



FORM FINDING FOR SHELLS

ORSOLYA GÁSPÁR

DEPARTMENT OF MECHANICS, MATERIALS
AND STRUCTURES
BME BUDAPEST

OVERVIEW

WHAT IS A SHELL?

Structural introduction

Advantages and disadvantages

BRIEF HISTORY OF SHELLS

FORM FINDING OF SHELLS

Methods of past and present

Physical testing/experiments

Heinz Isler

Frei Otto

CONTEMPORARY INSPIRATIONAL RESULTS

CHALLENGES OF FORM FINDING

Techniques

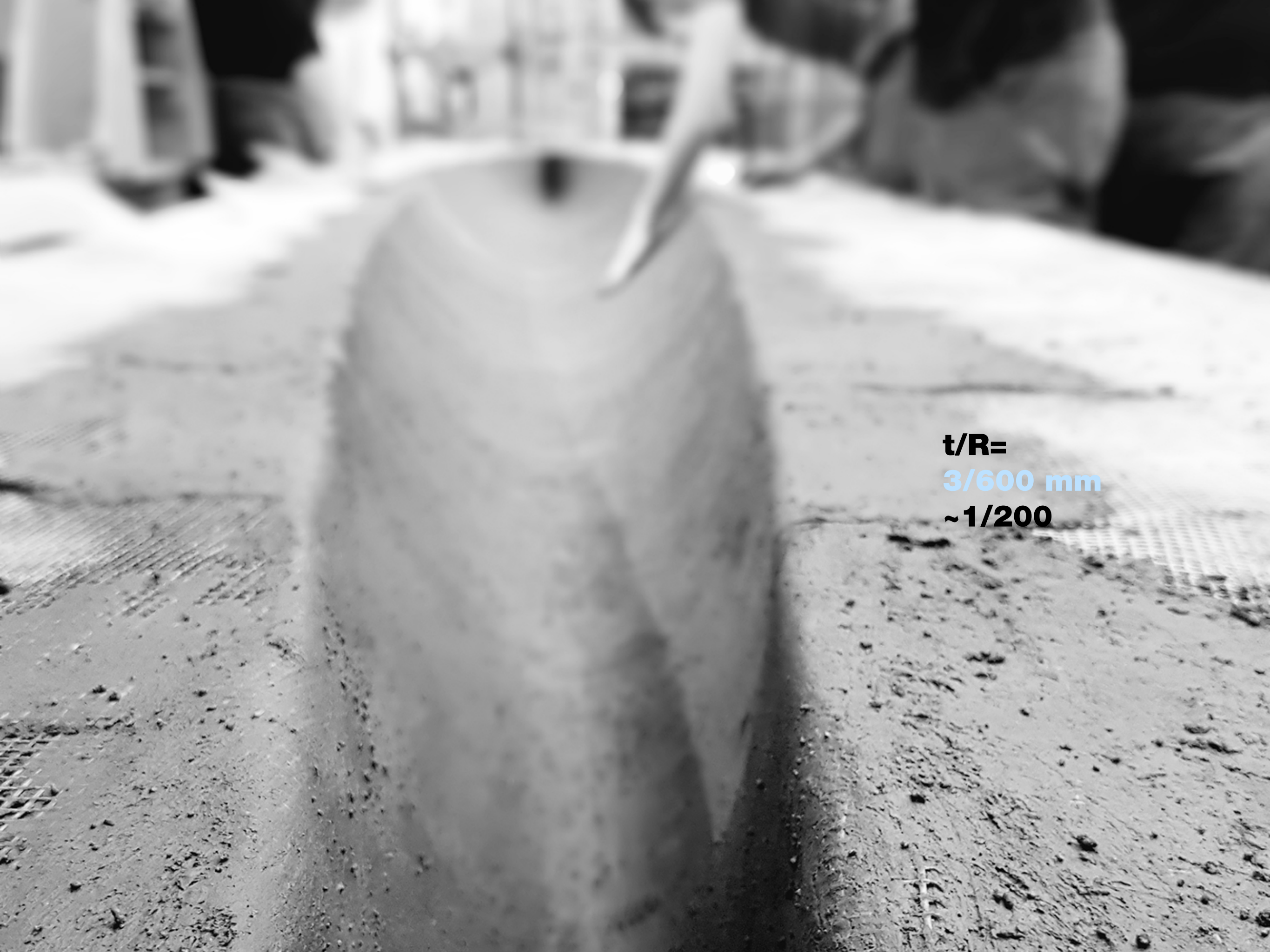
WHAT IS A SHELL?

BASICS





t/R=
0.3/55 mm
~1/200

A close-up, black and white photograph of a metal surface. The surface is textured and shows signs of wear, including small pits and scratches. A sharp, pointed edge is visible in the center, extending towards the background. In the background, a circular hole is visible in the metal. The overall scene is dimly lit, with a bright spot of light reflecting off the edge.

t/R=
3/600 mm
~1/200



t/R=
0.06/90 m
~1/1500!



Bus garage, Kelenföld (I. Menyhárd, J. Padányi Gulyás 1941)

THE PAPER AND THE BEAM

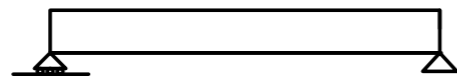
BENDING

'BENDING-FREE'

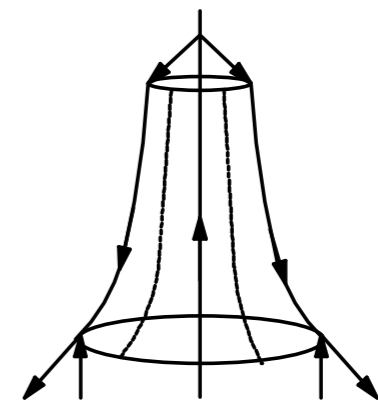
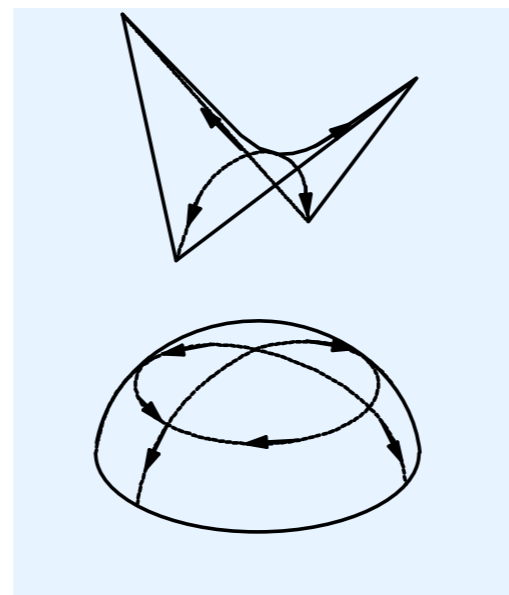
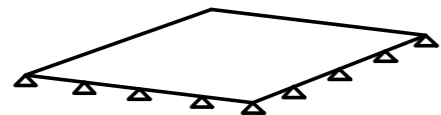
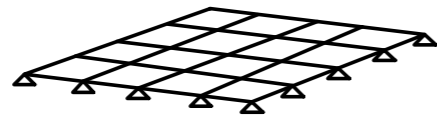
COMPRESSION

TENSION

2D
'LINE'



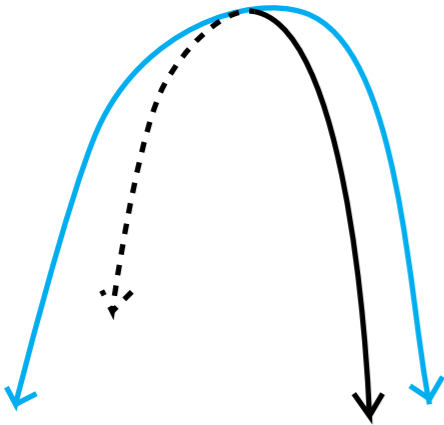
3D
'SURFACE'



TYPE OF SHELLS

CURVATURE

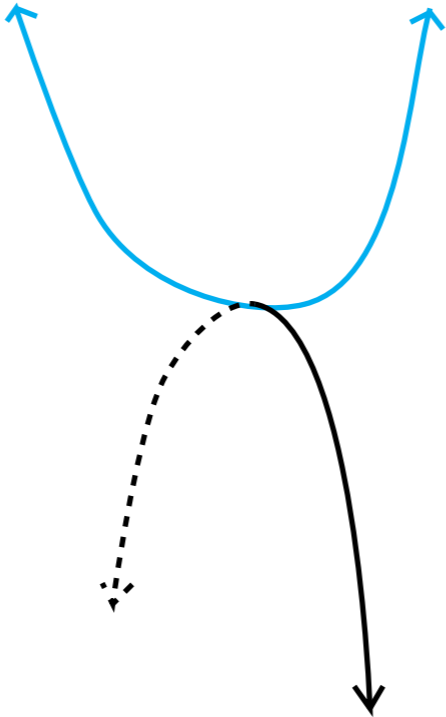
ELLIPTIC



+ **+**

+

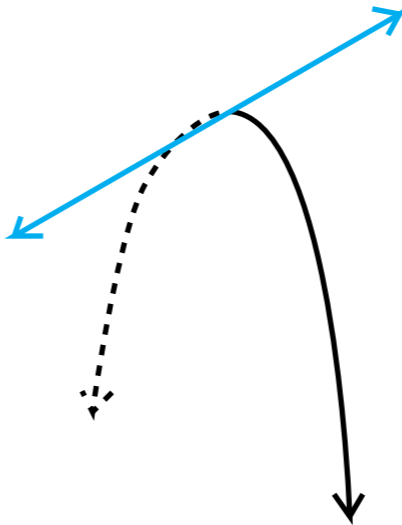
HYPERBOLIC



- **+**

-

PARABOLIC



0 **+**

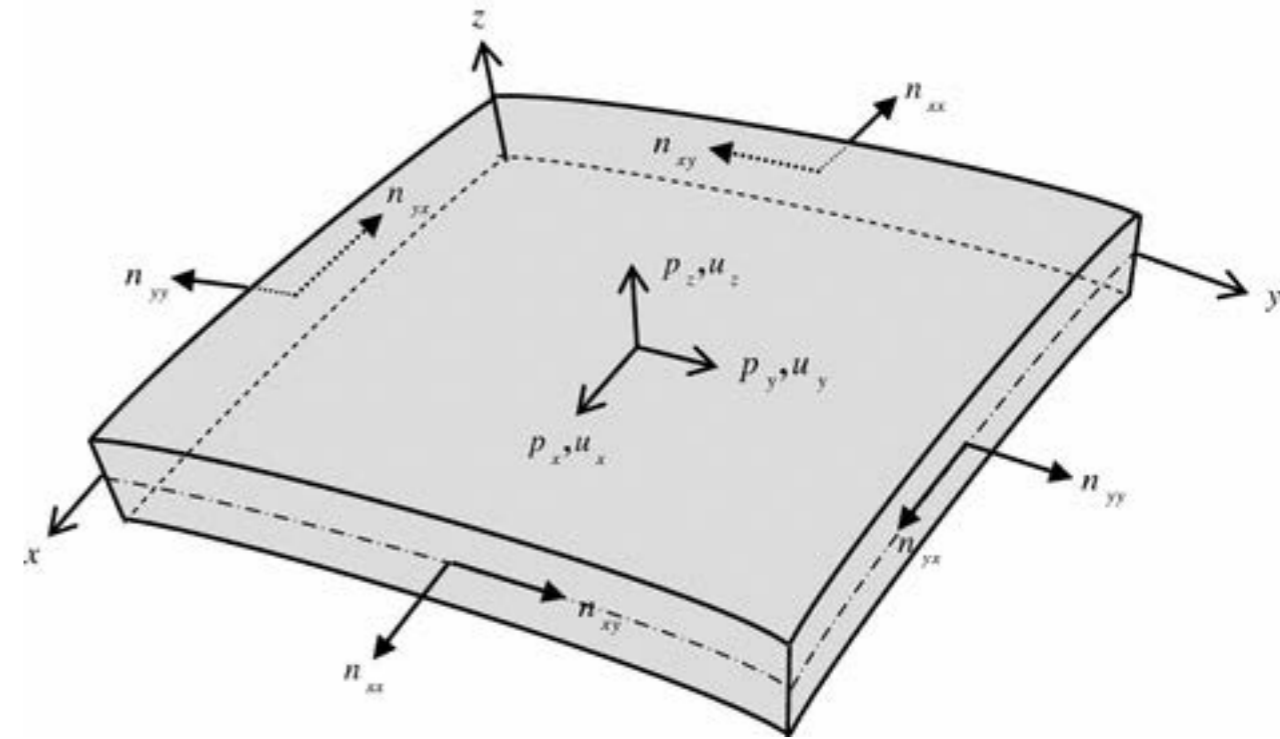
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FREE-FORM

VARIES

THEORY OF SHELLS

FILMS - **MEMBRANE SHELLS** - SHELLS



FAILURE OF MEMBRANE SHELLS

BUCKLING - ROLE OF BENDING STIFFNESS

'HONESTY OF HANGING CLOTH MODELS'

AREAS MOST AFFECTED BY BUCKLING: EDGES, HOLES

THEORY OF SHELLS

SUPPORTS

EQUILIBRIUM IS SEARCHED FOR

**(LIMITED) RANGE OF SHELL
GEOMETRIES + MEMBRANE
STRESS STATE =>
SUPPORTING CONDITION**

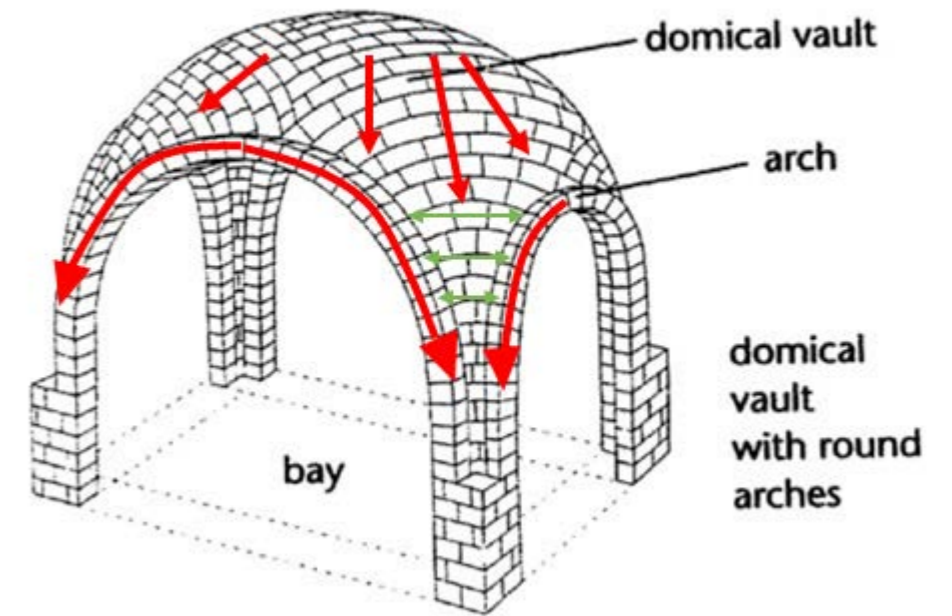
ENGINEERING ANALYSIS

VS

**(SUPPORTING) CONDITION +
MEMBRANE STRESS STATE =>
SHELL GEOMETRY
FUNICULAR SHELLS,**

**FORM-FINDING, FREE-FORM
SHELLS**

HANGING MODELS
OR COMPUTER-AIDED
(EG. TNA, FORCE DENSITY METHOD)



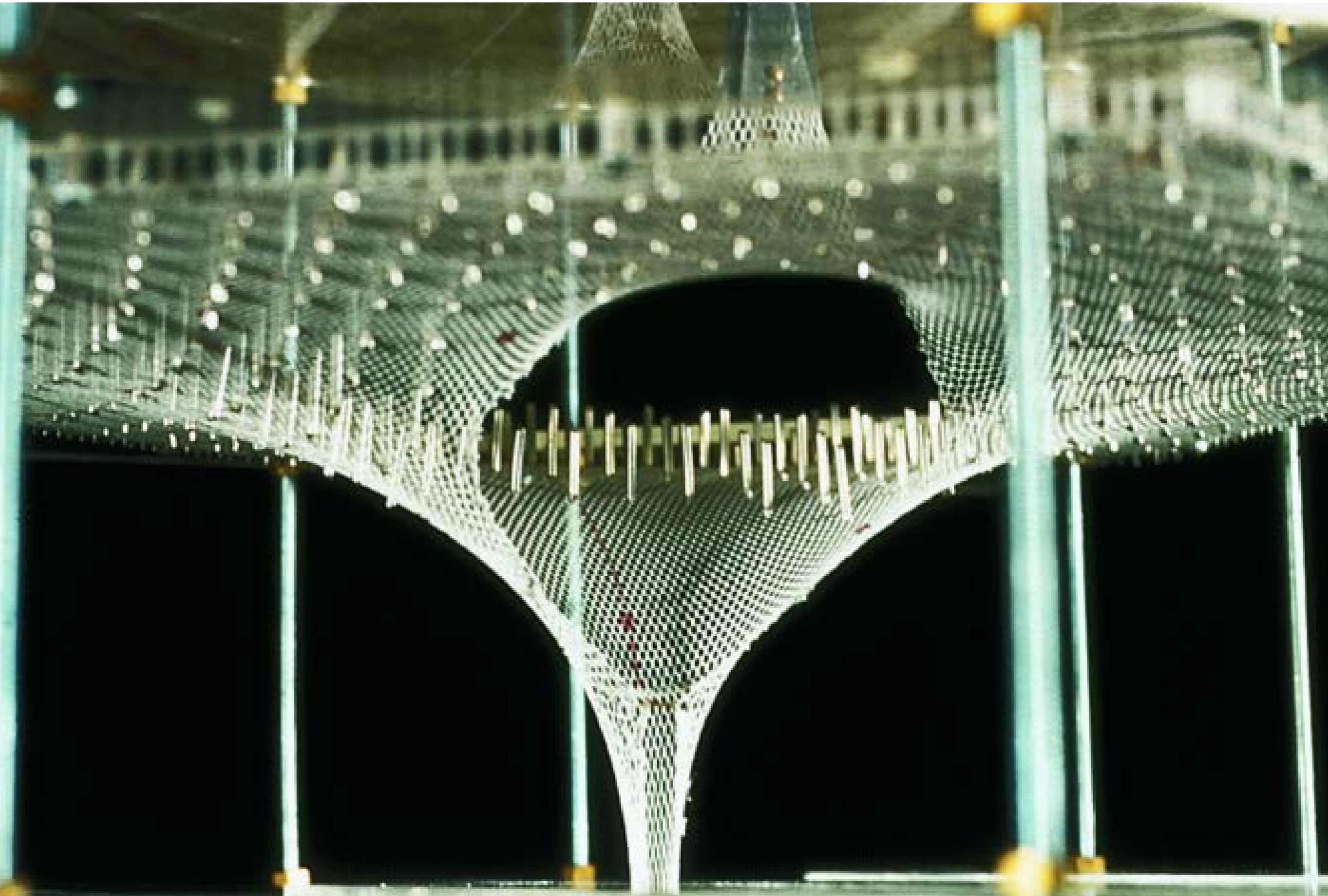
BRIEF HISTORY OF SHELLS

GENERAL TRENDS



**KEEP
CALM
AND
LOVE
MATH**





Bahnhof Stuttgart (F. Otto 1997)

ENGINEERING ANALYSIS

mathematical models

FORMFINDING, INTUITION

model building

GERMAN SCHOOL

E. TORROJA

P.L. NERVI

HUNGARIAN SCHOOL

F. CANDELA

SANTIAGO CALATRAVA

CECIL BALMOND

JÜRIG CONZETT

ANTONI GAUDI

ROBERT MAILLART

HEINZ ISLER

FREI OTTO



Hangar, Oriveto, Model (P. L. Nervi 1939)

PERIODIZATION

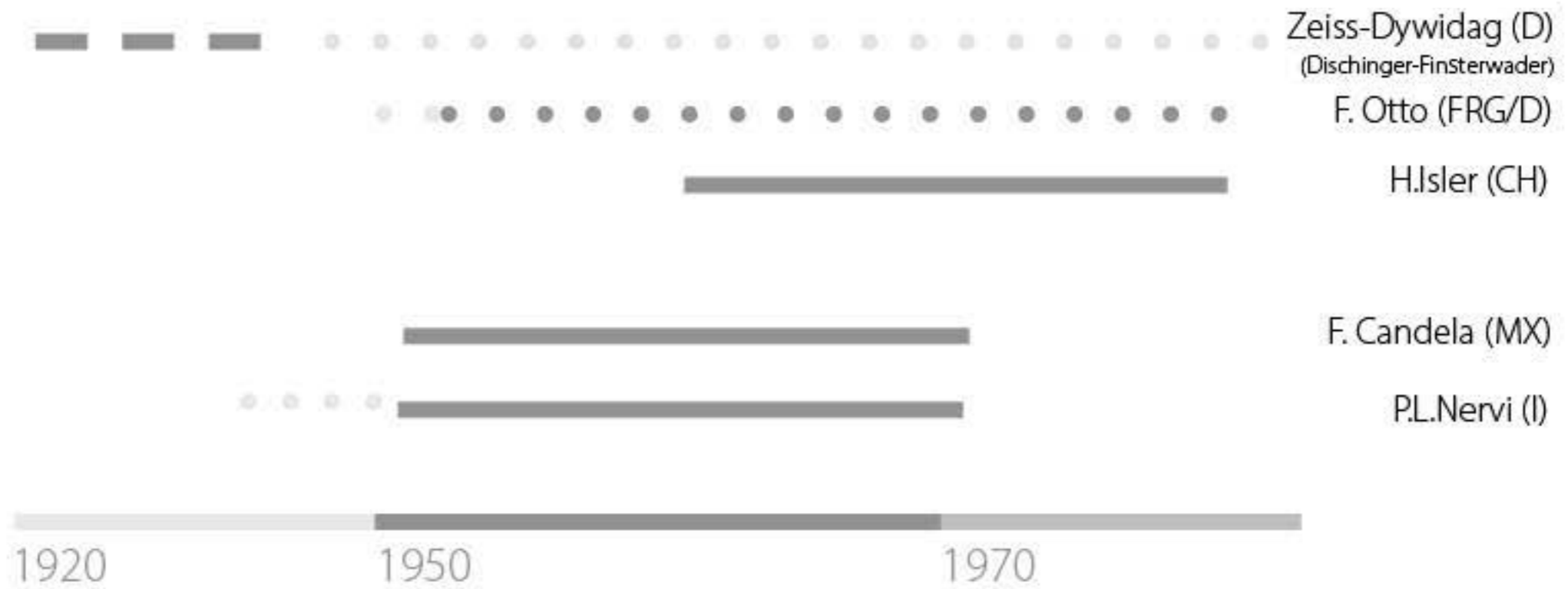
WHY TO BUILD SHELLS?



Pantehon, Rome (II. century AC)

PERIODIZATION

WHY TO BUILD SHELLS?



BEGINNING

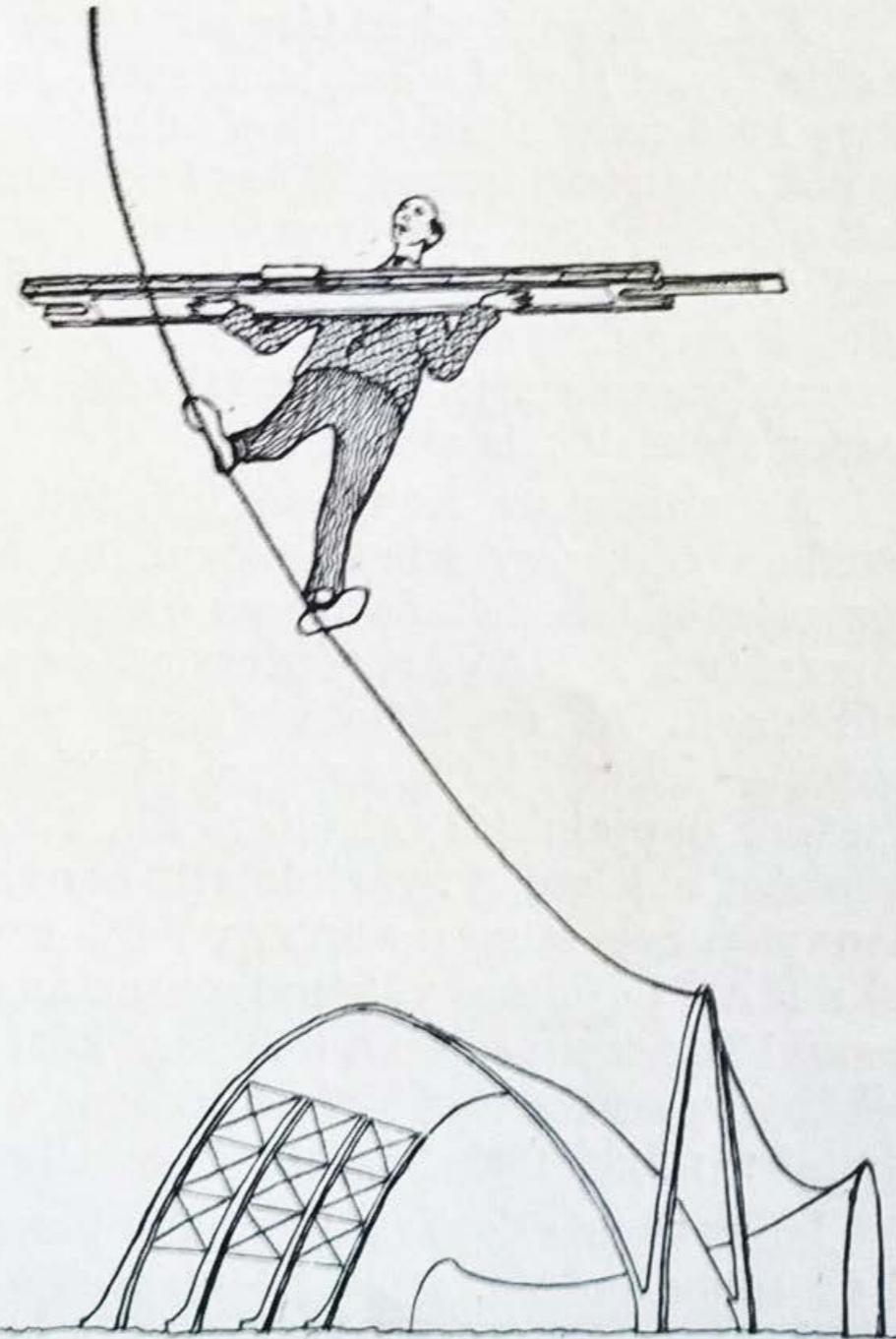


Tallin, Chrsitiani&Nielsen 1917

Csepel, Dywidag 1930

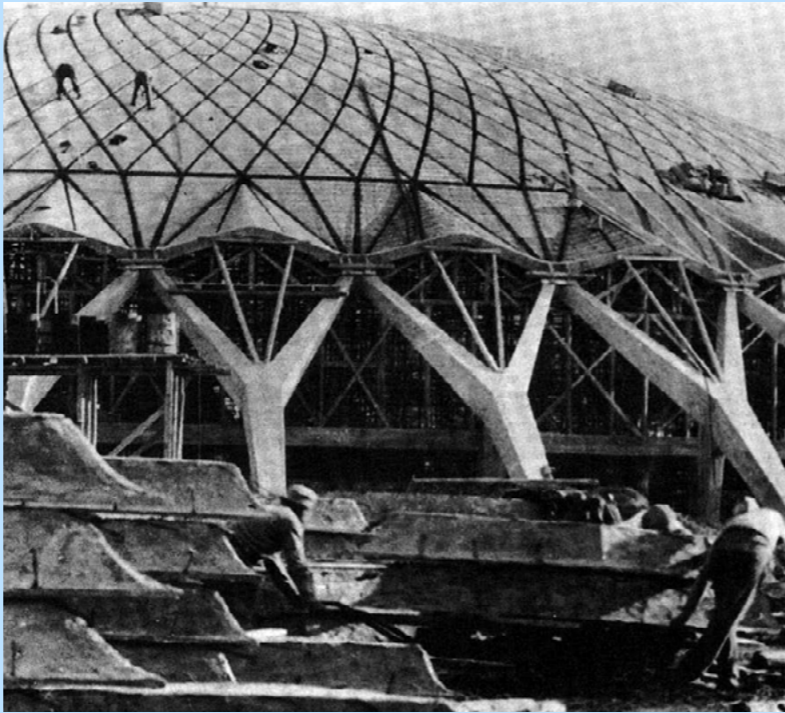
Frontón, Torroja 1935

Orvieto, Nervi 1939



A statikus merészsége
(Hoch István rajza)

HEYDAY

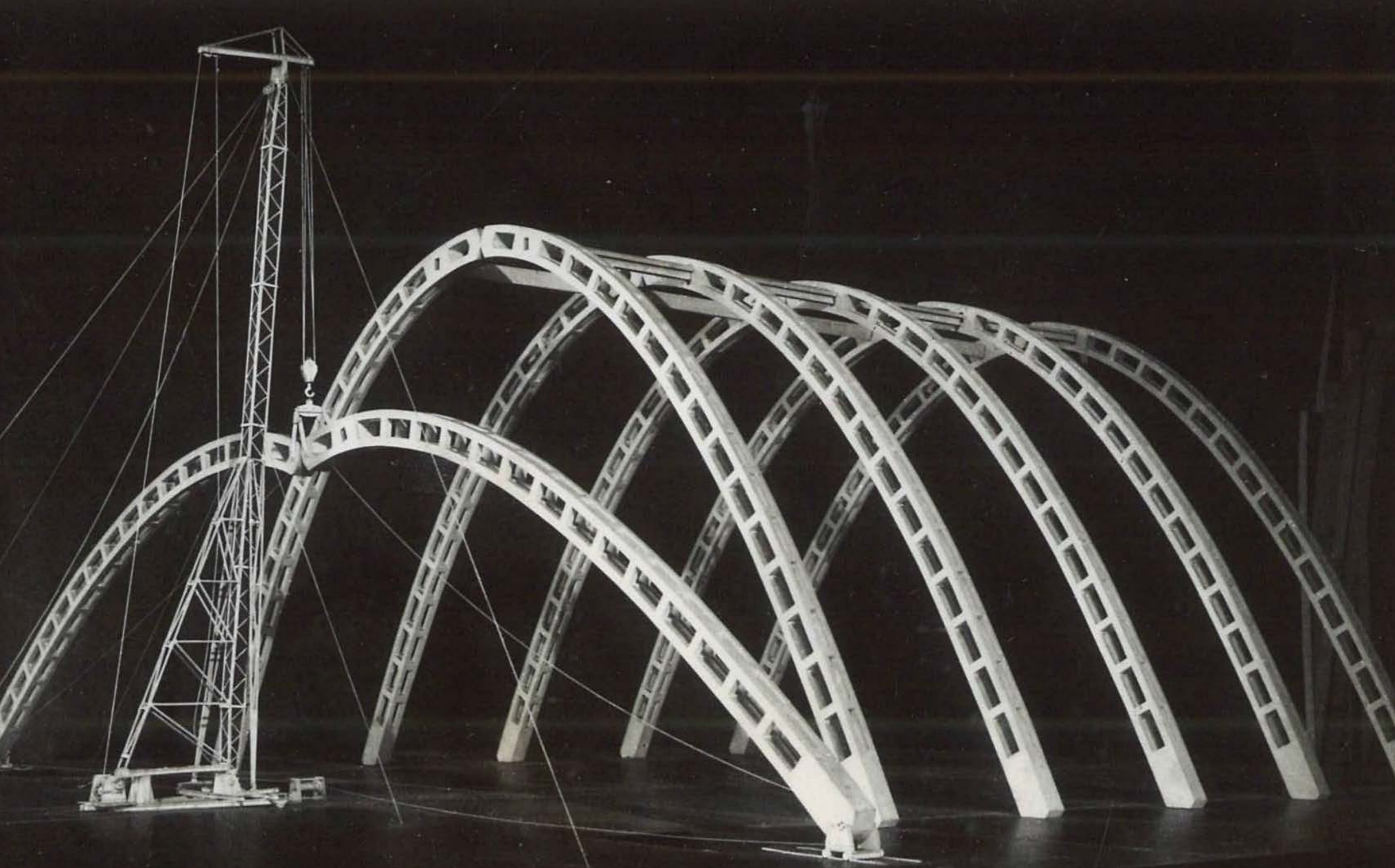


Nervi, Rome 1960

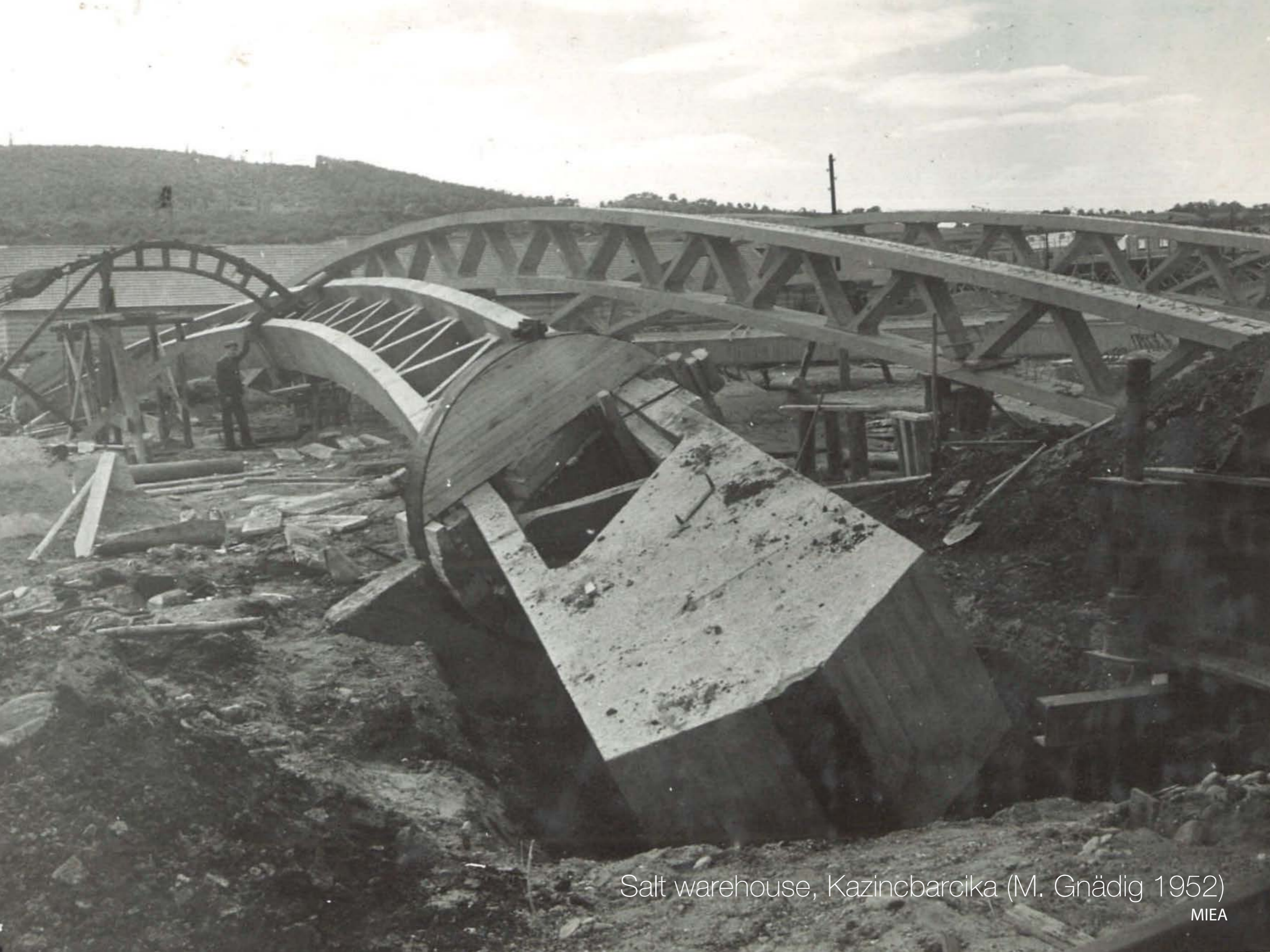
Esplanade Paris 1958

Candela, Mexico 1955

Isler, Lommiswil, 1969

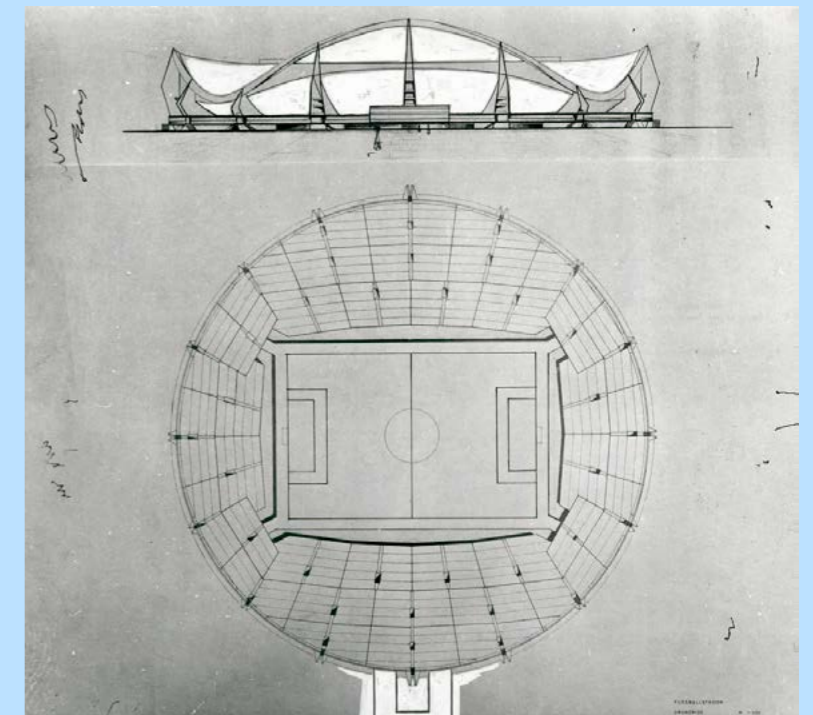


Salt warehouse, Kazincbarcika (M. Gnädig 1952)



Salt warehouse, Kazincbarcika (M. Gnädig 1952)

LATE PERIOD



Isler, Brügi, 1973

Otto, Mannheim 1972

Nervi, San Francisco, 1971

Polónyi, Müngersdorf



Slettebakken kirke, Bergen (Tore Sveram, Flach-Tonnensen 1971)



St. Hallvard kirke, Oslo (Lund+Slaatto, Borring+Rognerud 1966)

FORM FINDING OF SHELLS

FUNICULAR SHELLS

EFFECTIVE FORMS



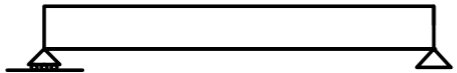
'BENDING-FREE'

BENDING

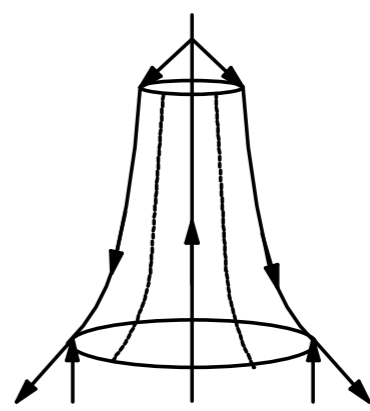
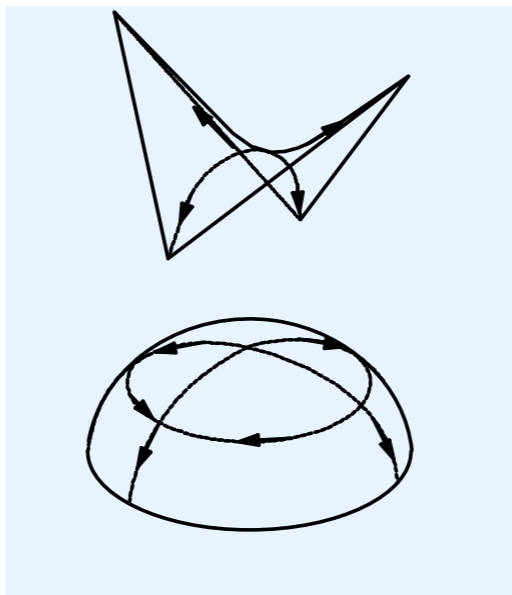
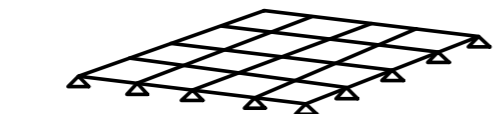
COMPRESSION

TENSION

2D
'LINE'



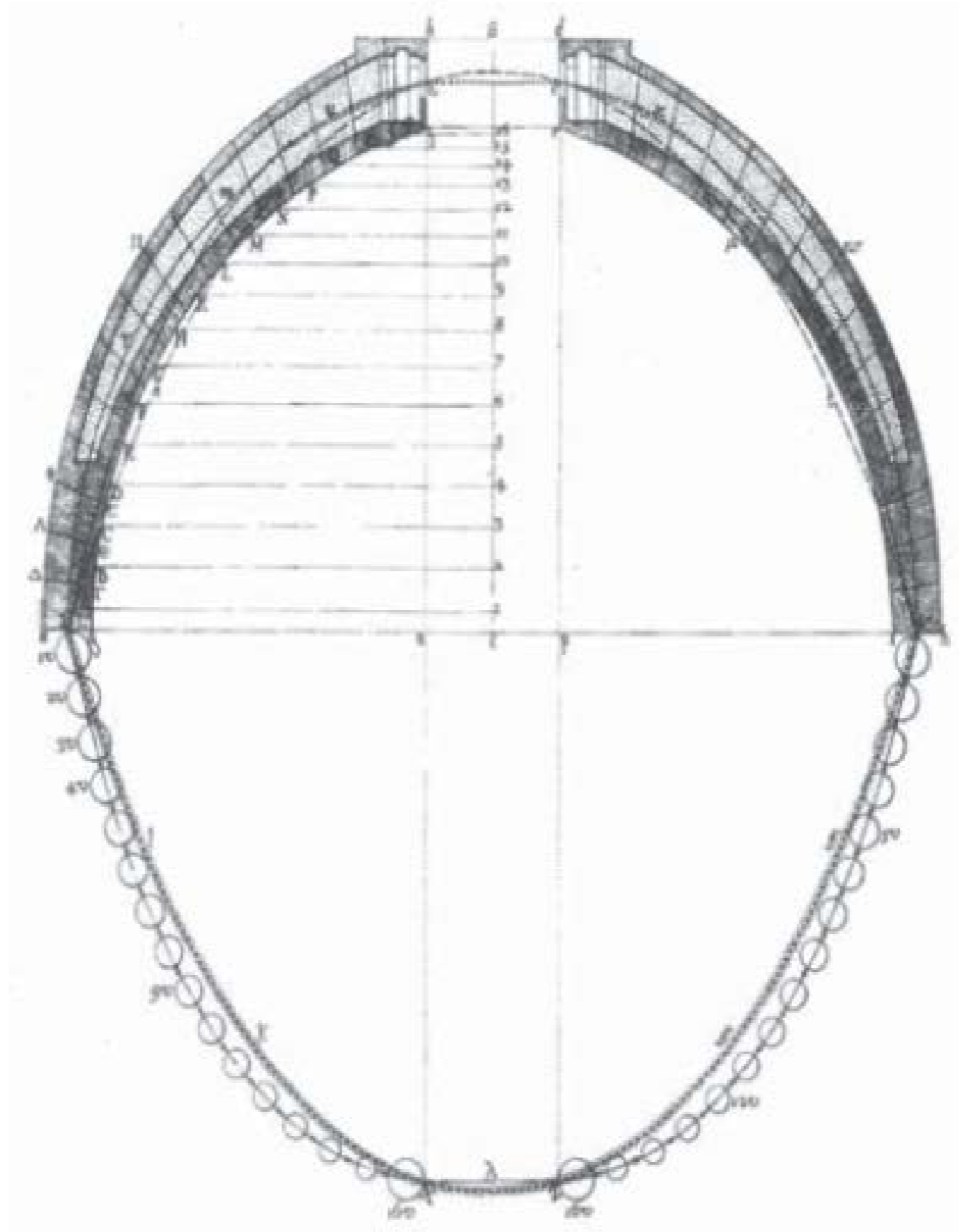
3D
'SURFACE'





ROBERT HOOKE
1635-1703
Scientist
Architect
Engineer

AS HANGS
SO, BUT
WILL STAND



THE FLEXIBLE LINE
INVERTED
THE RIGID ARCH





Colonia Güell crypt (Antoni Gaudí) 1898-1915

RESTIRCTIONS ON FORM

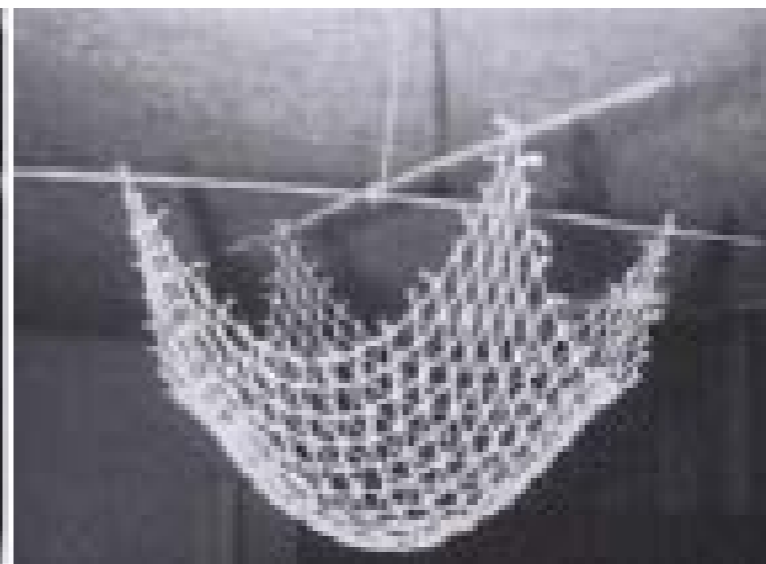
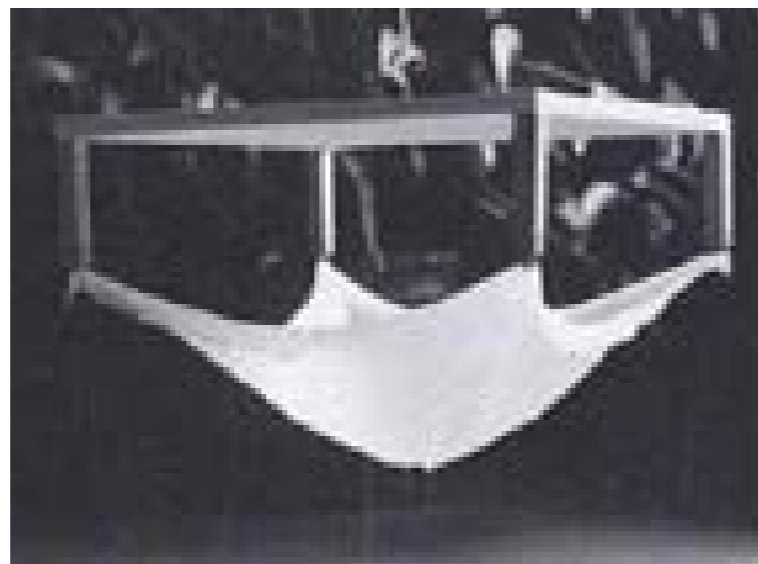
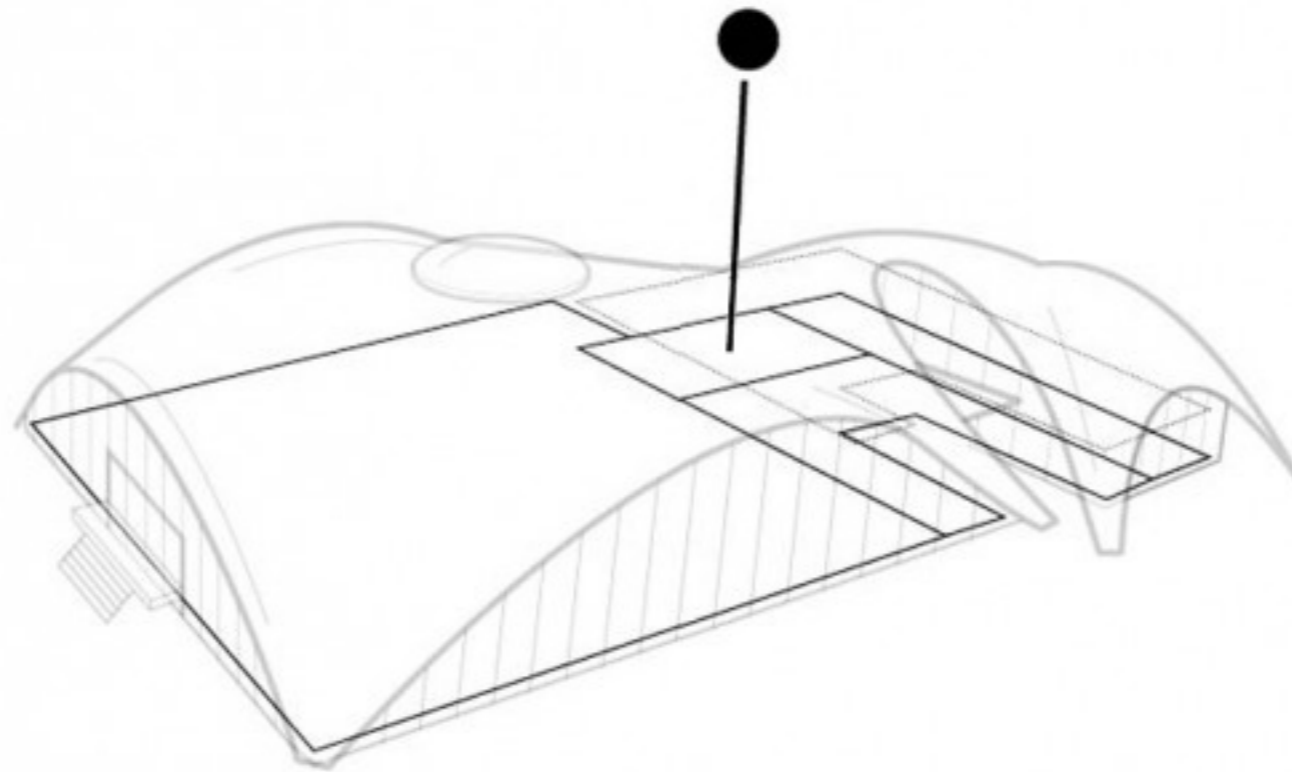




Pavillon Sicli, Geneve (H. Isler, C. Hilberer 1969)



Pavillon Sici, Geneve (H. Isler, C. Hilberer 1969)



Pavillon Sicli, perspective view+hanging models for form finding



Ice sculptures/hanging cloth models (H. Isler)

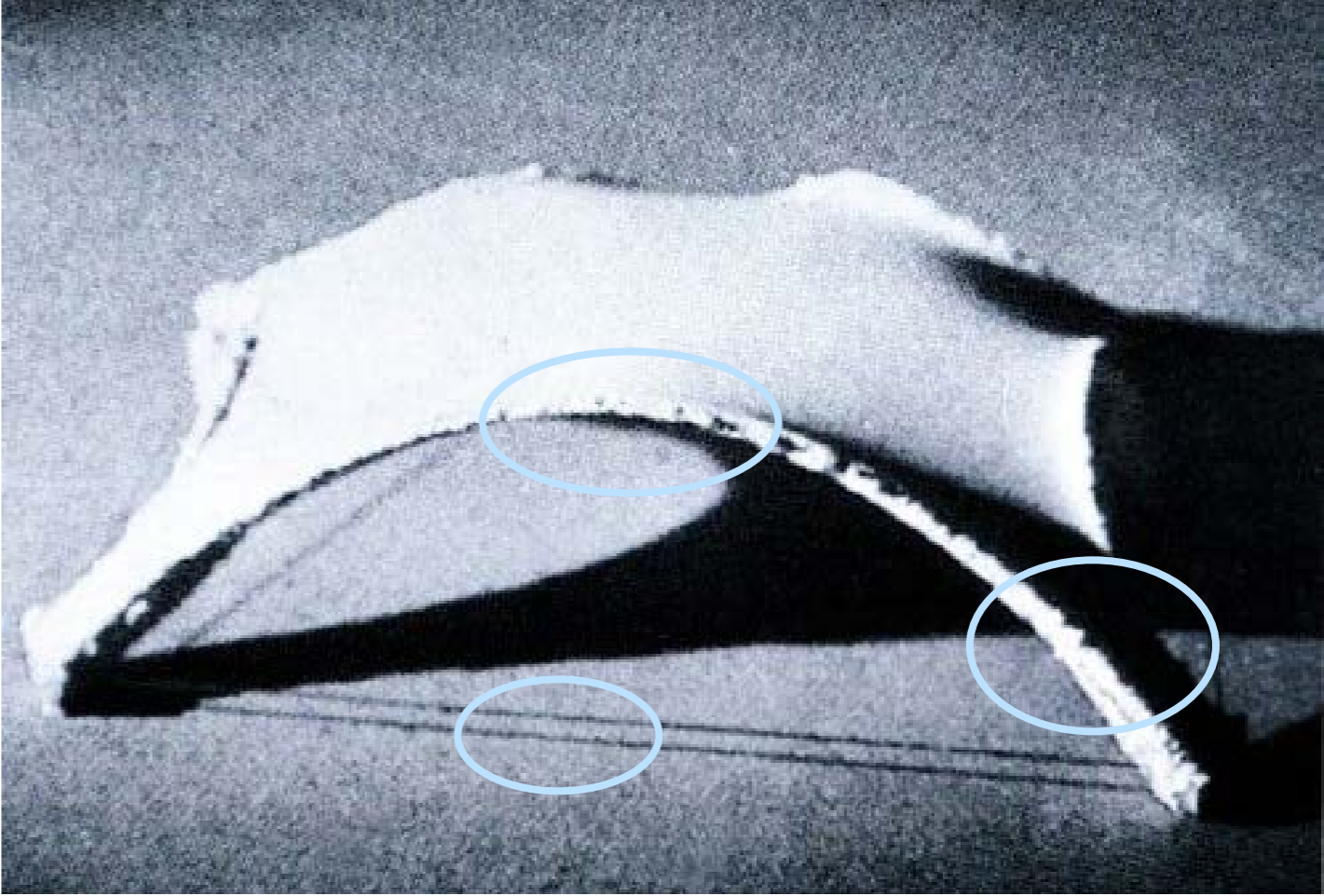


Pavillon Sicli, Model (H. Isler, 1958)



Naturtheater Grötzingen (H. Isler, M. Balz 1977)

**MODELLING
MATERIAL**



EDGE - BUCKLING

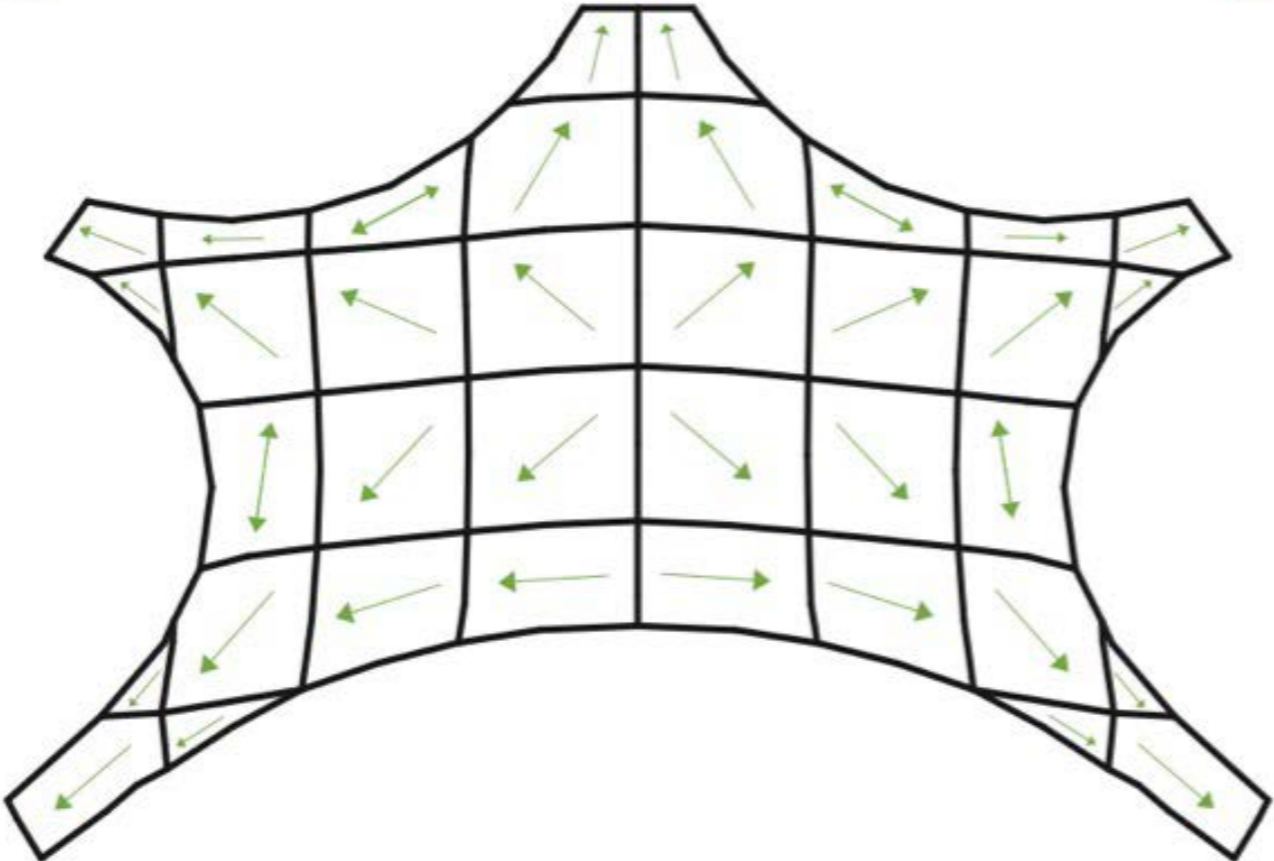
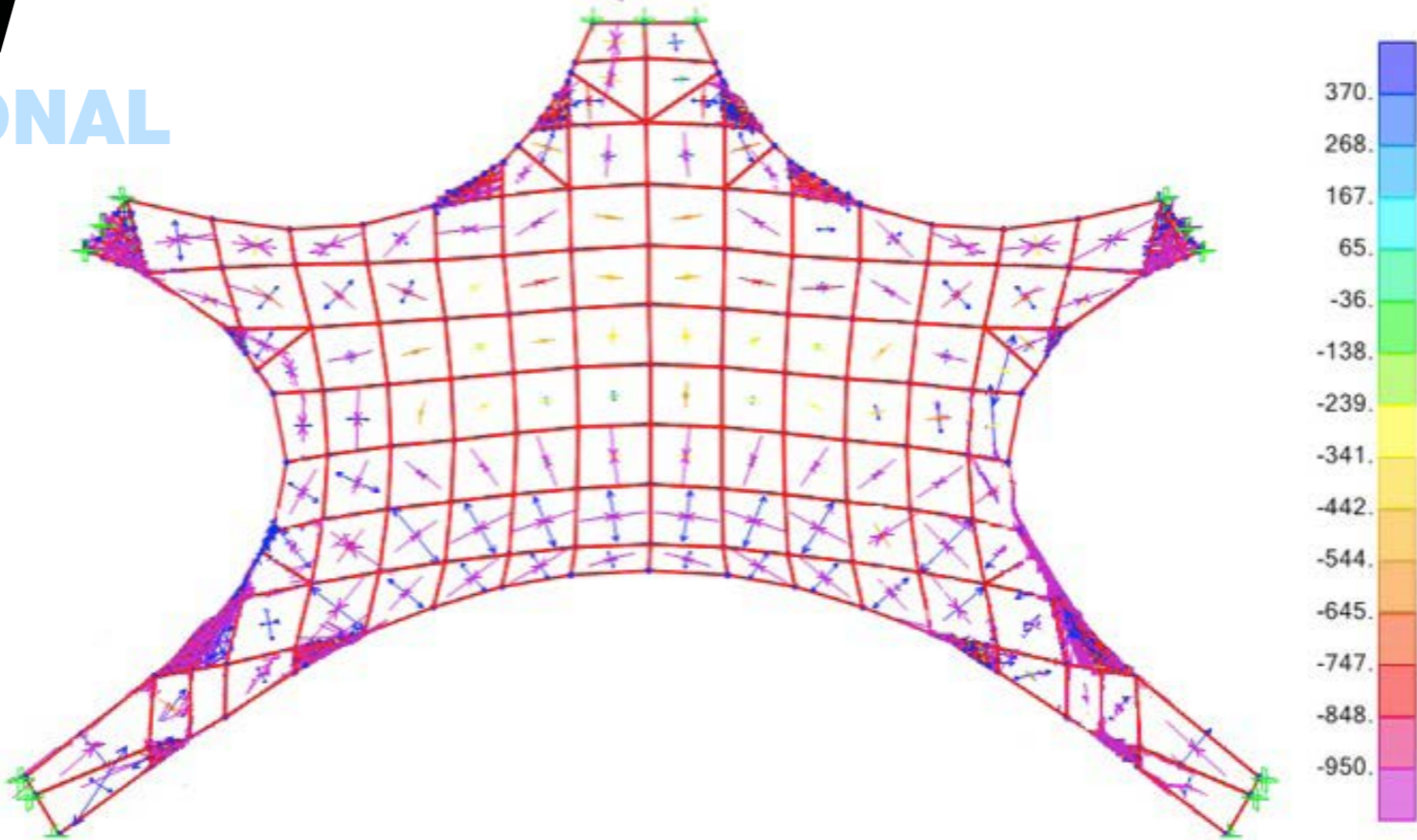
DOUBLE CURVATURE + STIFFNESS



Naturtheater Grötzingen, formwork edge + Garden centre, Wyss (H. Isler, 1961)

FORCE FLOW

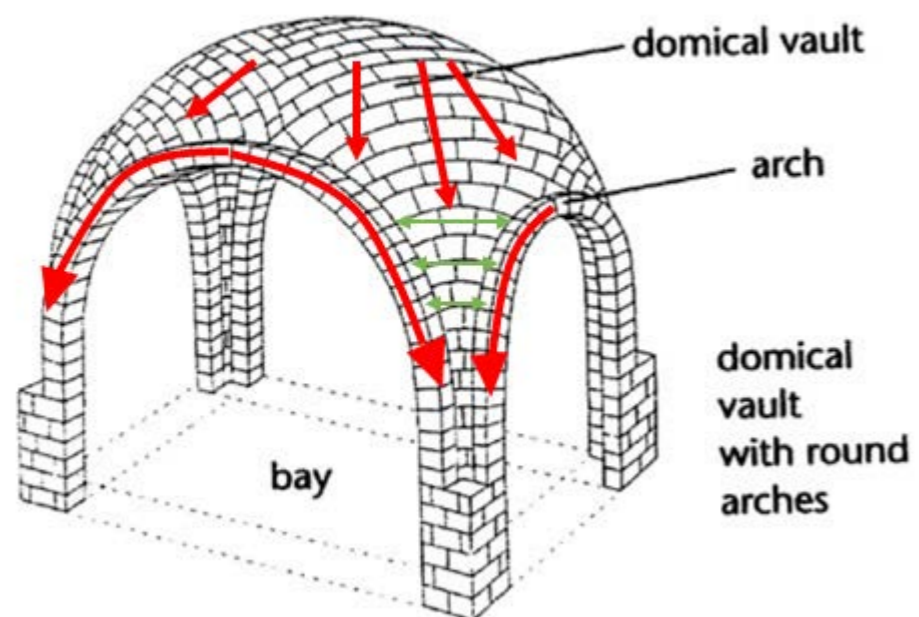
'TRANSLATIONAL SURFACE'



Naturtheater Grötzingen, force flow diagram

REINFORCEMENT

2-LAYER SYSTEM + SEMI-RIGID EDGE



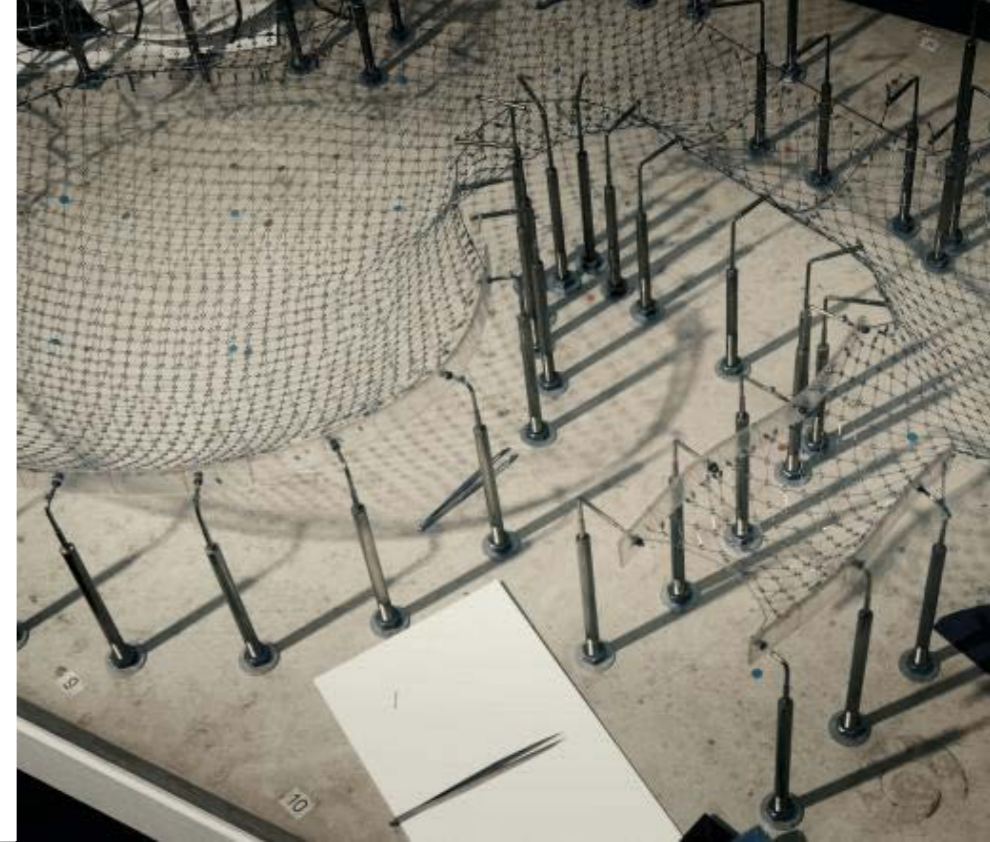
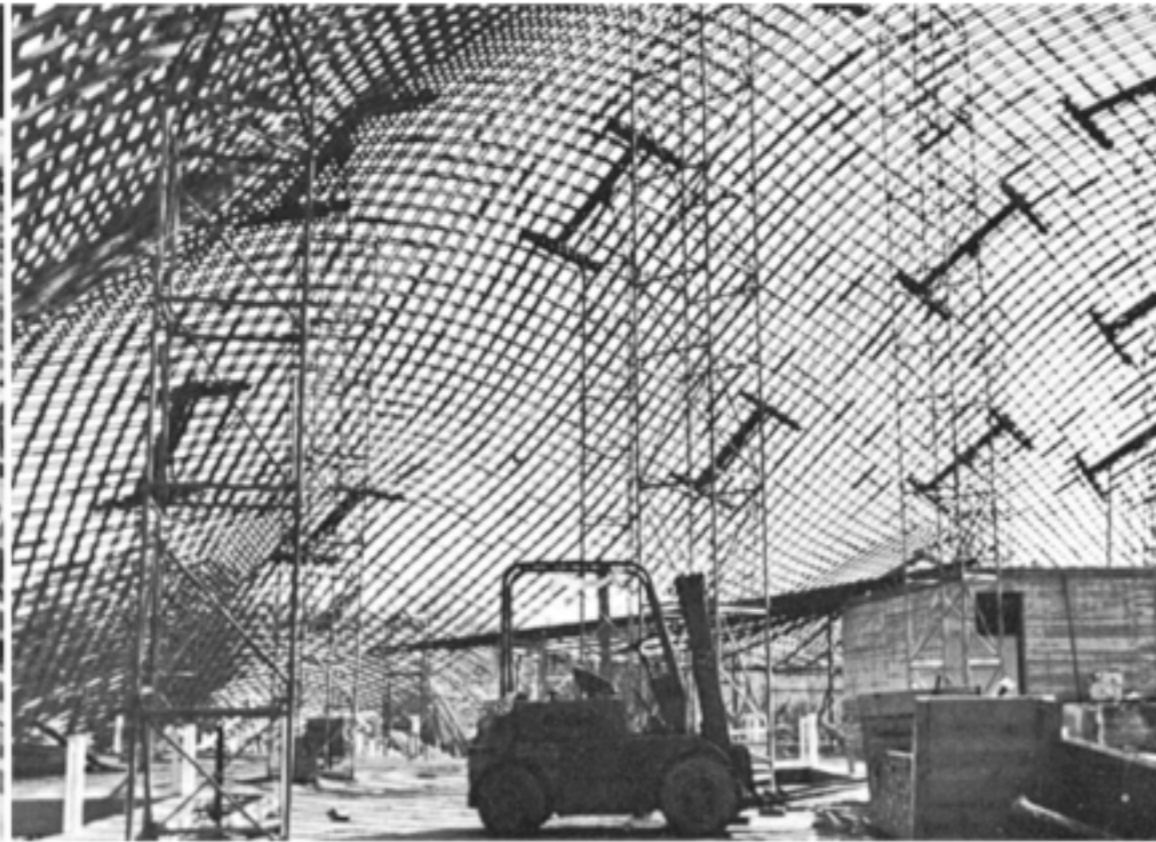
Naturtheater Grötzingen (H. Isler, M. Balz 1977)



Multihalle Mannheim (F. Otto, Mutschler+Langner, 1975)

OPTIMIZATION - POST-PROCESSING

STRESS DISTRIBUTION, CONSTRUCTION TECHNIQUE!!



SHELLS OF TODAY
SOURCES OF INSPIRATION



Droneport, Venice Biennale 2016 (Foster+Partners with BRG and MecocoConcept)



Armadillo Vault, Venice Biennale 2016 (BRG)



Gabinete de Arquitectura, Solano Benitez (Golden Lion) Venice Biennale 2016



Japan Pavilion, EXPO 2000, S. Ban, F. Otto+Buro Happold



Japan Pavilion, EXPO 2000, S. Ban, F. Otto+Buro Happold



Rolex Learning Centre, Lausanne (SANAA, SAPS, Bollinger & Grohmann et al. 2010



Rolex Learning Centre, Lausanne (SANAA, SAPS, Bollinger & Grohmann et al. 2000)



Rolex Learning Centre, Lausanne (SANAA, SAPS, Bollinger & Grohmann et al. 2000)



_IMPORT ZURICH

LOGEMENT COOPÉRATIF: NOUVELLES FORMES D'HABITER

Exposition du 22.09.2016 au 14.10.2016

**Pavillon Sicli, route des Acacias 45,
1227 Acacias. Genève.**



Open air theater, Opole, PL (Florian Jesionowski, 1963)



Summer theater, Szczecin, PL (Flanagan Lawrence, 2018)



Summer theater, Szczecin, PL (Flanagan Lawrence, 2018)

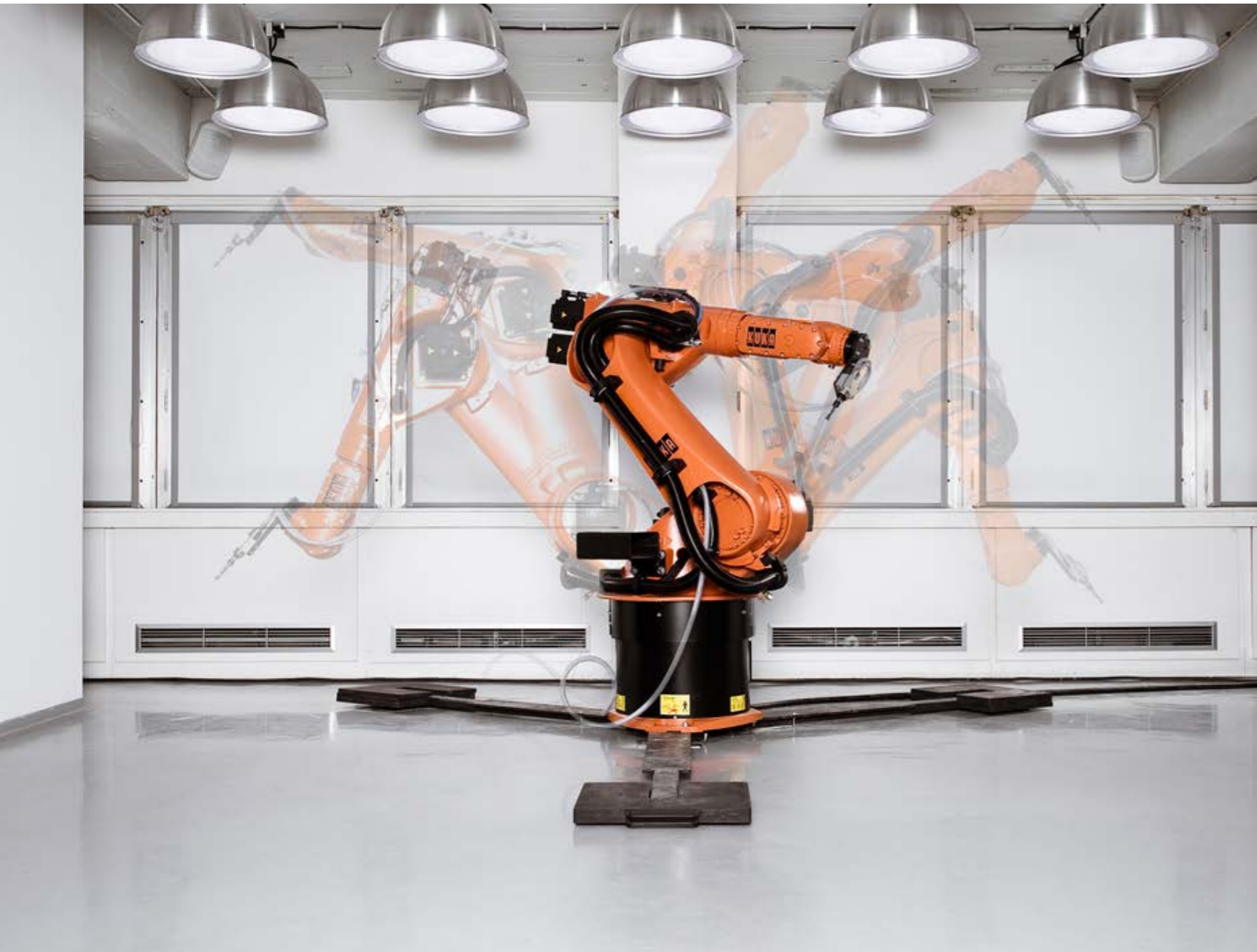


Acoustic Shells, Littlehampton, UK
(Flanagan Lawrence, 2014)

FORM FINDING
IN ACTION

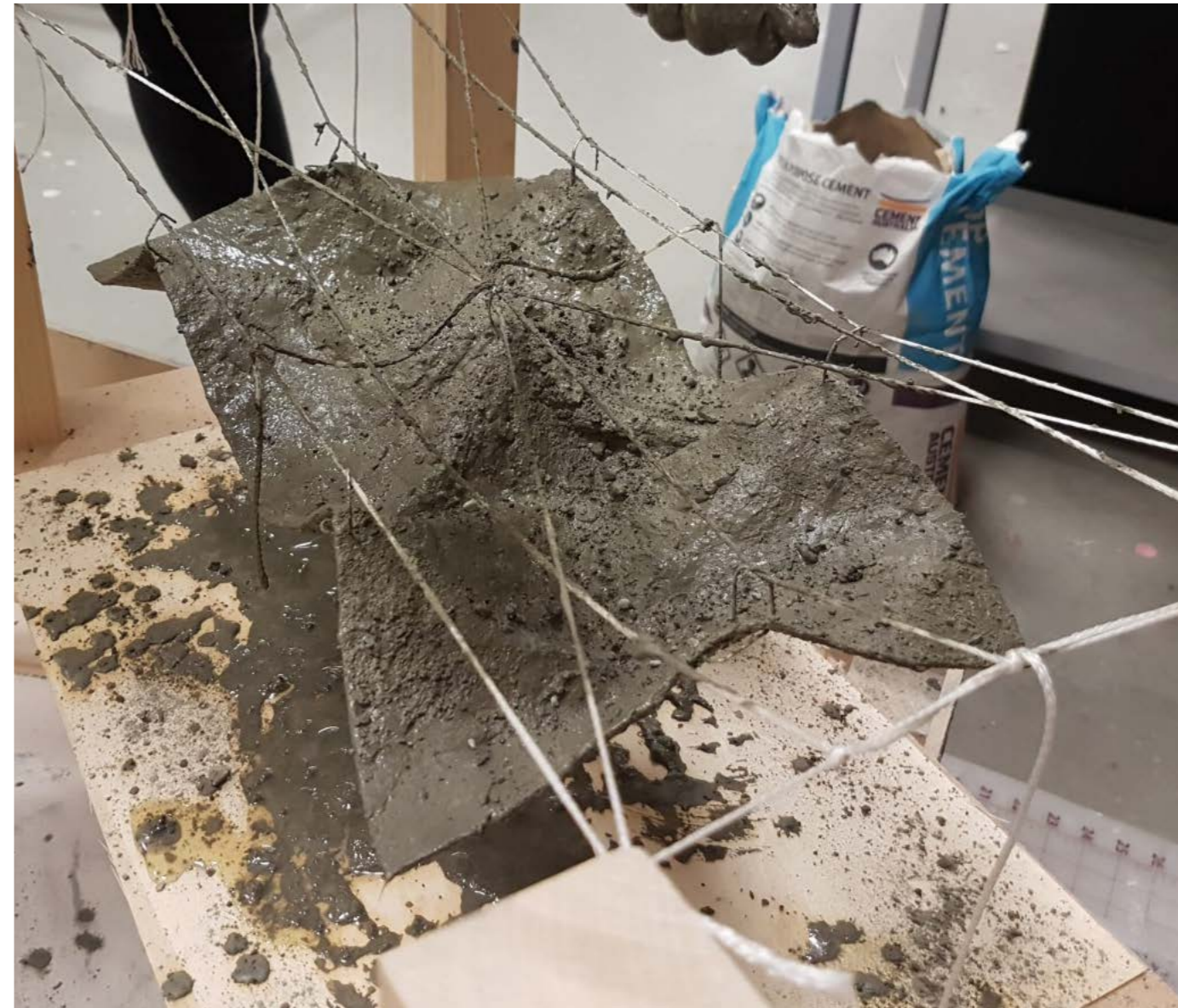
LIMITS

AVAILABLE RESOURCES



SUITABLE EQUIPMENT

MATERIALS, SUPPORTS

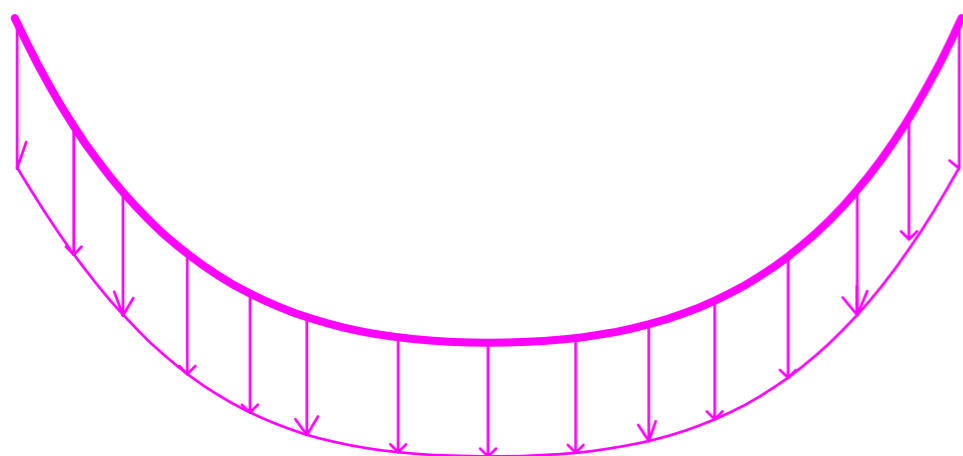


NOTE THE CRITICAL AREAS
BUCKLING!

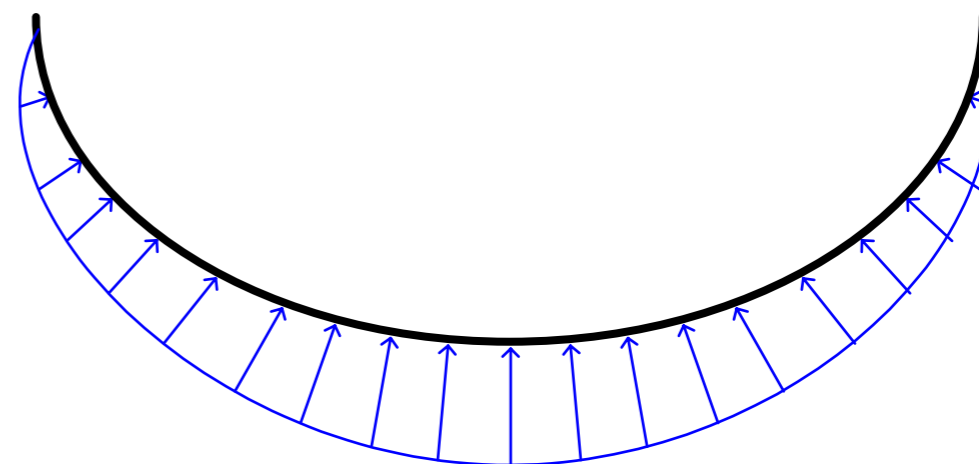


GOOD ENGINEERING SENSE

STATICS - ADAPTIVE GEOMETRY



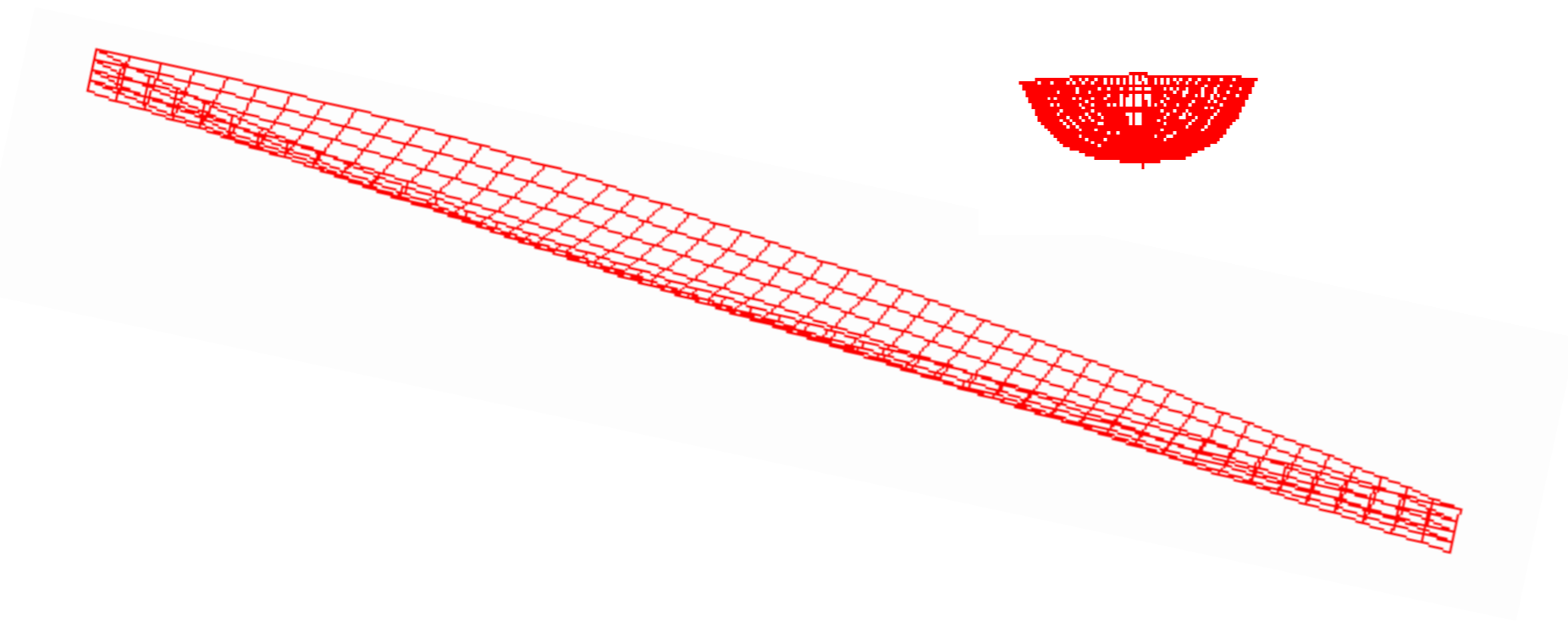
a) dead load - catenary (2D)



b) hidrostatic load (3D)

MEASURING THE MODEL

3D SCAN

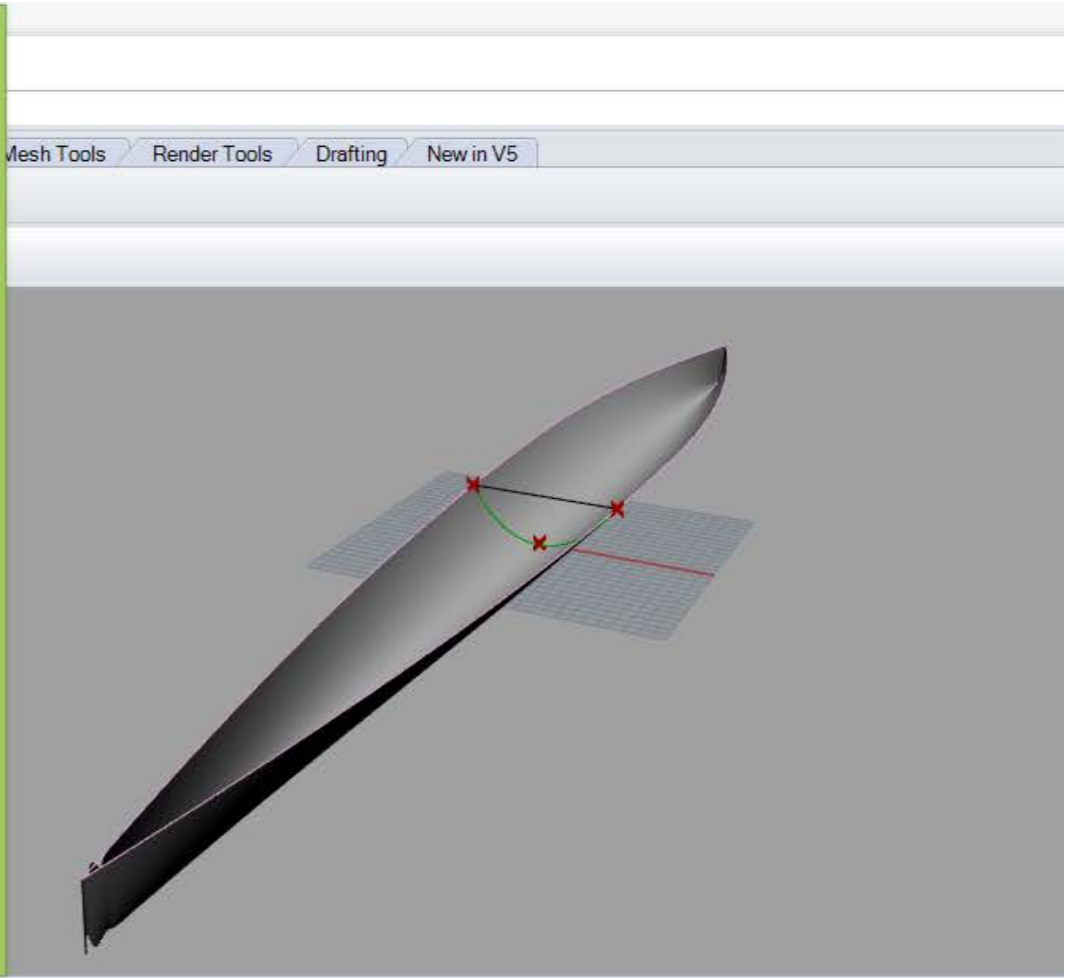


3D ZEPHYR,
SCANN3D
MEASURE 3D

REFINING YOUR MODEL - OPTIMIZATION, POST-PROCESSING

SMOOTHING, STRESS-DISTRIBUTION EVALUATION

The image shows the Grasshopper 3D software interface. The main workspace contains a workflow for creating a catenary curve. It starts with three 'Pt' (Point) components connected to 'startPt', 'midPt', and 'endPt' inputs of a 'C#' component. The 'C#' component is connected to an 'IntCrv' (Intersect Curve) component, which is then connected to a 'Crv' (Curve) component. A yellow box displays the equation for the catenary curve:
$$z = 300.07 * \cosh(x + 0.00) / 300.07 + -281.58$$
 and
$$z = 22.96 * \cosh(x + 0.00) / 22.96 + -25.51$$
. The 'Equation (2d)' component also shows iteration logs: '1 took 40 iterations solve', '2 18.4991252818074 error', '3 took 33 iterations solve', and '4 -2.5574277814312 error'. Below the workflow are sliders for 'Control points' (set to 11), 'Iterations' (set to 15), and 'Tolerance' (set to 0.0250). The status bar at the bottom indicates 'essfully completed... (160 seconds ago)' and '0.9.0076'.



The image shows the 2D orthographic views of the catenary curve. The 'Front' view shows a semi-elliptical curve with control points and a grid. The 'Right' view shows a long, thin, curved object with a grid. The 'Perspective' view shows the object from a 3D angle. The status bar at the bottom indicates 'Plane x 150.182 v 37.053 z 0.000 Millimeters Default Grid Snap Ortho Planar Osnap SmartTrack Gumball Record History Filter Minutes from last save: 1'.

Interestingly a structure that defines a new trend is always based on an idea of a more efficient solution. Any trend has followers.

There are two types: one is about to solely imitate the form, which was originally an adequate answer to a specific problem. The result is a structure, that formally closely resembles the original – not completely, since there was a natural desire in the designer to be original - but lacks its meaning, hence it becomes superfluous and even formally incomplete. The other designer understands and re-evaluates the original setting and implements it according to the given circumstances. The thus created structures are not only efficient, but without any further effort they take on a new and aesthetical form.

The first type of followers end up imitating by trying to avoid it, while the others take pleasure in following a good lead, and by doing so, end up creating something unique.

(József Pelikán, MÉI 1964)

THANK YOU FOR YOUR ATTENTION!

gaspar@szt.bme.hu
www.szt.bme.hu

Szilárdságtani és
Tartószerkezeti Tanszék
*Department of
Mechanics, Materials and Structures*

