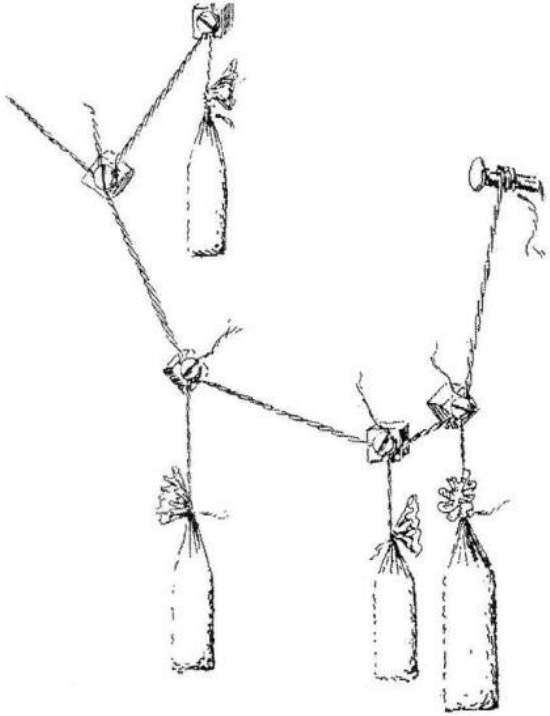




The hanging model, depicting the interior of the church of the Colonia Güell. Right, drawings to show the interior space | Images: Puig Boada, 1976

Physical Form Finding Models

Three-dimensional hanging models



Redesign of Gaudí's hanging model for the Colonia Güell | Images: Beotis, 2007

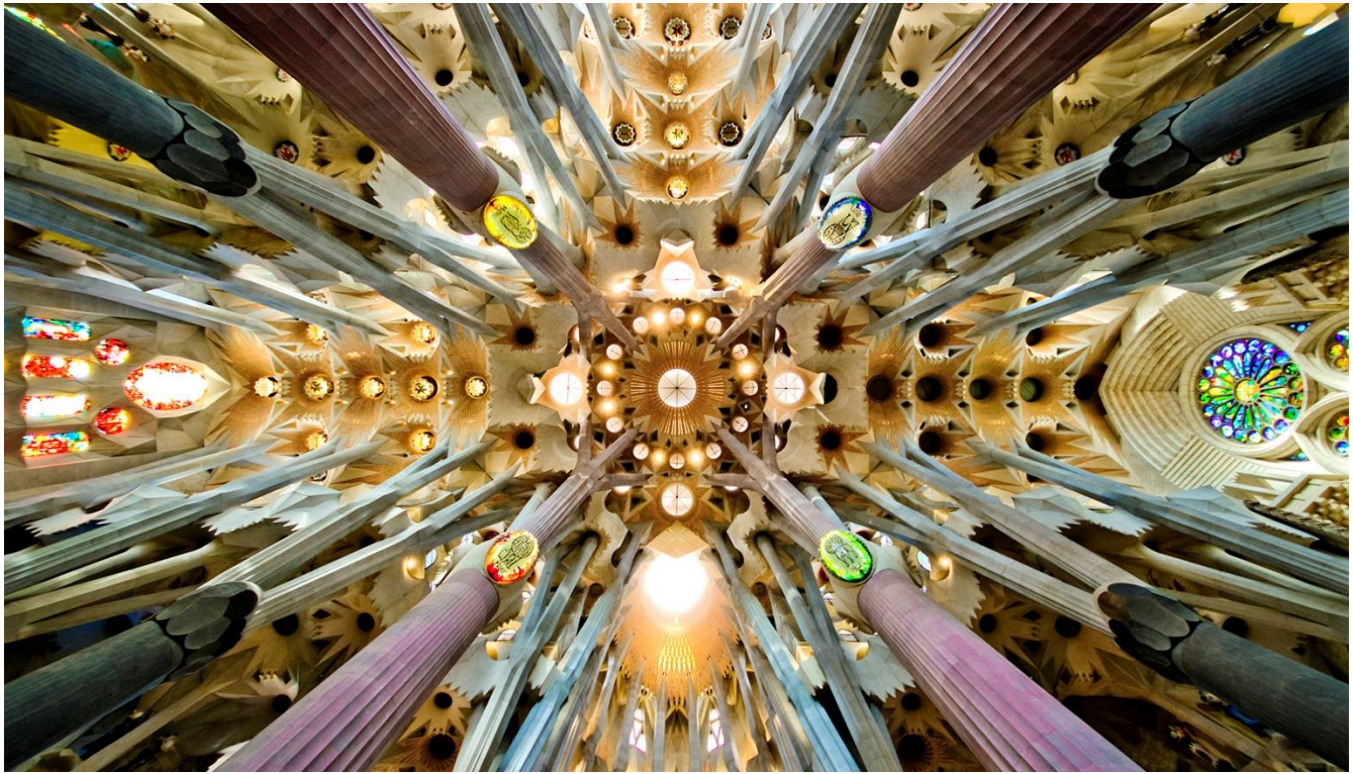
Physical Form Finding Models

Three-dimensional hanging models

Gaudí's Sagrada Família | Images: Wikipedia

Physical Form Finding Models

Three-dimensional hanging models



Gaudí's Sagrada Família | Images: Wikipedia

Physical Form Finding Models

Three-dimensional hanging models

Gaudí's Church of Colònia Güell, 1898

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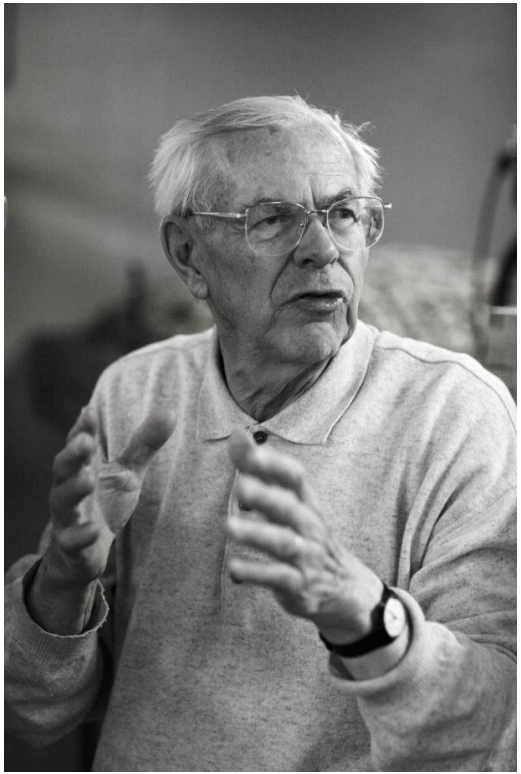
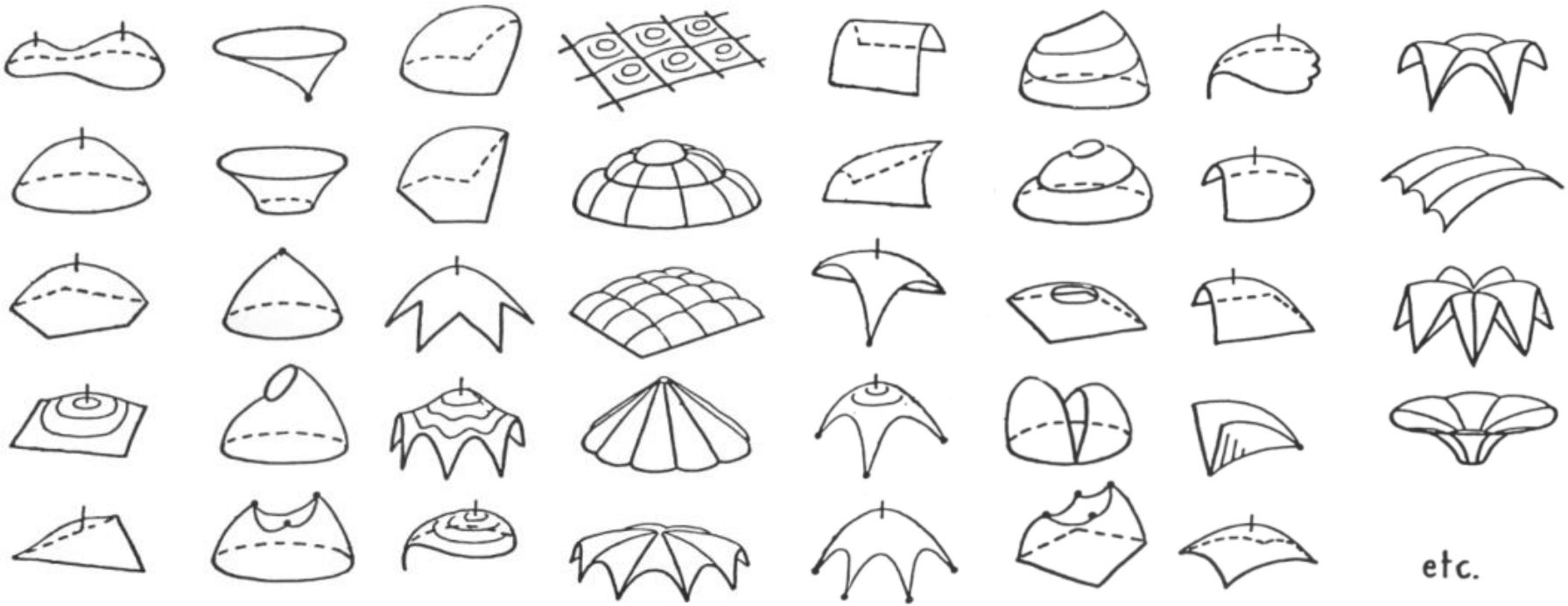


Heinz Isler (1926 - 2009)

Physical Form Finding Models

Three-dimensional hanging models



"New shapes for shells" Heinz Isler, First Congress of the International Association for Shell Structures (IASS) in 1959

Physical Form Finding Models

Three-dimensional hanging models

Image: Wilfried Dechau

Physical Form Finding Models

Three-dimensional hanging models

Image: Isler Archive

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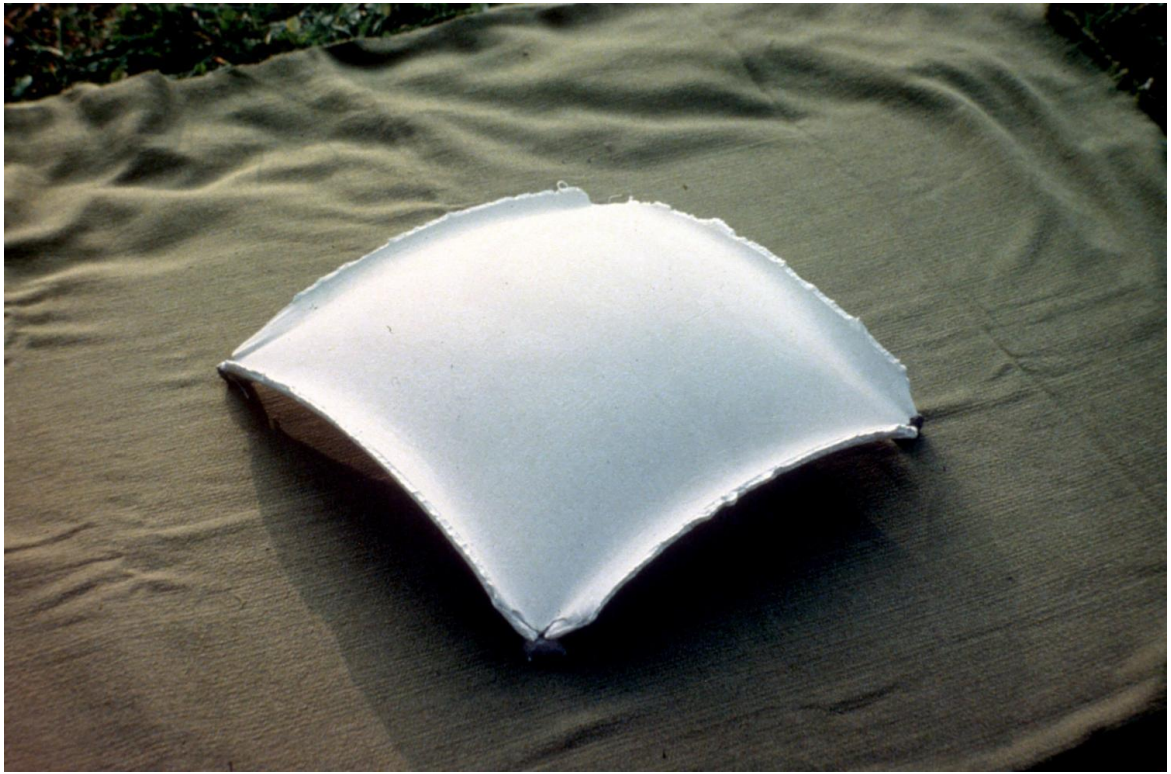

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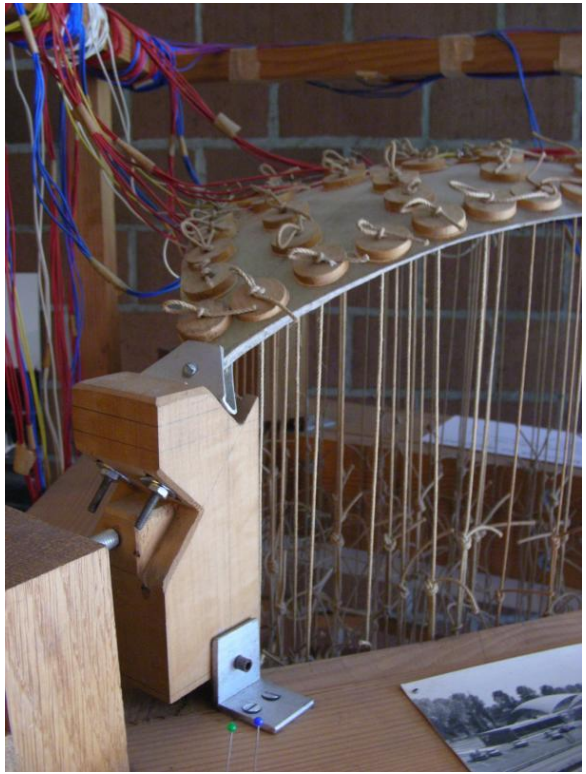

Image: Isler Archive

Physical Form Finding Models

Three-dimensional hanging models

Tankstelle Deitingen Süd, Schweiz, 1968, Ing.: Heinz Isler

Physical Form Finding Models

Three-dimensional hanging models

Tankstelle Deitingen Süd, Schweiz, 1968, Ing.: Heinz Isler

Physical Form Finding Models

Three-dimensional hanging models

Tennishalle, Grenchen, Schweiz, 1978, Heinz Isler

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Tennishalle, Grenchen, Schweiz, 1978, Heinz Isler

Physical Form Finding Models

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Gebäude der Sicli Firma, Genf, Schweiz, 1969-70, Heinz Isler

Physical Form Finding Models

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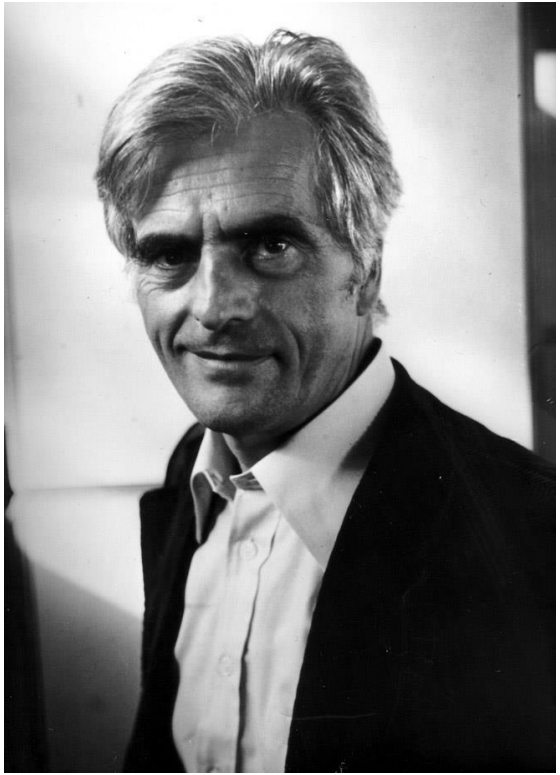
Gebäude der Sicli Firma, Genf, Schweiz, 1969-70, Heinz Isler

Physical Form Finding Models

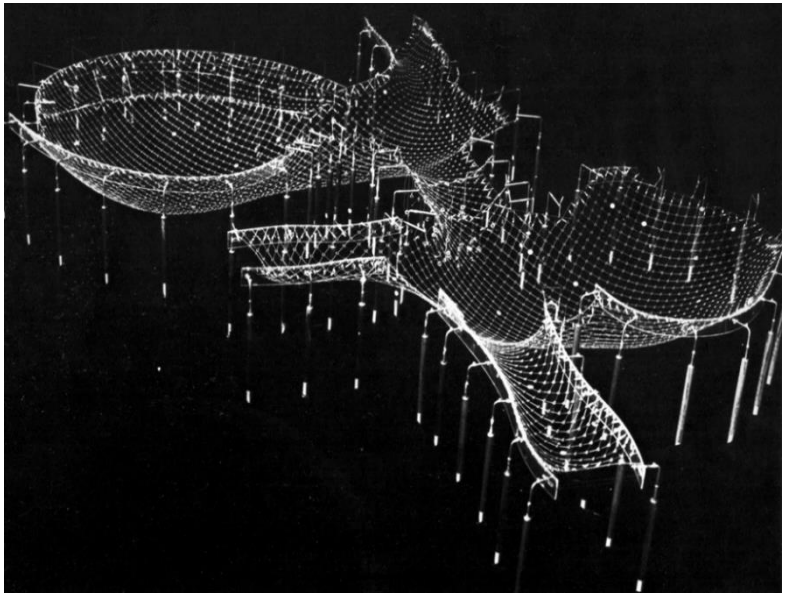
Three-dimensional hanging models



Frei Otto (1925-2015)

Physical Form Finding Models

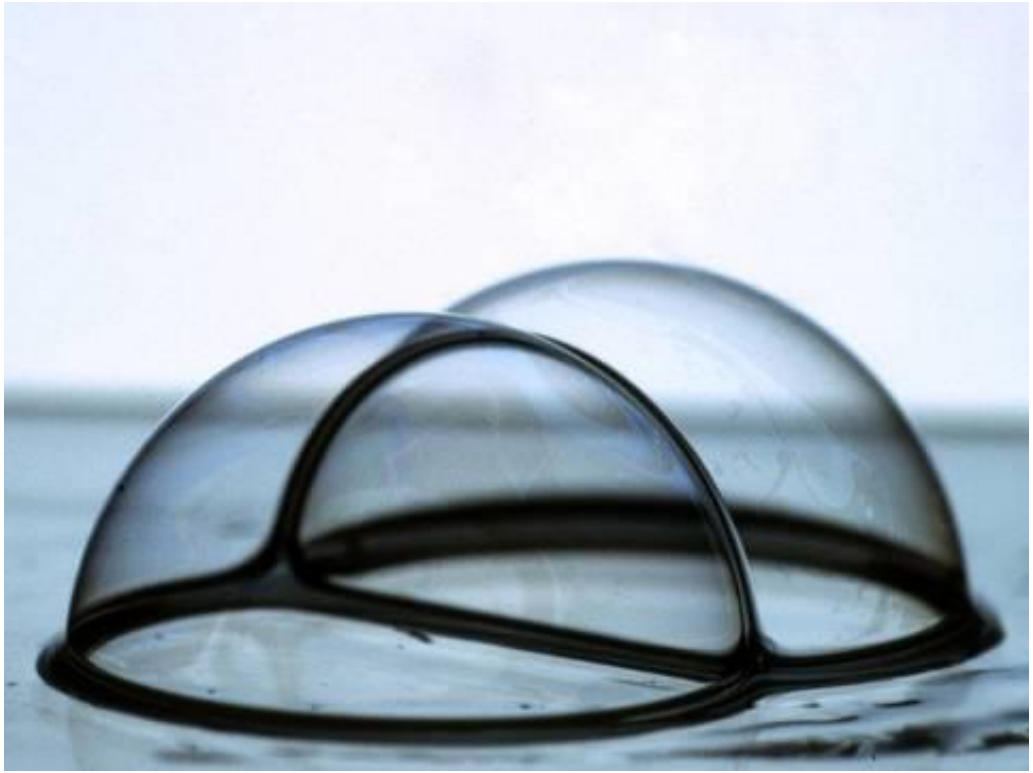
Three-dimensional hanging models



Multihalle, Mannheim, Germany, 1974 | Frei Otto

Physical Form Finding Models

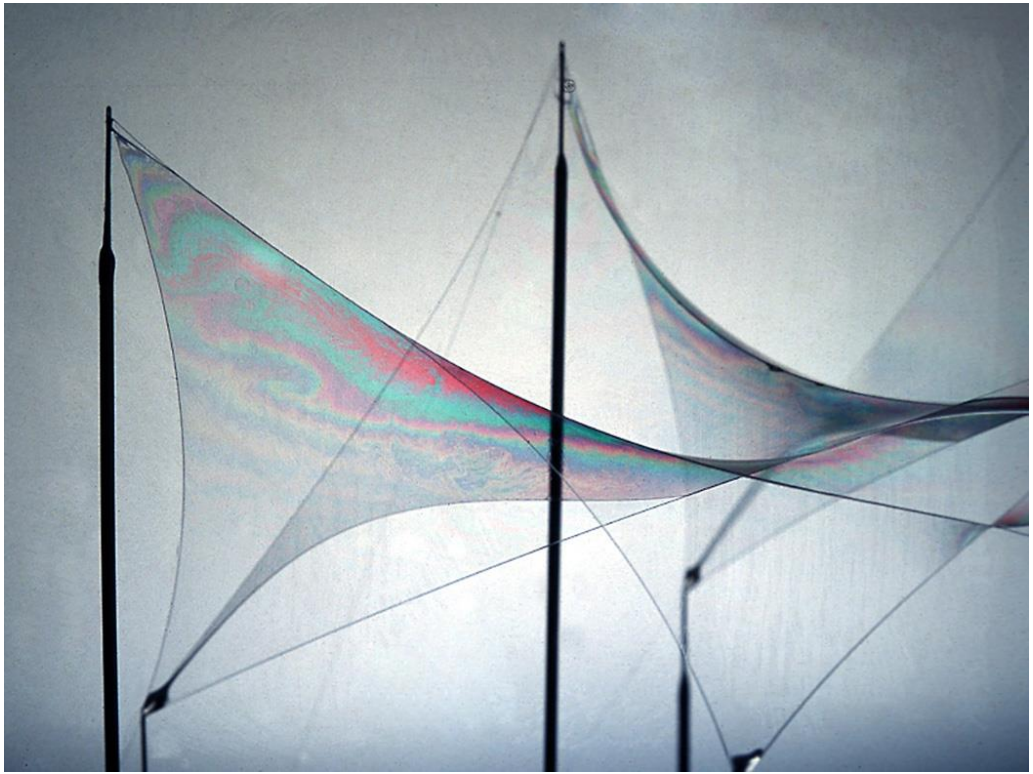
Modelling with Soap Films



Soap bubble experiment, Frei Otto

Physical Form Finding Models

Modelling with Soap Films

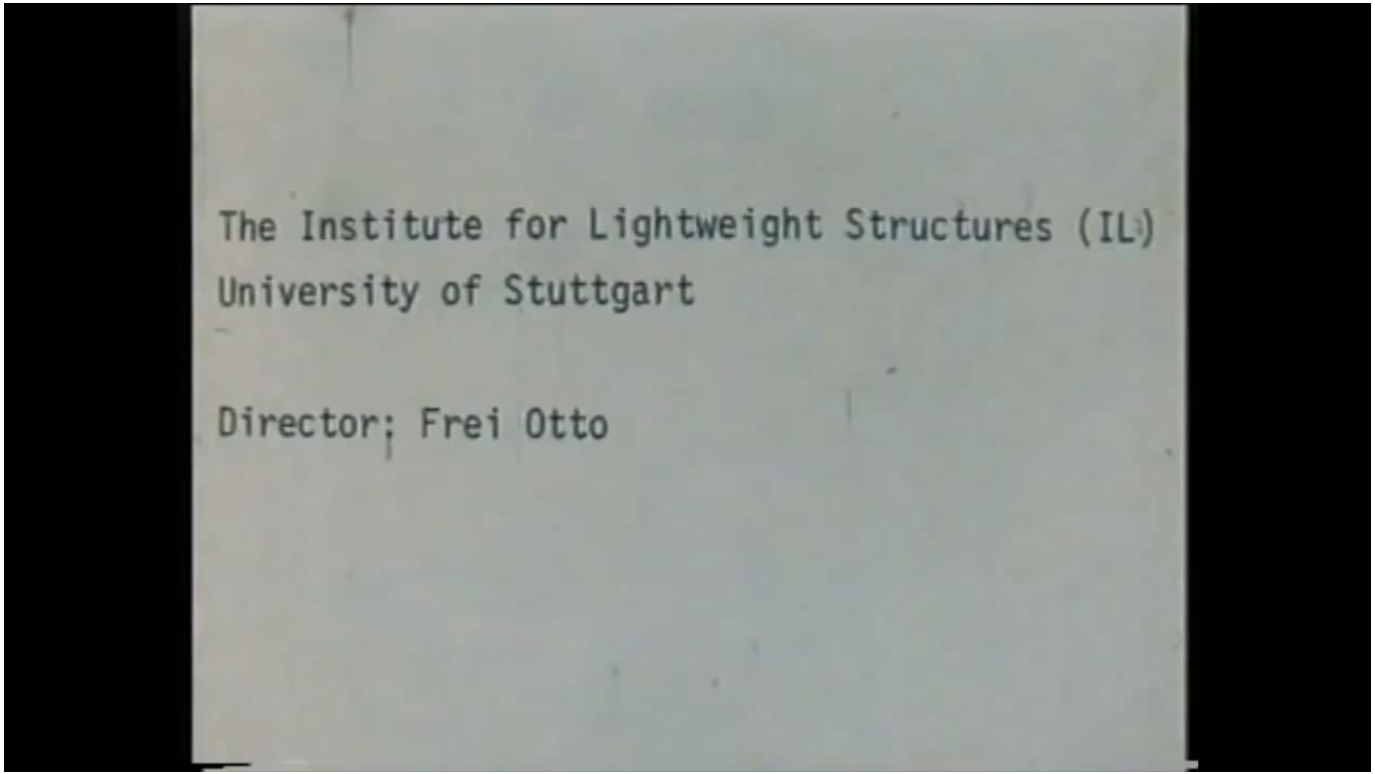


Soap bubble experiment, Frei Otto

Physical Form Finding Models

Modelling with Soap Films

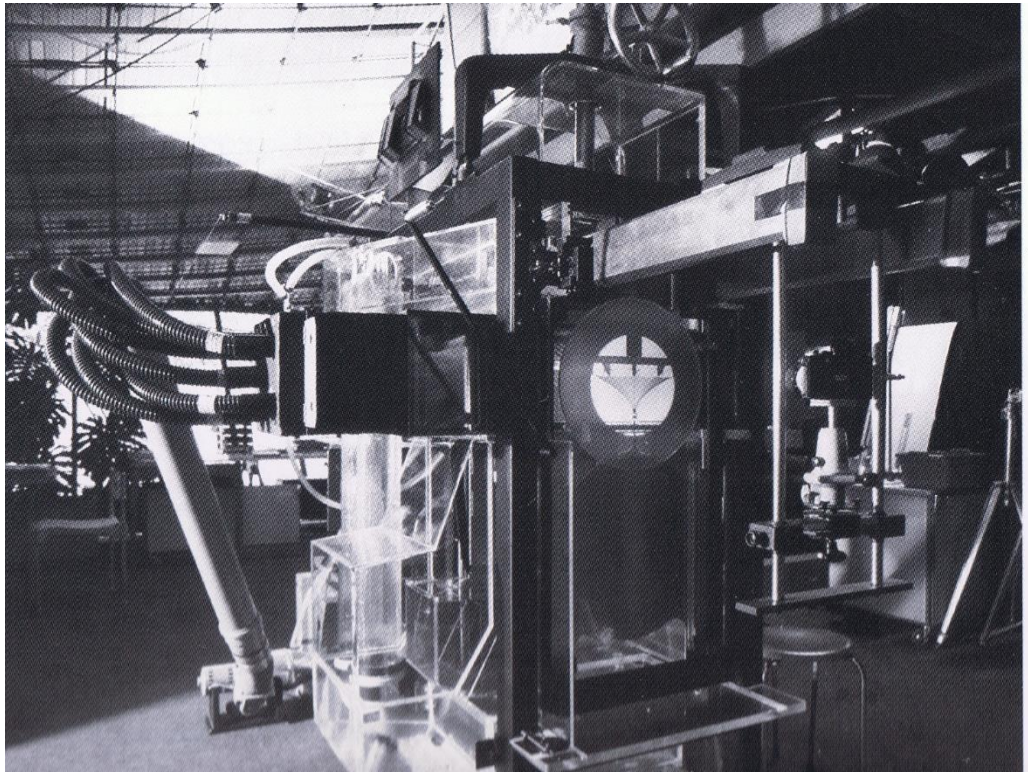
https://www.youtube.com/watch?v=-IW7o25NmeA

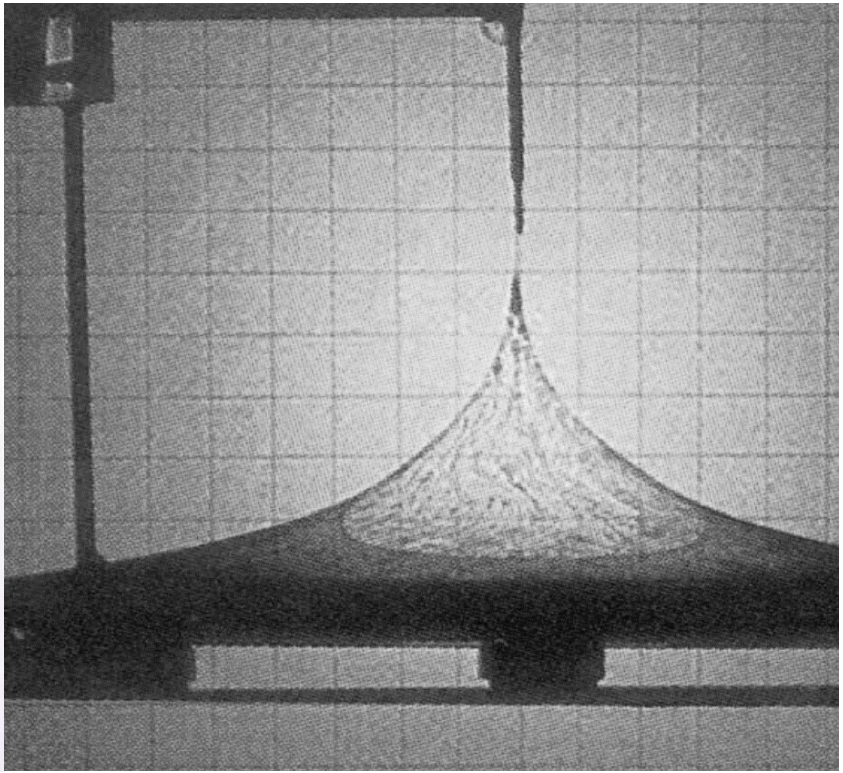


Soap bubble experiments, Frei Otto

Physical Form Finding Models

Modelling with Soap Films

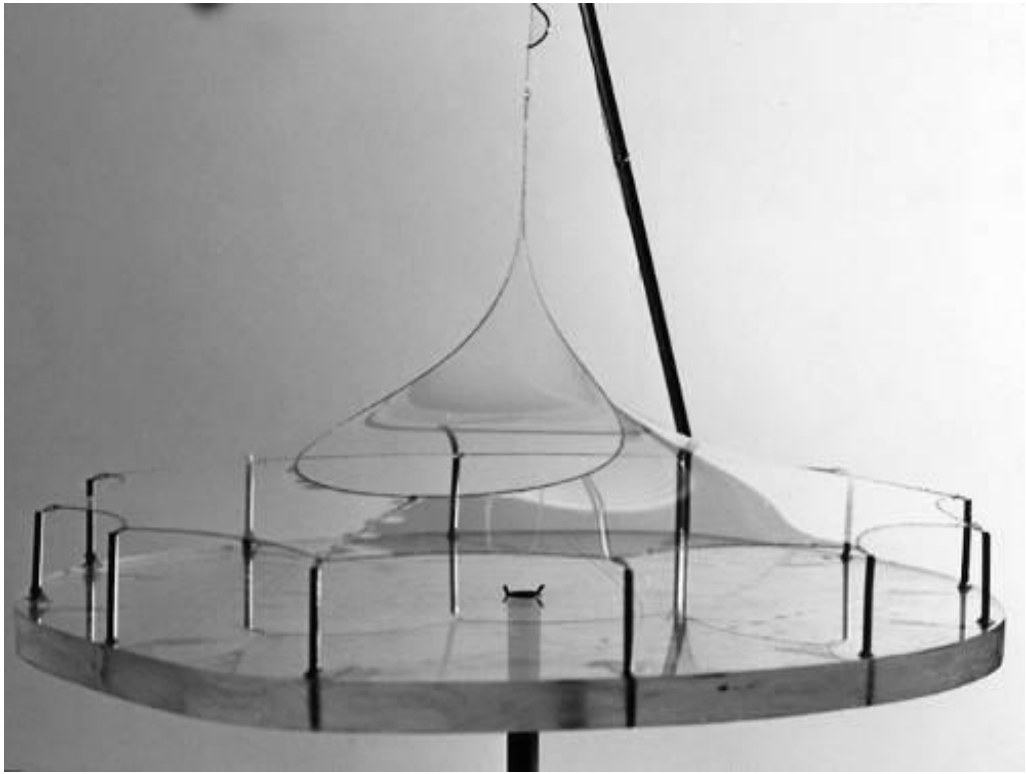




Soap bubble experiments, Frei Otto

Physical Form Finding Models

Modelling with Soap Films



Soap bubble experiments, Frei Otto

Physical Form Finding Models

Modelling with Soap Films

Soap bubble experiments, Frei Otto

Physical Form Finding Models

Modelling with Soap Films

IL Building, 1966

Physical Form Finding Models

Modelling with Soap Films

German Pavillion, Montreal, Canada, 1967

Physical Form Finding Models

Modelling with Soap Films

German Pavillion, Montreal, Canada, 1967

Physical Form Finding Models

Modelling with Soap Films

Günter Behnisch, Frei Otto: Olympic stadium, Munich, 1972

Physical Form Finding Models

Experimental Analysis

Montreal Pavilion measuring model, 1966

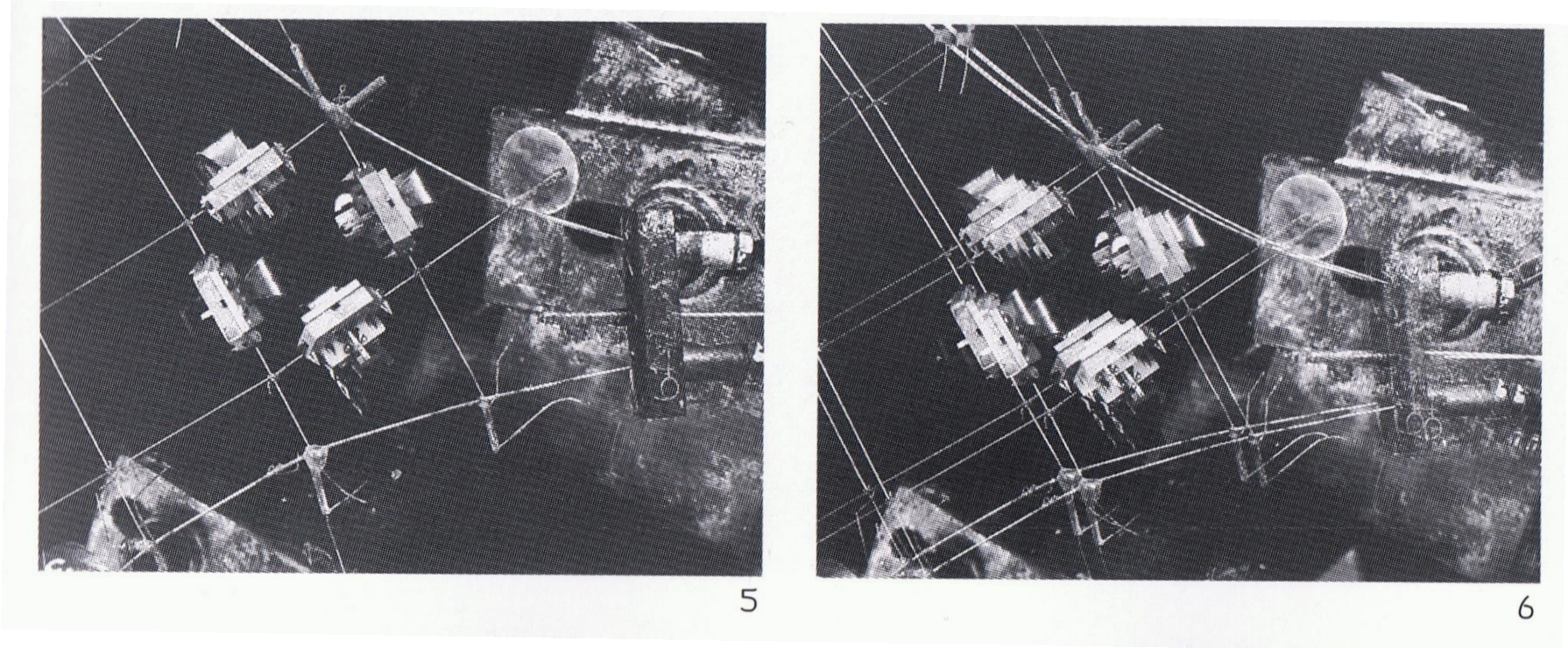
Physical Form Finding Models

Experimental Analysis

Munich Stadium measuring model, ca. 1970

Physical Form Finding Models

Experimental Analysis



Munich Stadium measuring model, ca. 1970

Definition of Form Finding

Why Form Finding?

Physical Form Finding Models

Computational Form Finding

Computational Tools

Computational Form Finding

Force Density Method (FDM)

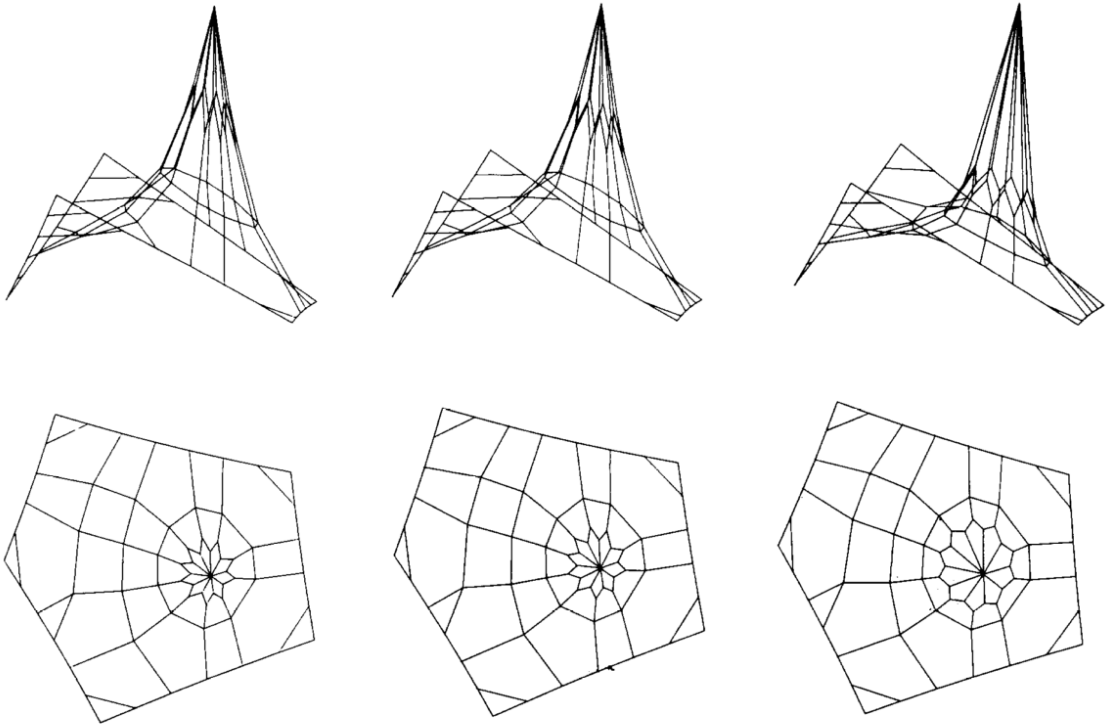


Fig. 7. Global changes in the force densities and lengthening of the radial branches.

Linkwitz and Schek (1971)

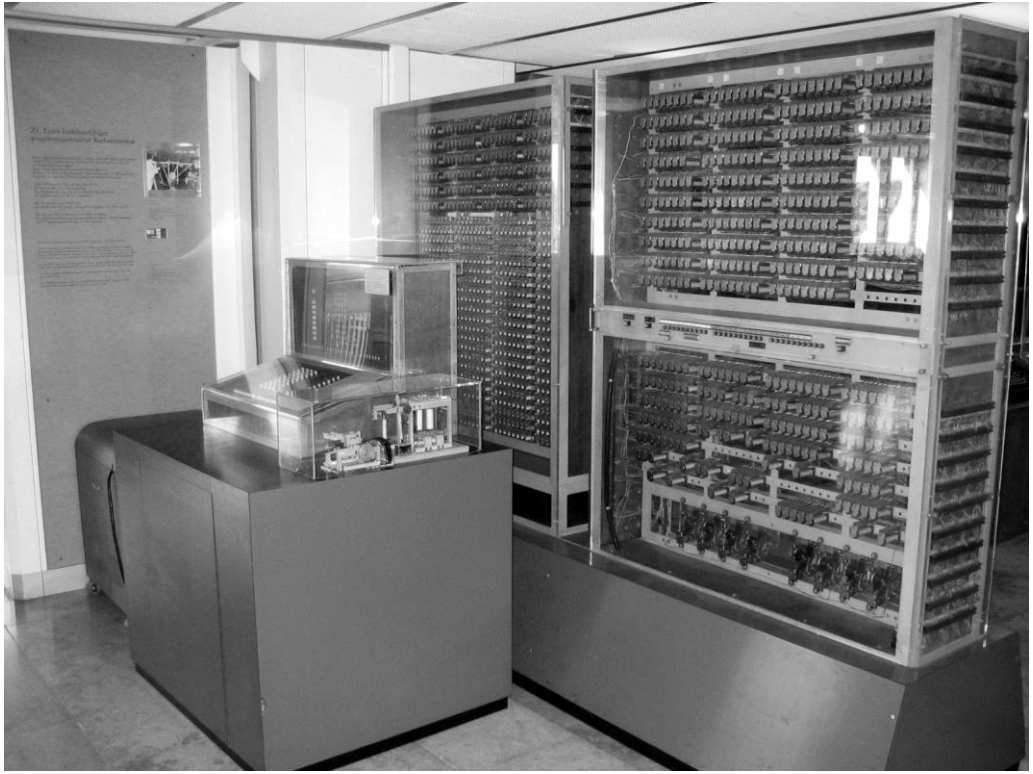
Computational Form Finding

Force Density Method (FDM)

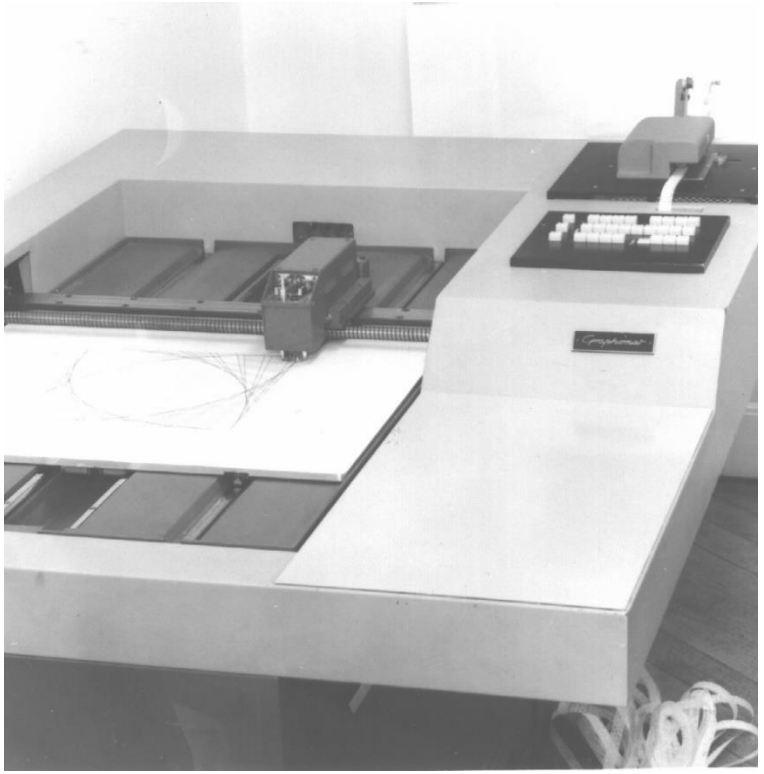
German Pavillion, Montreal, Canada, 1967

Computational Form Finding

Force Density Method (FDM)



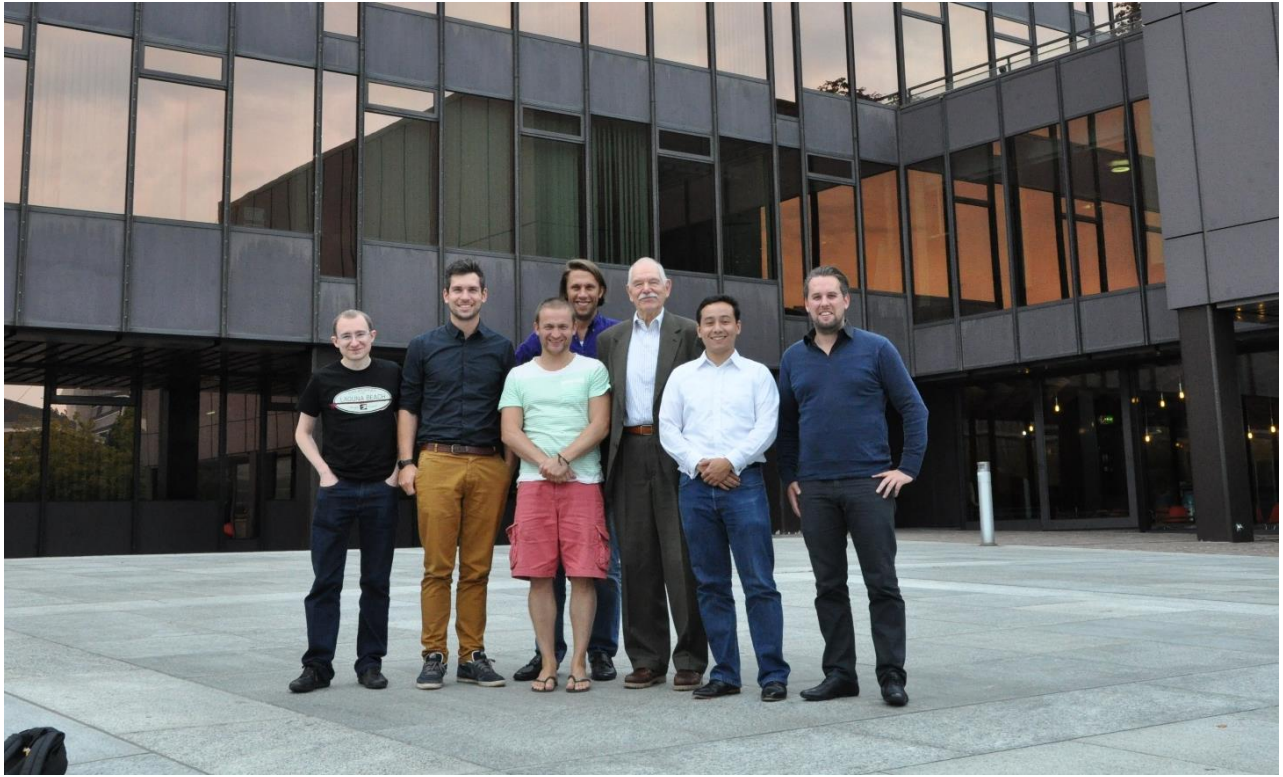
Zuse z3 (replica) exhibited in Montreal 1967



Zuse Plotte z64 exhibited in Montreal 1967

Computational Form Finding

Force Density Method (FDM)



Linkwitz visits the BRG (2012)

Computational Form Finding

Dynamic Relaxation Method (DRM)

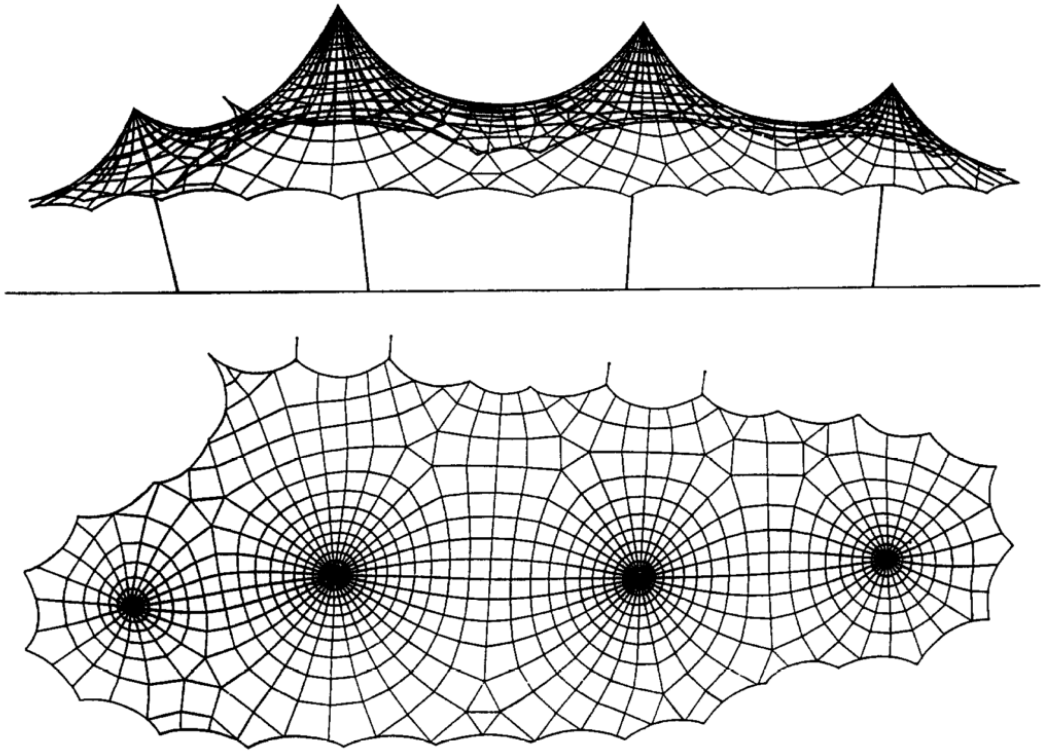
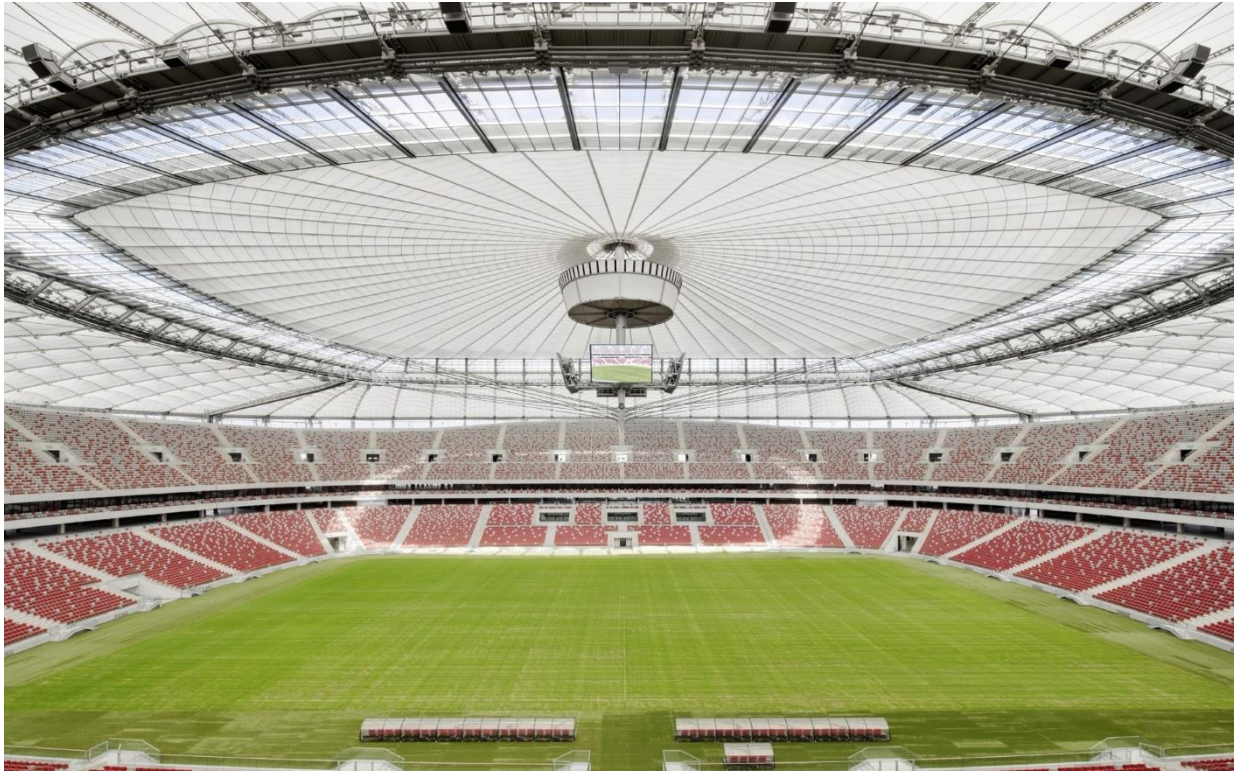


Fig. 11

Barnes (1975)

Computational Form Finding

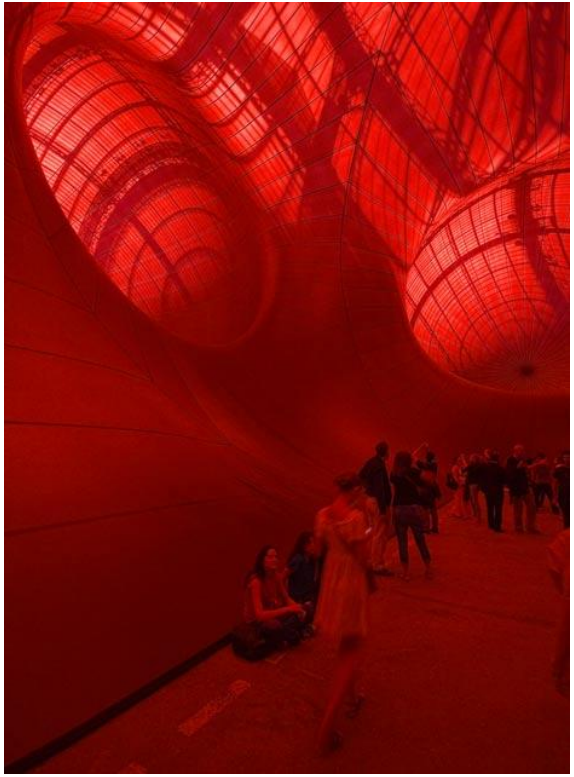
Dynamic Relaxation Method (DRM)



National Stadium, Warsaw, Poland, SBP, 2011

Computational Form Finding

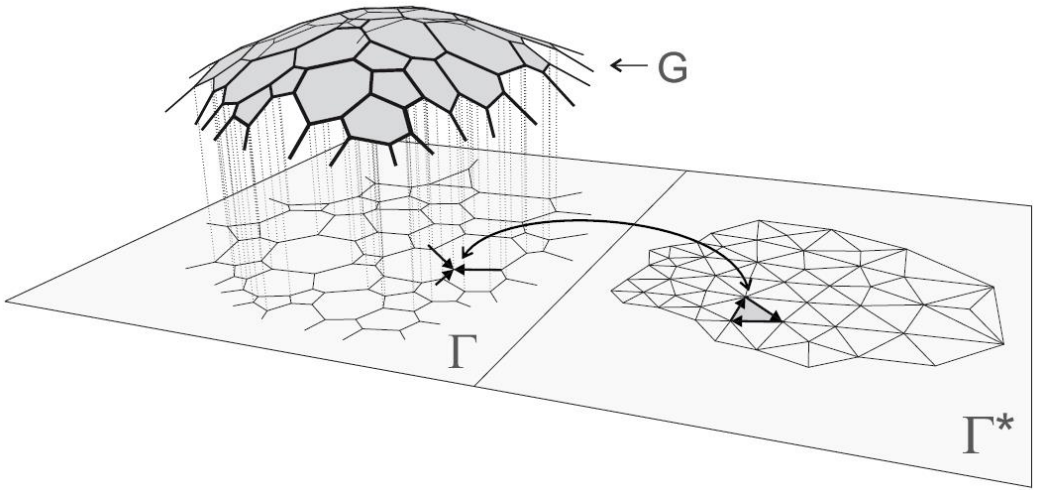
Dynamic Relaxation Method (DRM)



Leviathan by Anish Kapoor, Paris, France, 2011

Computational Form Finding

Thrust Network Analysis (TNA)

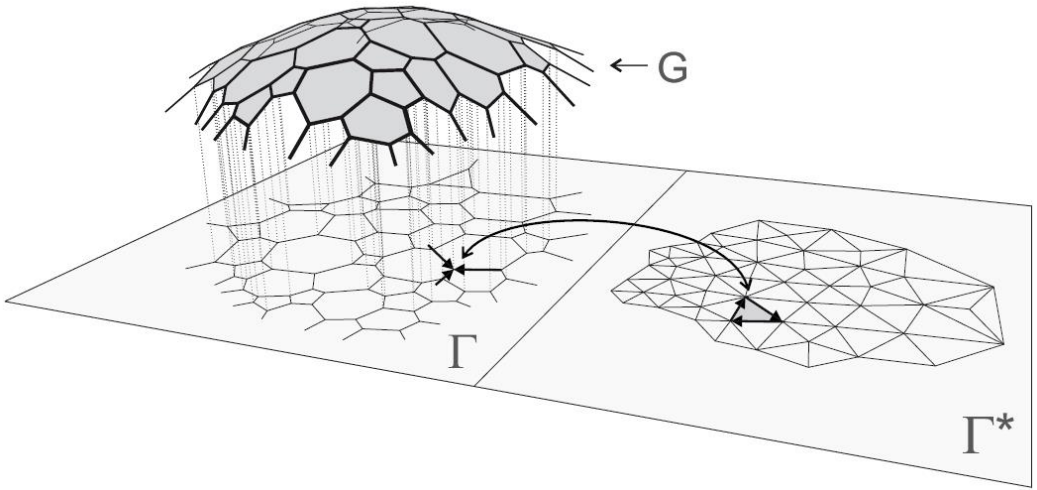


Block and Ochsendorf (2007)

Computational Form Finding

Thrust Network Analysis (TNA)

- Control over plan
- Combine tension and compression easily
- Graphical (uses diagrams as used in graphic statics)



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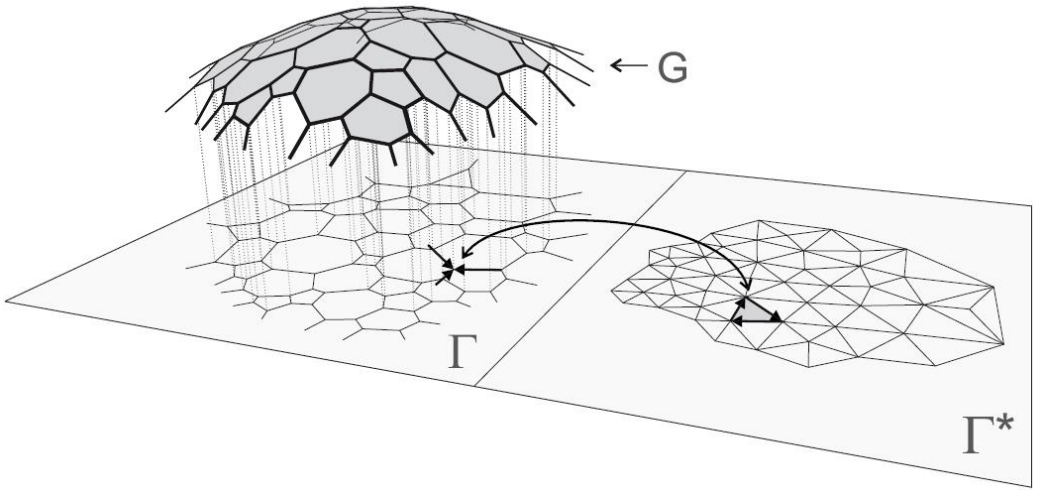
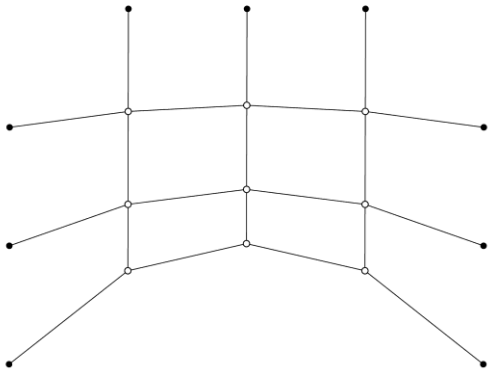


Block and Ochsendorf (2007)

Computational Form Finding

Thrust Network Analysis (TNA)

- Form Diagram Γ

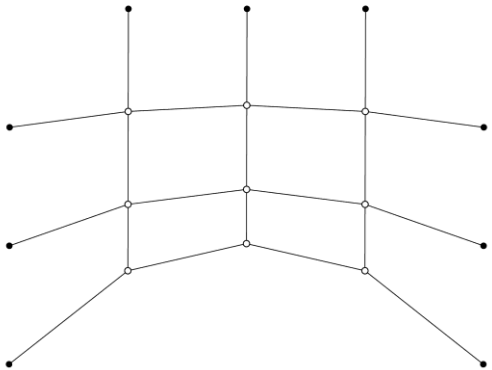


Γ
Form Diagram

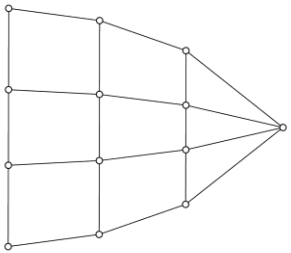
Computational Form Finding

Thrust Network Analysis (TNA)

- Form Diagram Γ
- Force Diagram Γ*



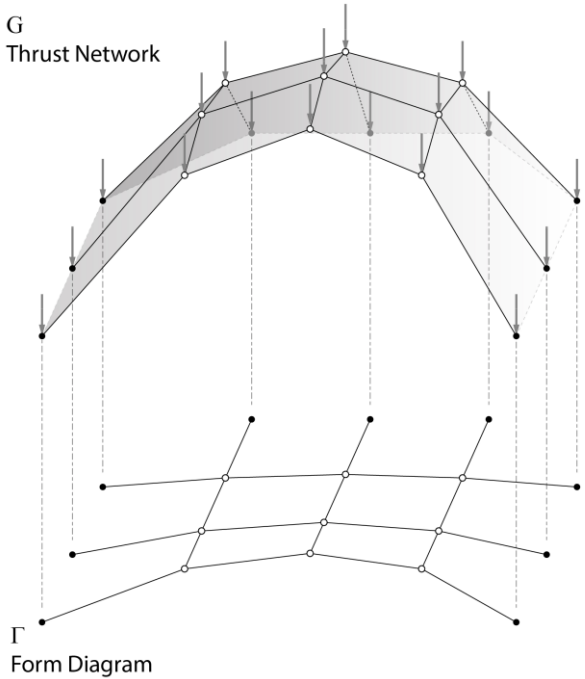
Γ
Form Diagram



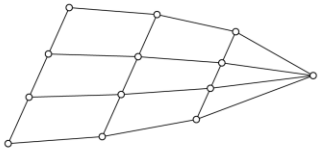
Γ* ζ
Force Diagram

Computational Form Finding

Thrust Network Analysis (TNA)



- Form Diagram Γ
- Force Diagram Γ*
- Thrust Network G

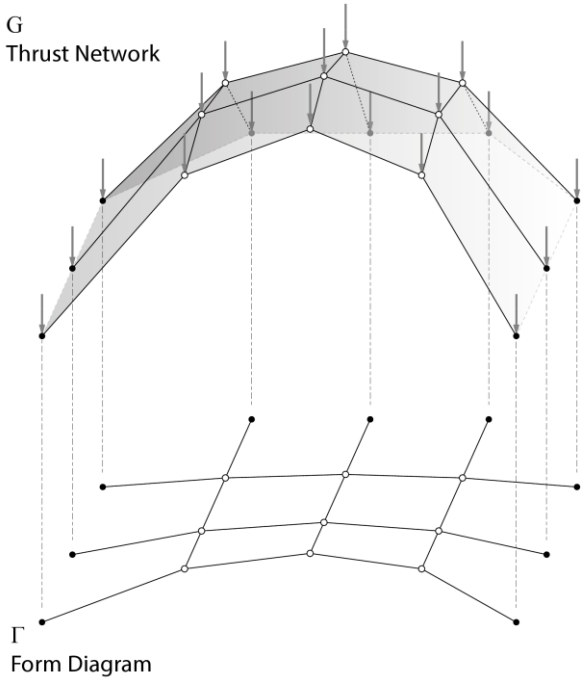


Equilibrium of an internal node in Γ is represented by a **closed force polygon** in Γ*.

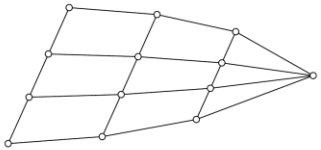
The **length** of the reciprocal edges in Γ* (multiplied with the scale factor ζ) is equal to the **magnitude** of the **horizontal force components** in the corresponding edges in G.

Computational Form Finding

Thrust Network Analysis (TNA)



- Form Diagram Γ
- Force Diagram Γ*
- Thrust Network G



Step 1 - Solving horizontal equilibrium:

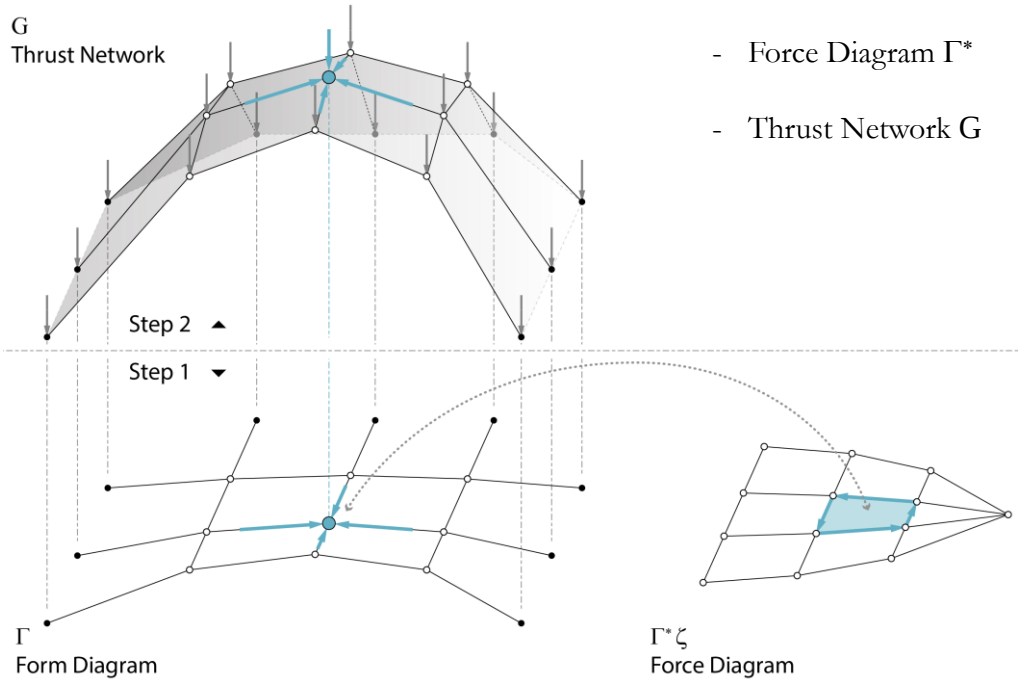
The in-plane equilibrium of Γ represents the horizontal equilibrium of G, independently of the applied (vertical) loads.

Step 2 - Solving vertical equilibrium:

A unique thrust network G in equilibrium can be found for a given in-plane horizontal equilibrium, the given loading and support vertices.

Computational Form Finding

Thrust Network Analysis (TNA)



- Form Diagram Γ
- Force Diagram Γ*
- Thrust Network G

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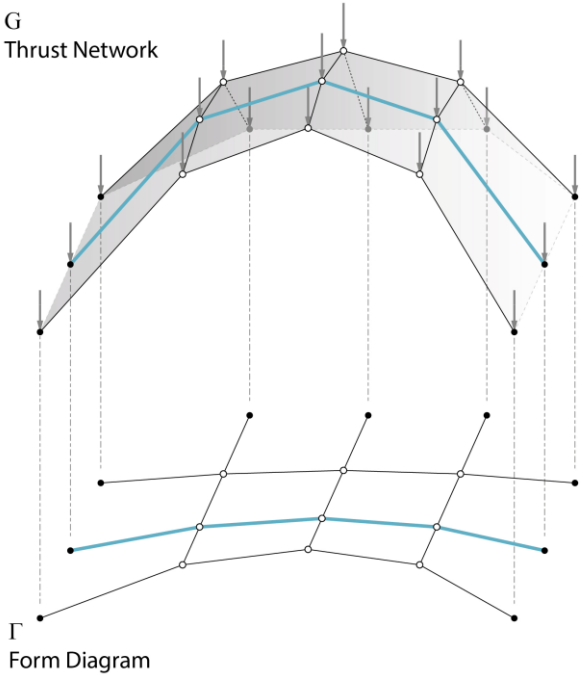
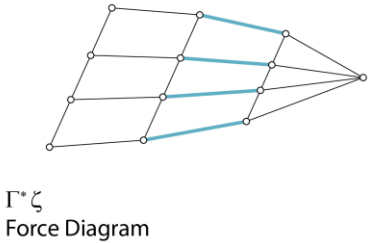
Computational Form Finding

Thrust Network Analysis (TNA)



- Form Diagram Γ
- Force Diagram Γ*
- Thrust Network G



Example of a simple modification of vertex $\mathbf{v}_j^*$ in Γ*.

Computational Form Finding

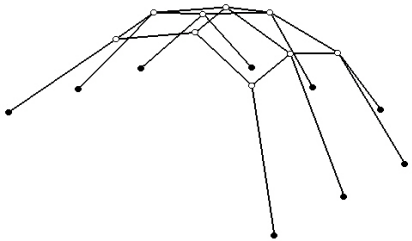
Thrust Network Analysis (TNA)

- Form Diagram Γ
- Force Diagram Γ*
- Thrust Network G

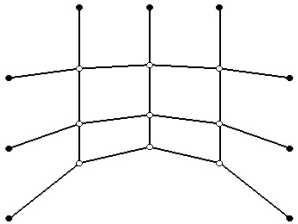
Unidirectional:

Modifying the force diagram Γ*

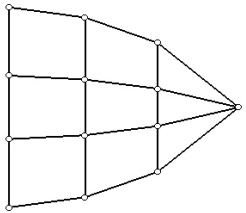
→ automatic adjustment of the form diagram Γ using $\gamma = 0$



G



Γ



Γ*

Computational Form Finding

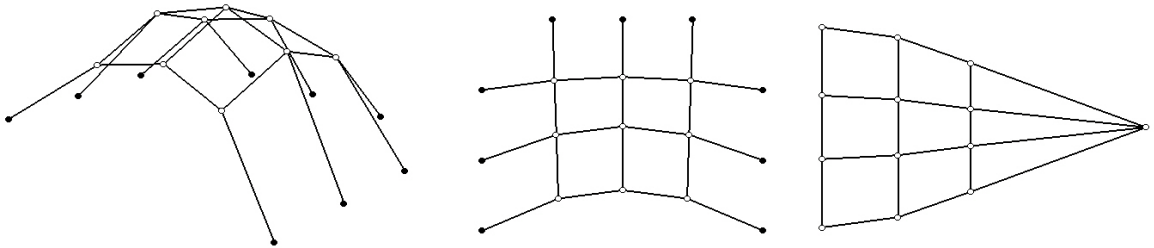
Thrust Network Analysis (TNA)

- Form Diagram Γ
- Force Diagram Γ*
- Thrust Network G

Unidirectional:

Modifying the force diagram Γ*

→ automatic adjustment of the form diagram Γ using $\gamma = 0$



G Γ Γ*

Computational Form Finding

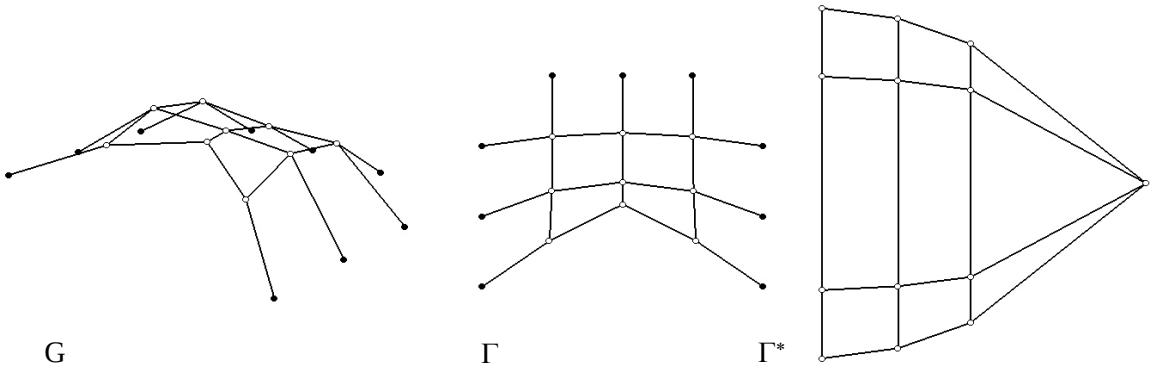
Thrust Network Analysis (TNA)

- Form Diagram Γ
- Force Diagram Γ*
- Thrust Network G

Unidirectional:

Modifying the form diagram Γ

→ automatic adjustment of the force diagram Γ* using $\gamma = 1$



G Γ Γ*

Computational Form Finding

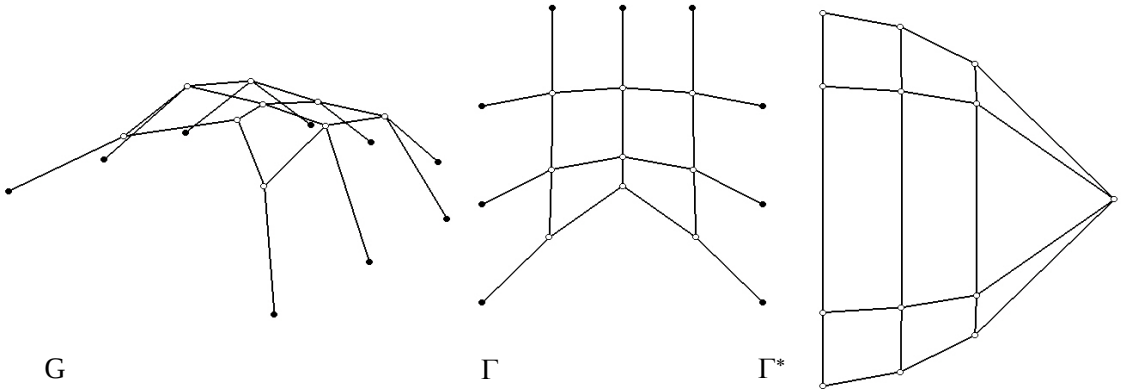
Thrust Network Analysis (TNA)

- Form Diagram Γ
- Force Diagram Γ*
- Thrust Network G

Bidirectional:

Modifying the form diagram Γ

→ automatic adjustment of the form diagram Γ and the force diagram Γ* using $\gamma = 0.5$



G Γ Γ*

Computational Form Finding

Thrust Network Analysis (TNA)

Armadillo Vault, Block Research Group, Venice Architecture Biennale, Italy, 2016

Definition of Form Finding

Why Form Finding?

Physical Form Finding Models

Computational Form Finding

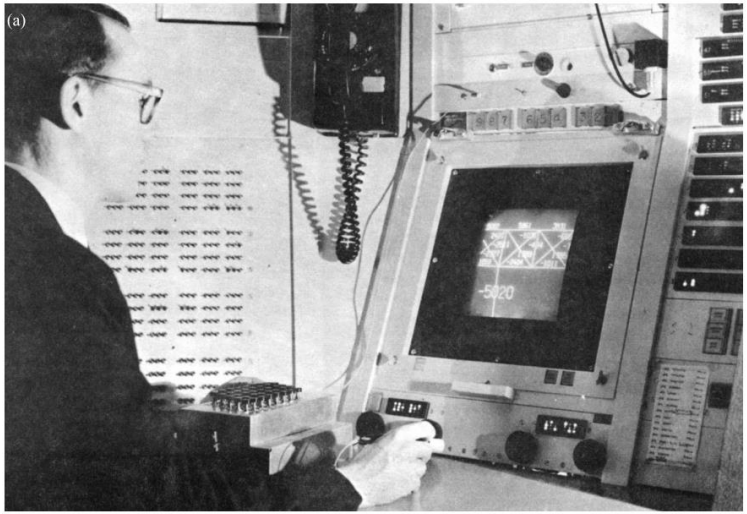
Computational Tools

Computational Tools

Design by Analysis

https://www.youtube.com/watch?v=USyoT_Ha_bA

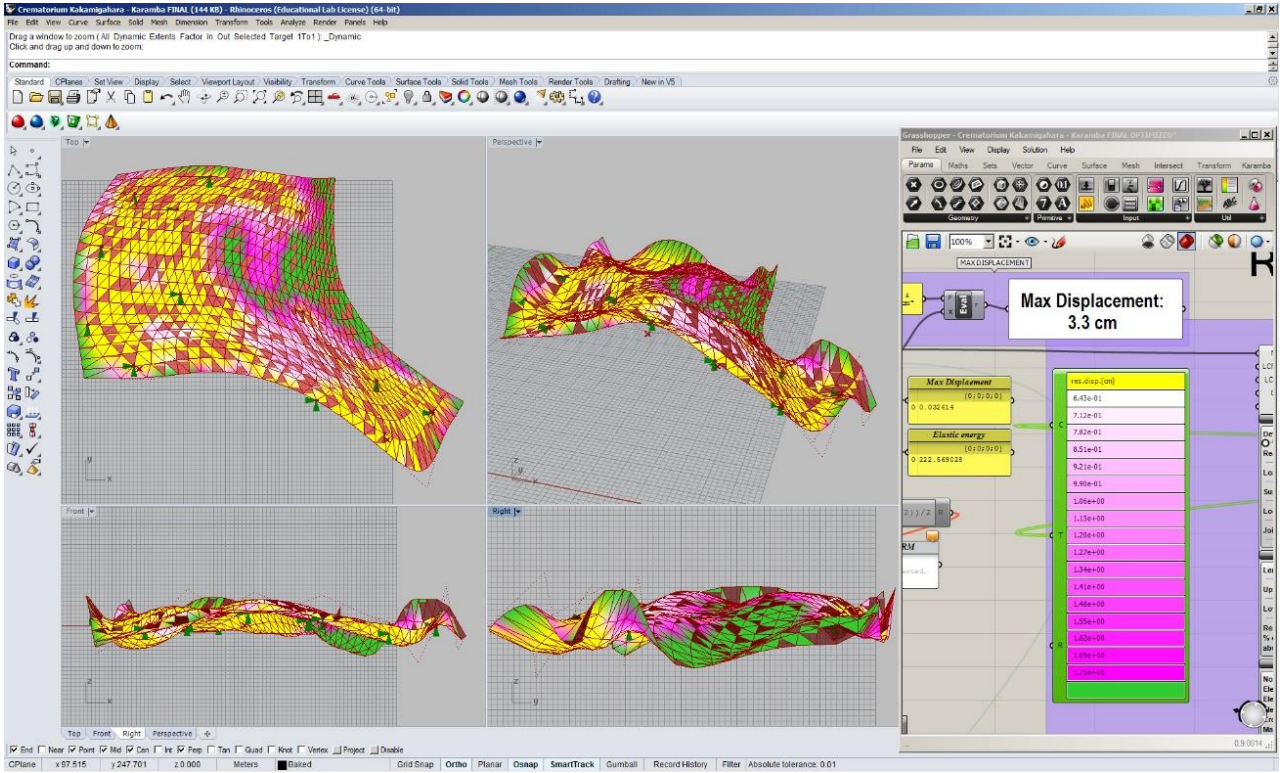
https://www.youtube.com/watch?v=BKM3CmRqK2o



Sketchpad, Ivan Sutherland (1963)

Computational Tools

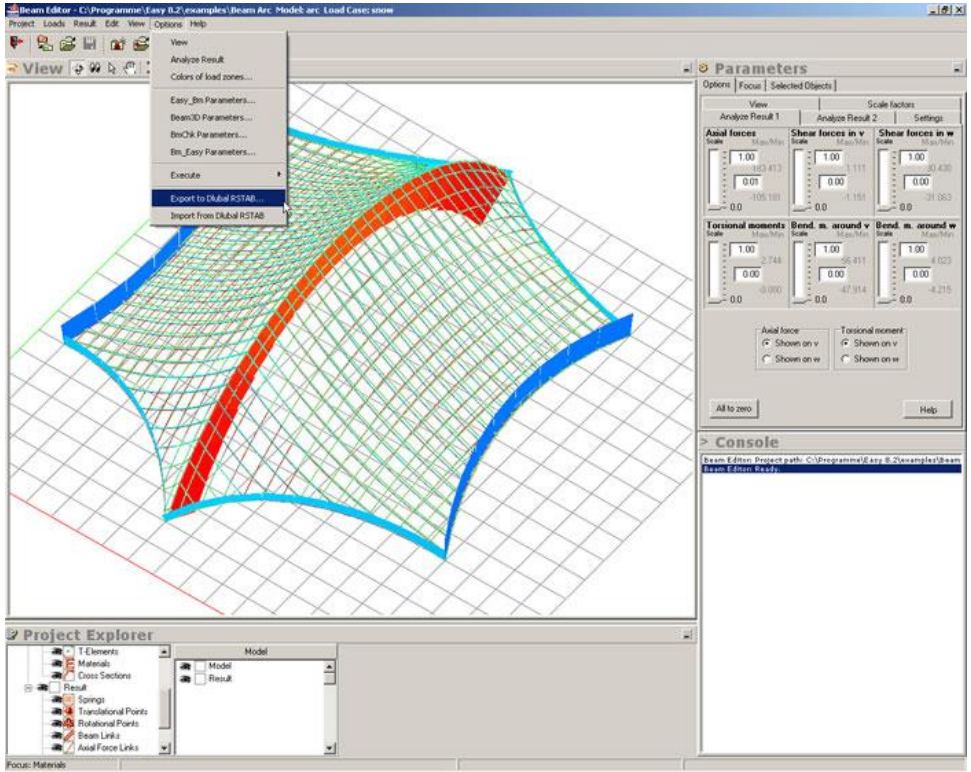
Design by Analysis



Karamba, Clemens Preisinger and Bollinger-Grohmann-Schneider ZT GmbH (2011)

Computational Tools

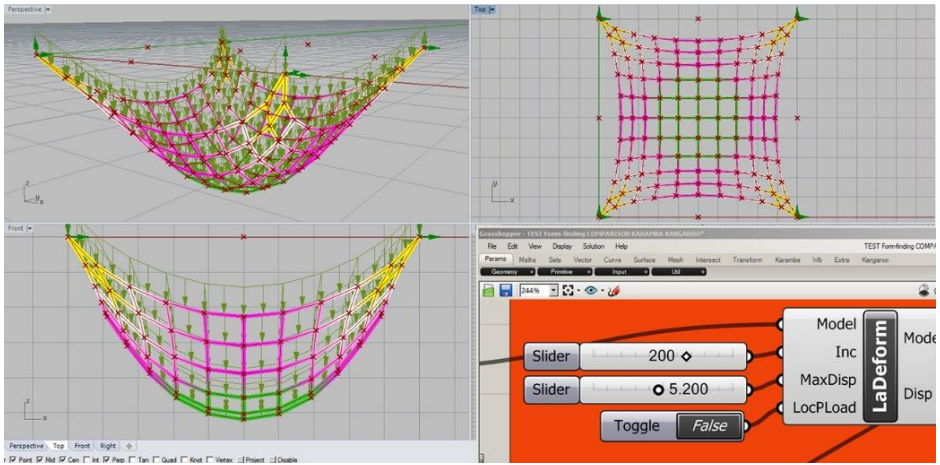
Form-Finding Design Tool (FDM)



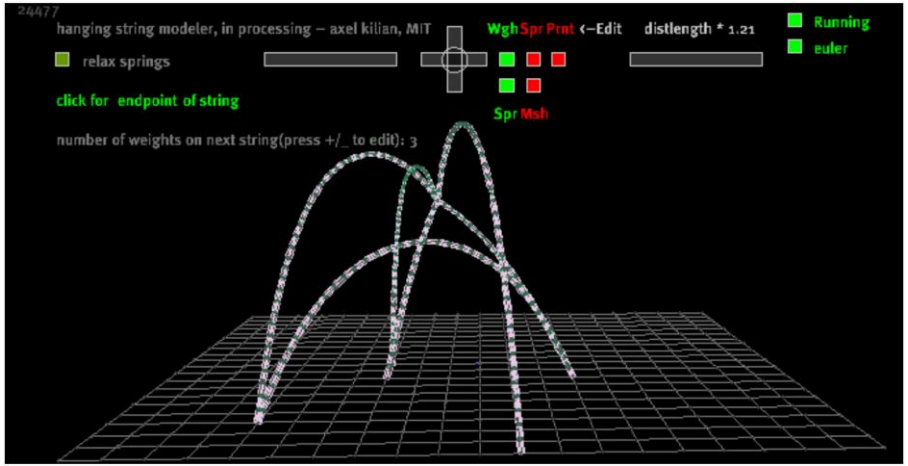
Easy.Form technet GmbH (1990)

Computational Tools

Form-Finding Design Tool (DR)



Kangaroo, Daniel Piker (2010)



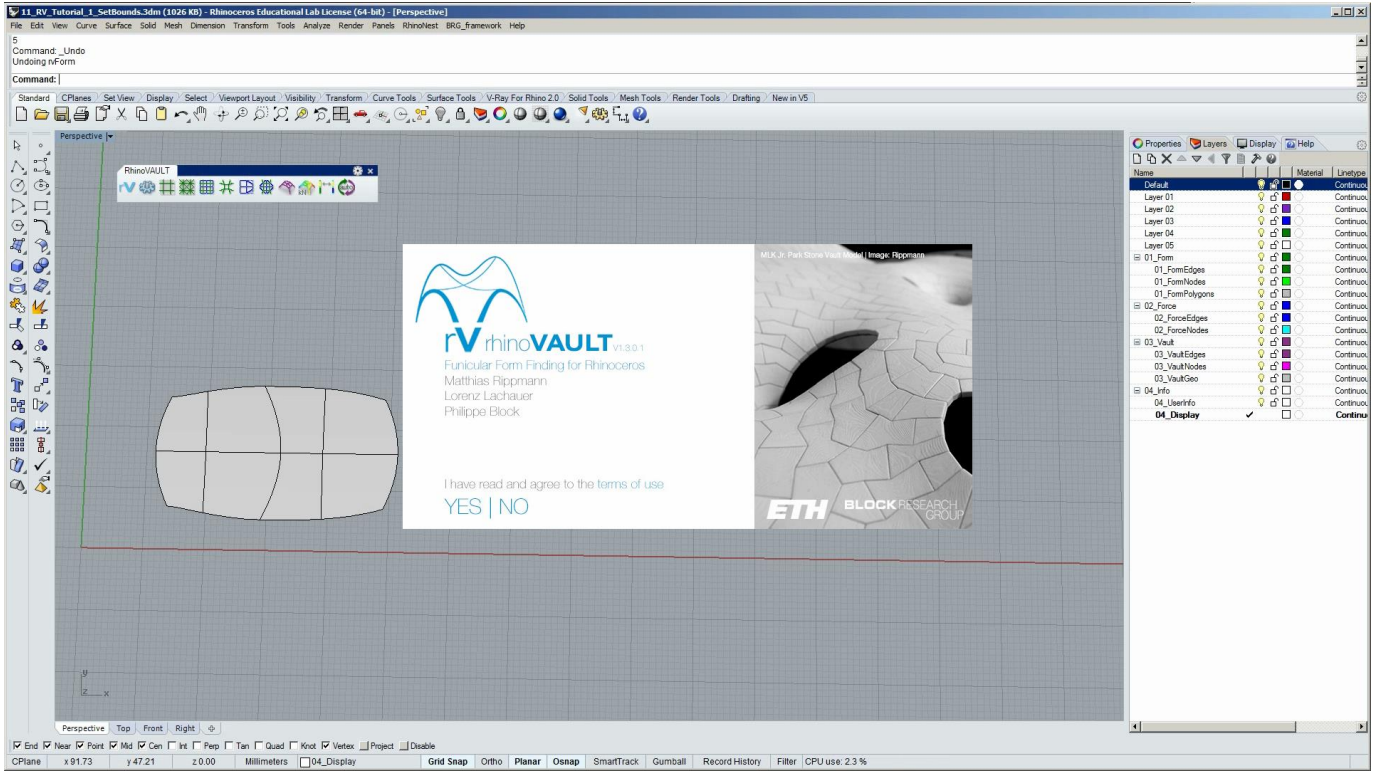
Cadenary, Axel Kilian (2002)

Computational Tools

Form-Finding Design Tool (TNA)

https://vimeo.com/177711821

http://www.block.arch.ethz.ch/brg/content/tool/rhinovault/tutorials



RhinoVAULT, Rippmann, Lachauer, Block (2012)

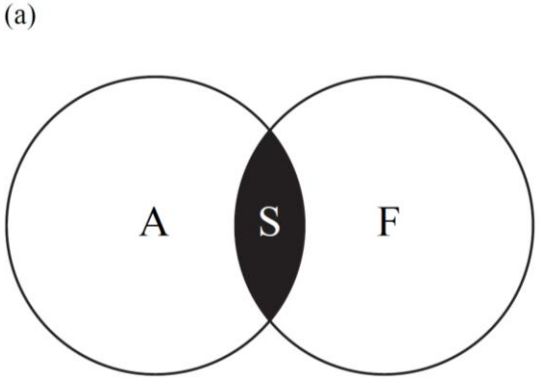
Computational Tools

Form-Finding Design Tool (TNA)

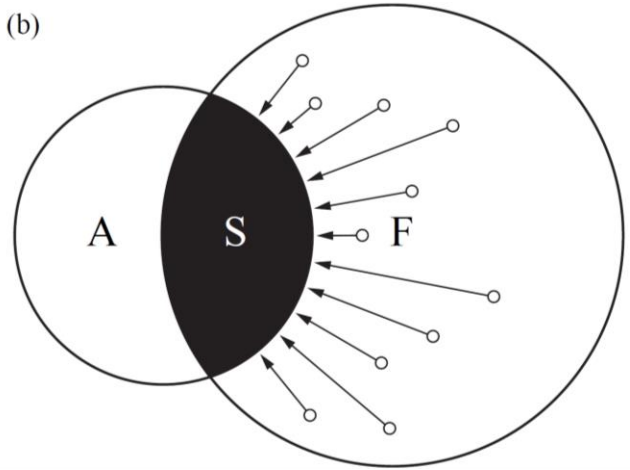
A: set of all possible shapes accepted by the architect for a specific design problem

F: set of all possible funicular shapes for the design problem

S: the possible design space for the design problem



Use of form-finding tools 1987 (Sobek)



Use of form-finding tools 2015 (Rippmann)

Structural Design VI: Computational Methods

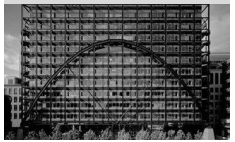
Introduction

Computational Methods in Structural Design

Parametric Design

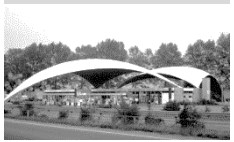
Fabrication-aware Structural Design

Parametric Graphic Statics

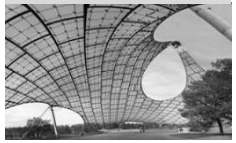


Digital Fabrication Of Structures

Form Finding



Construction and Panelisation of Shells and Tensile Structures



Advanced topics

Optimisation

Design to Production

Computational Methods in the Architectural Practice

Structural Design VI

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