11 february 2010

Experimental structures

Flexible Hybrids

Marine Bagnéris

LMGC

STRUCTURES LÉGÈRES POUR L'ARCHITECTURE

Outline

- Shape classification
  - Design process of flexible shapes
    - Complexity vs complication
- New paradigms in the design process through interoperability
  - New materiality through numerical tools
    - More suitable geometrical models
    - More suitable mechanical models
    - “From file to factory” (Oosterhuis)

Flexible_Geometrically constrained

- Need of new design tools dedicated to architectural applications

  - Catia, Maya, Blender etc designed by other industries

  - We are limited to build what can be communicated

Jeongok Prehistoric museum – Nox – South Corea – 2005

- Need of new design tools dedicated to architectural applications

  - Catia, Maya, Blender etc designed by other industries
  - We are limited to build what can be communicated
  - Back to geometry through parametrical approach

    Architectural geometry

    Grasshopper

    Generative Components
  - Algorithmic approach to structure our mental representation

- Algorithmic approach used as a language

  - Cecil Balmond & Arup Advanced Geometry Unit

    "The informal is neither random nor arbitrary (…). 'Chaos' is thus a succession of several orders, quite different from the idea of trapping the arbitrary and calling it order."

Portuguese Pavilion Expo 2000 – Alvaro Siza -Germany 2000

- Algorithmic approach used as a language

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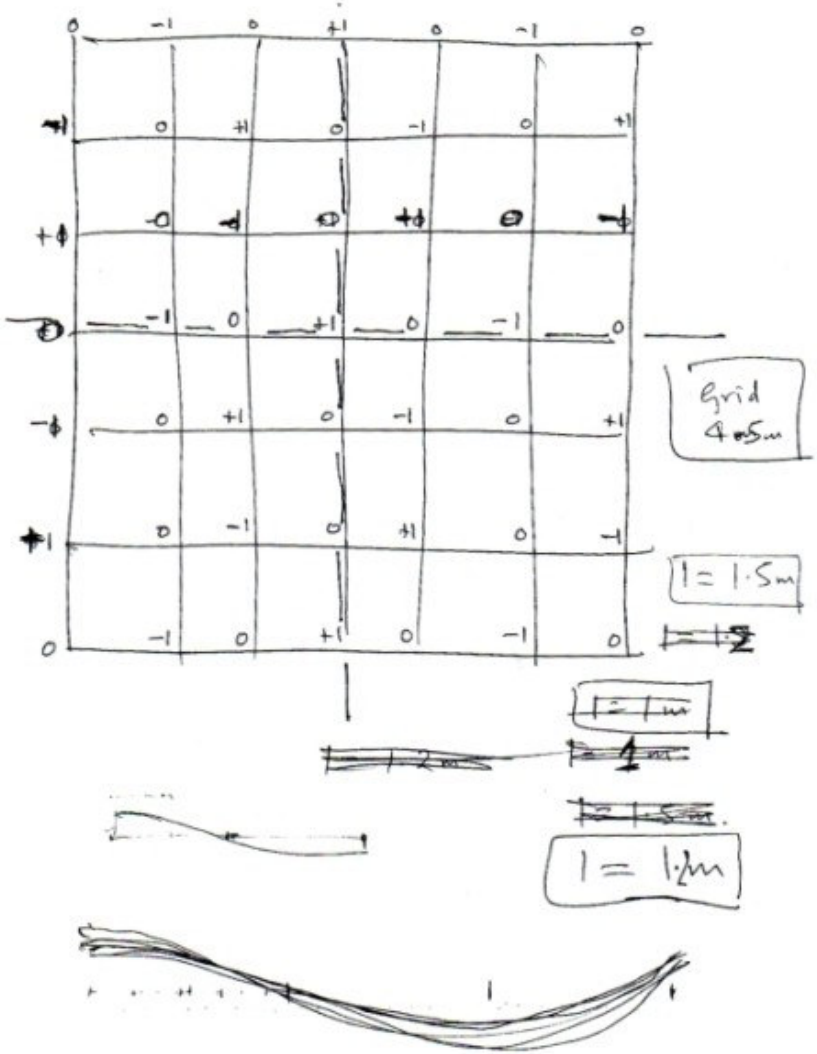

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Serpentine Gallery Pavilion – Toyo Ito –UK - 2002

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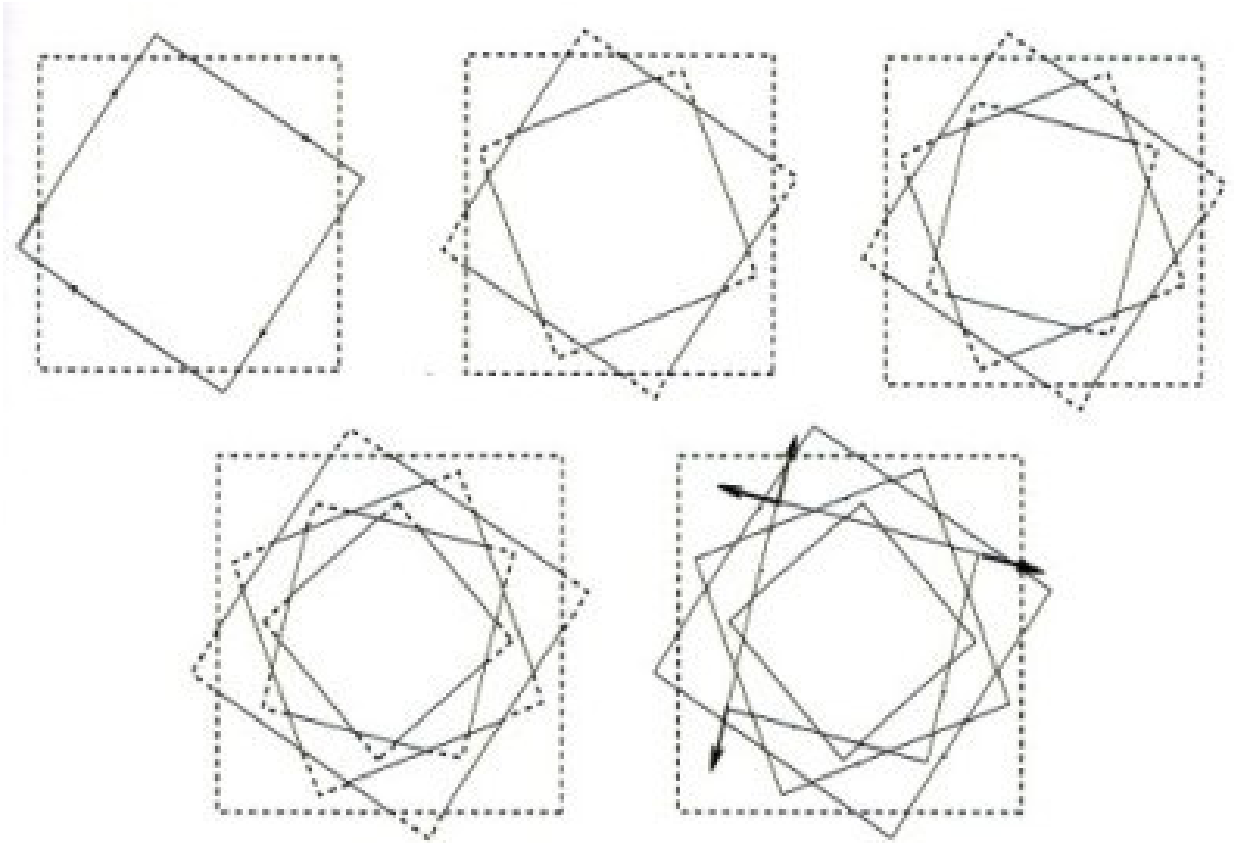

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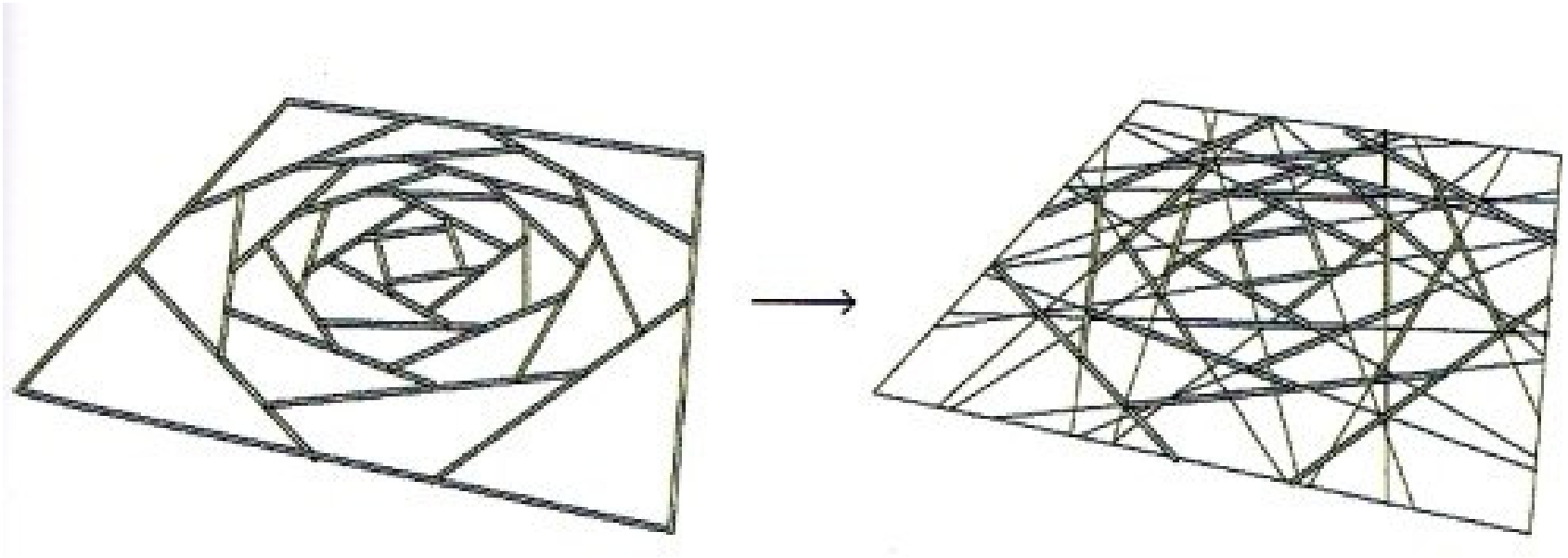


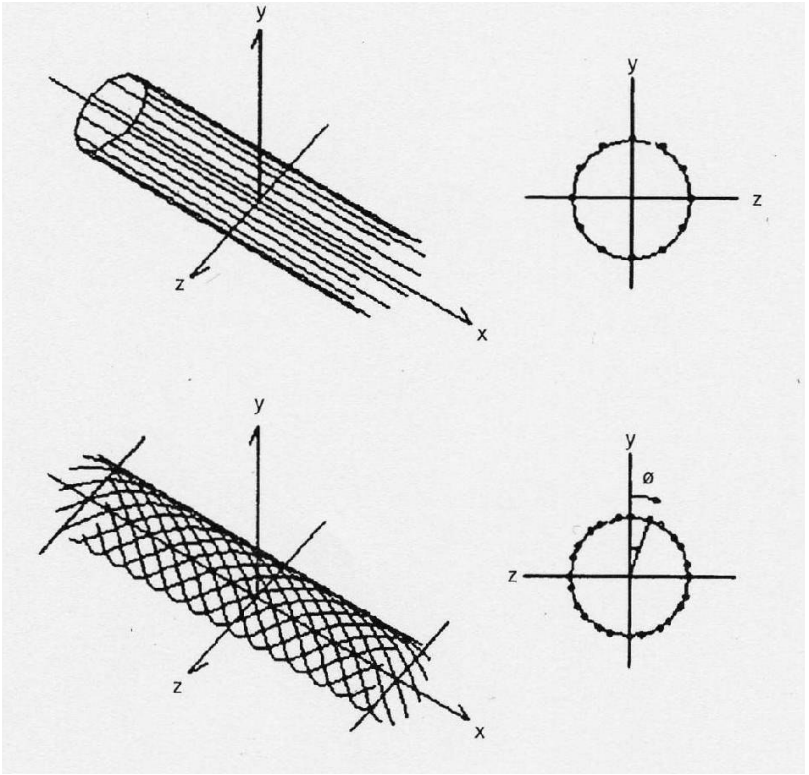
- Algorithmic approach & parametrics

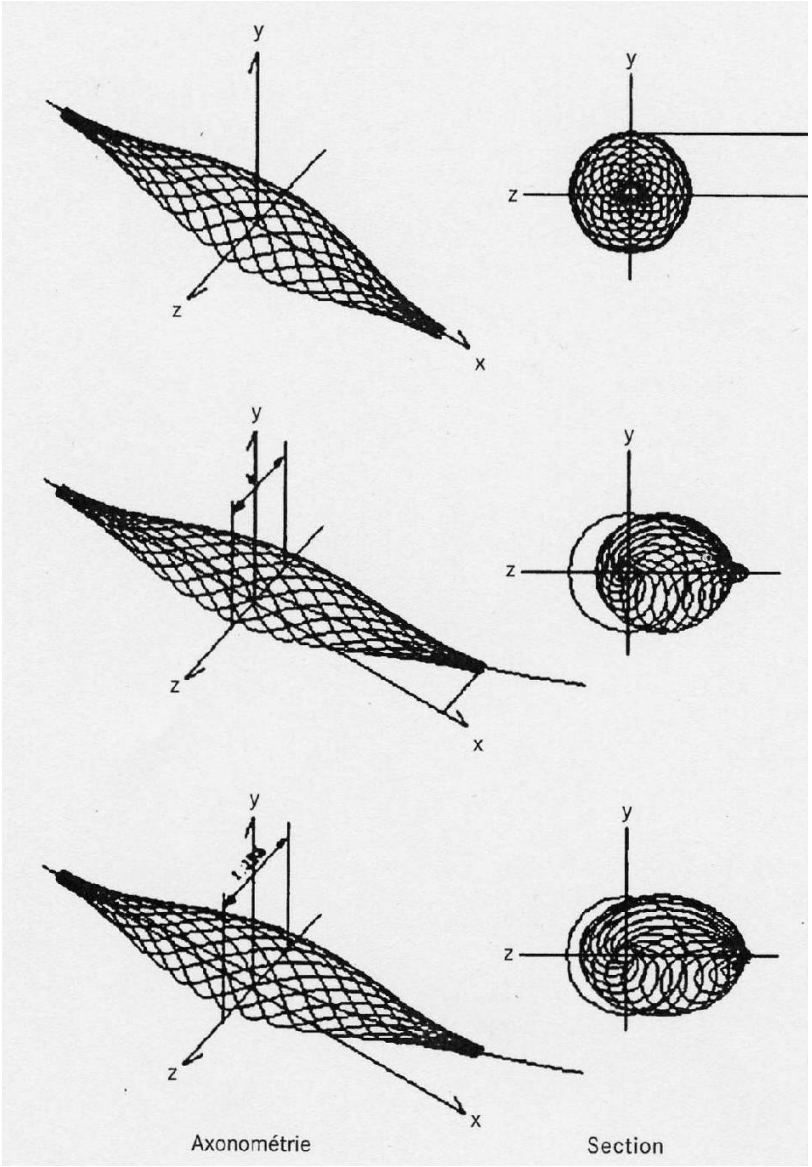
  - Toyo Ito & Sasaki

Parque de Relaxation – Toyo Ito – Spain – 2006

- Algorithmic approach & parametrics

  - Toyo Ito & Sasaki





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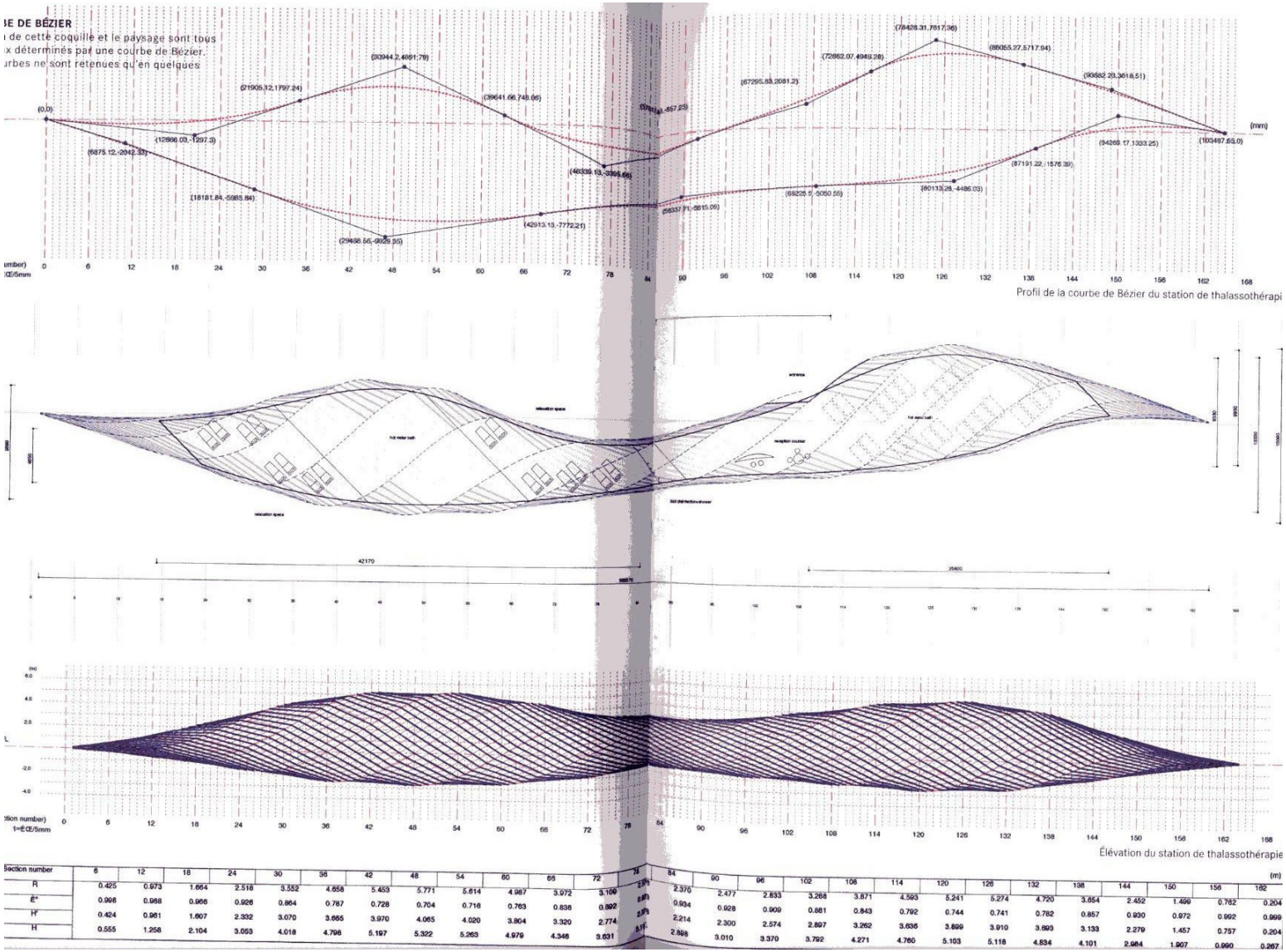

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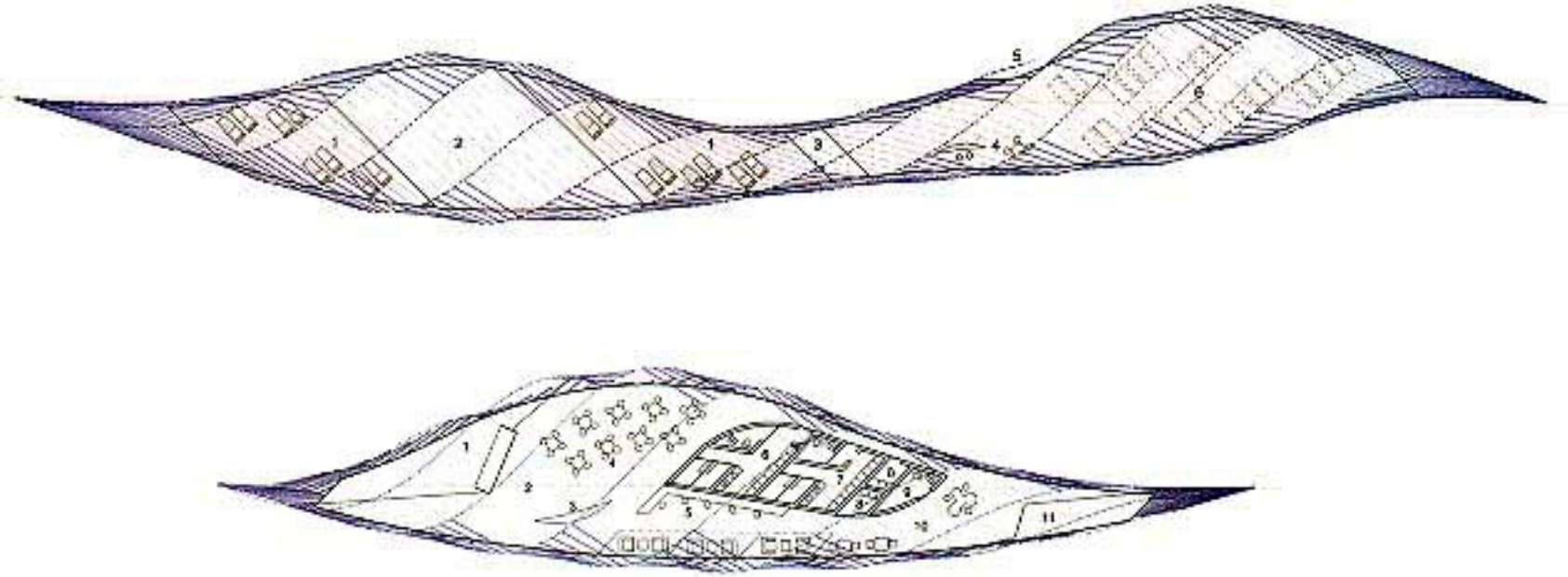

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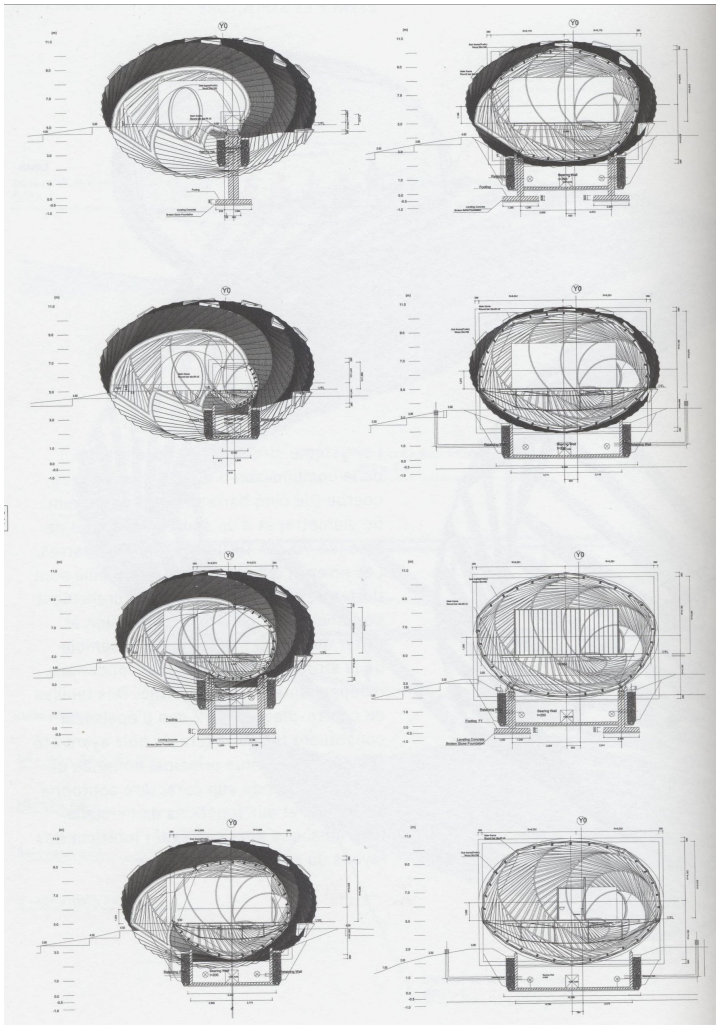

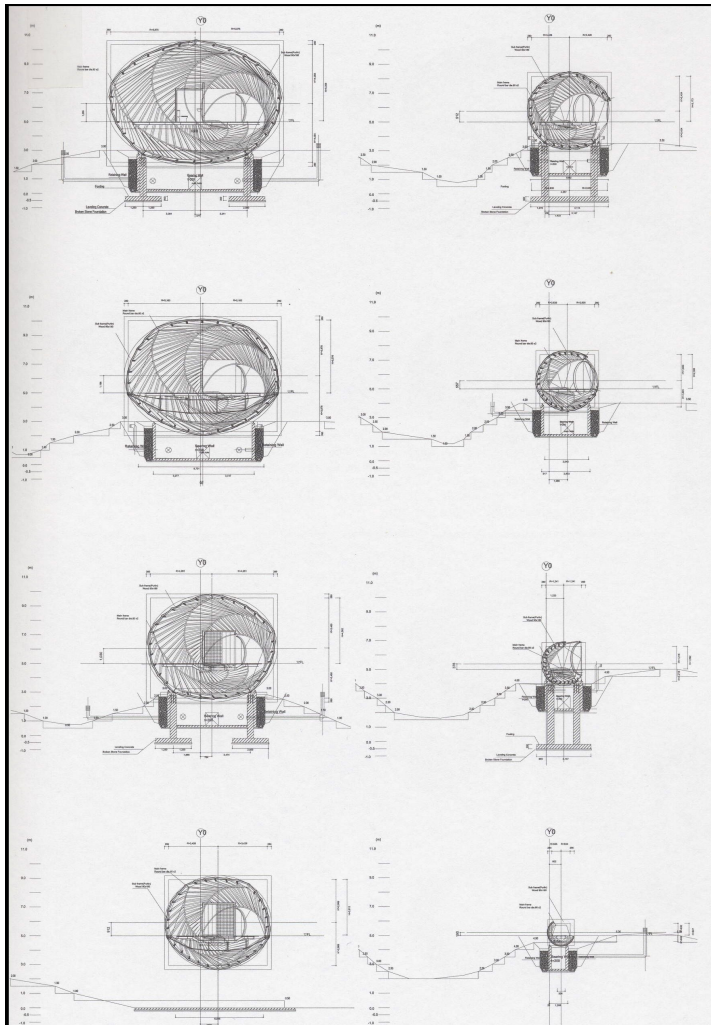

Parque de Relaxation – Toyo Ito – Spain – 2006

Flexible_Geometrically constrained

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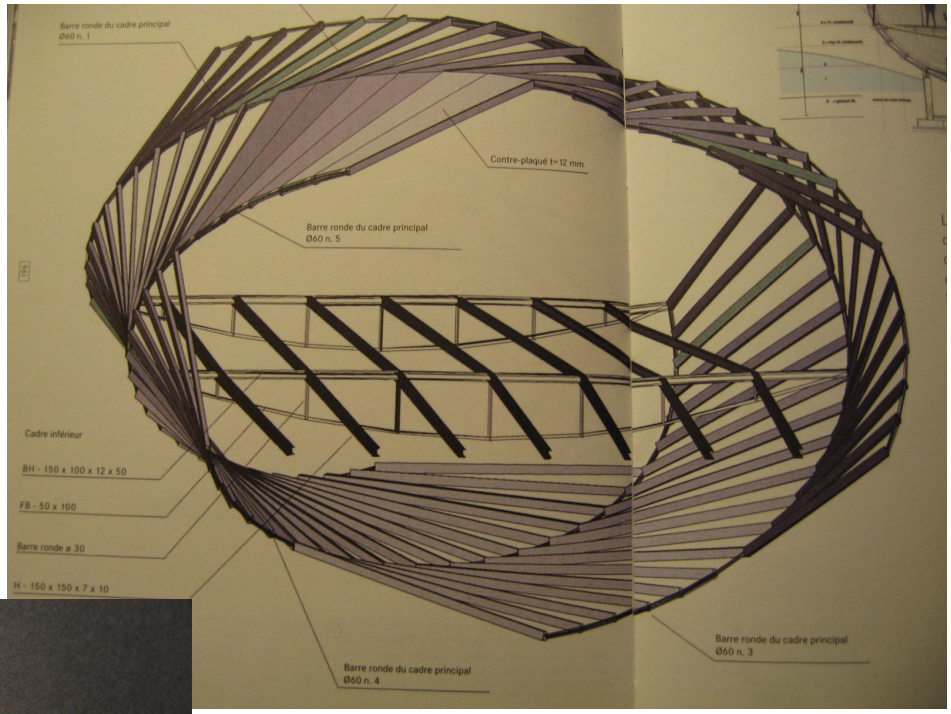

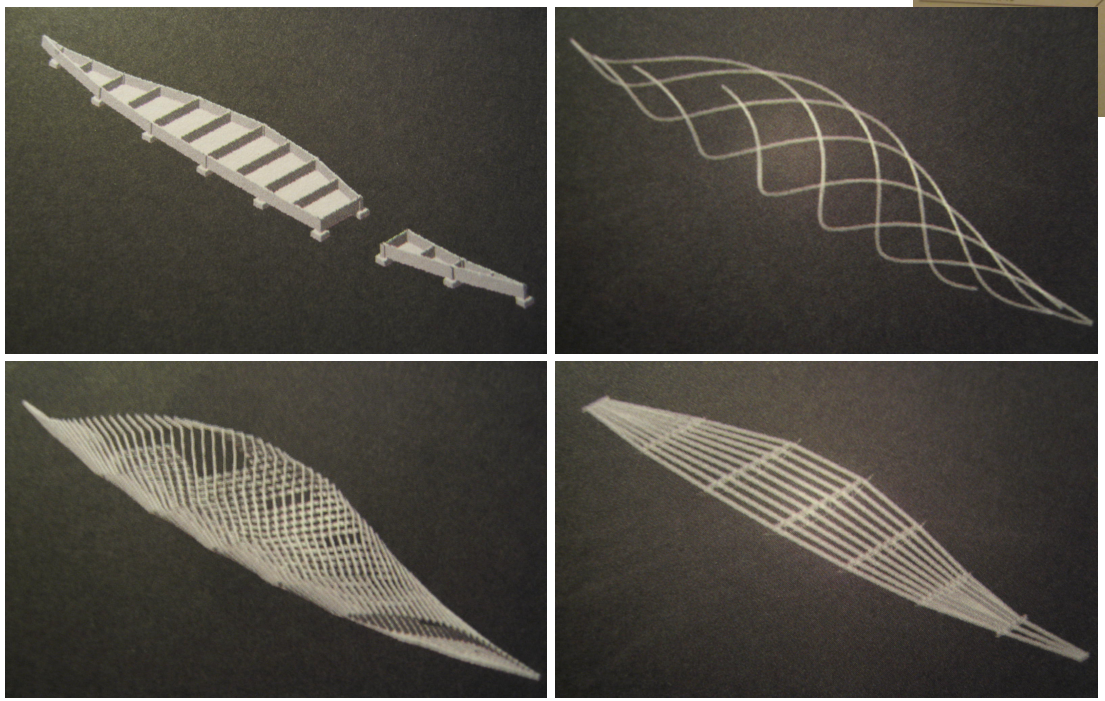

Parque de Relaxation – Toyo Ito – Spain – 2006

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Parque de Relaxation – Toyo Ito – Spain – 2006

- Architectural geometry

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Taichung Opera Metropolitan – Toyo Ito –UK – 2005-2009

- Architectural geometry

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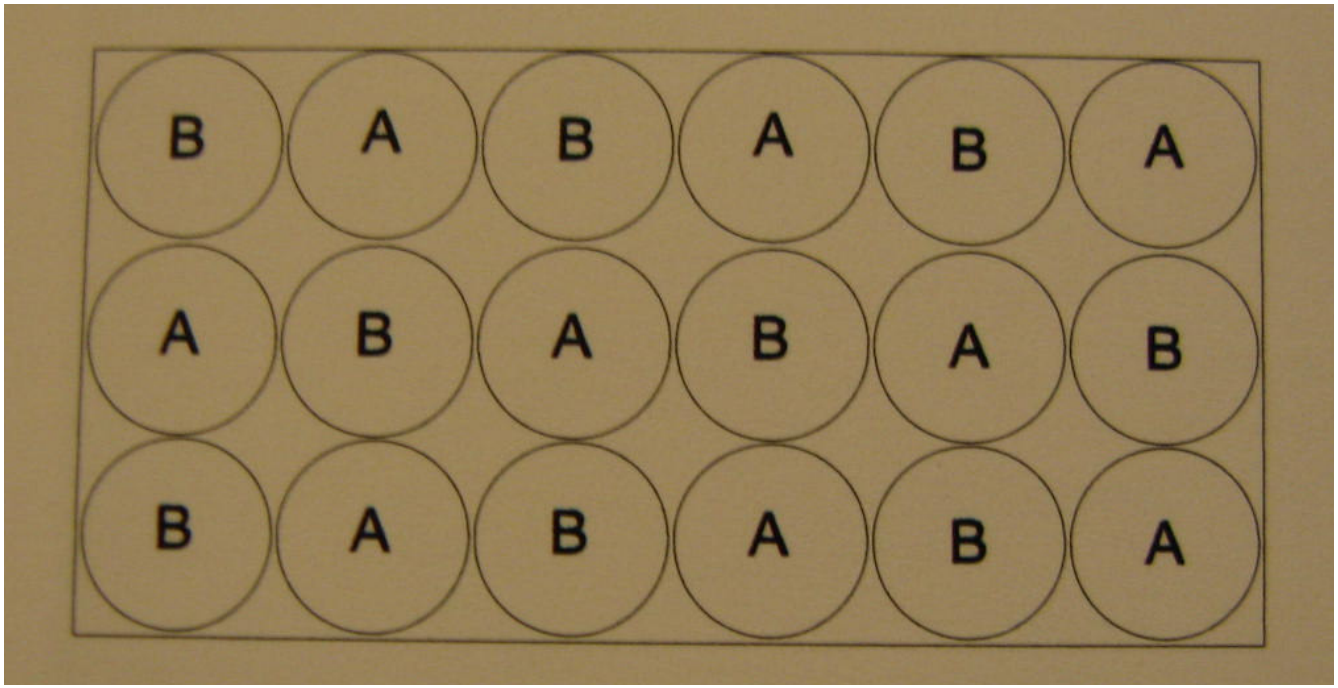

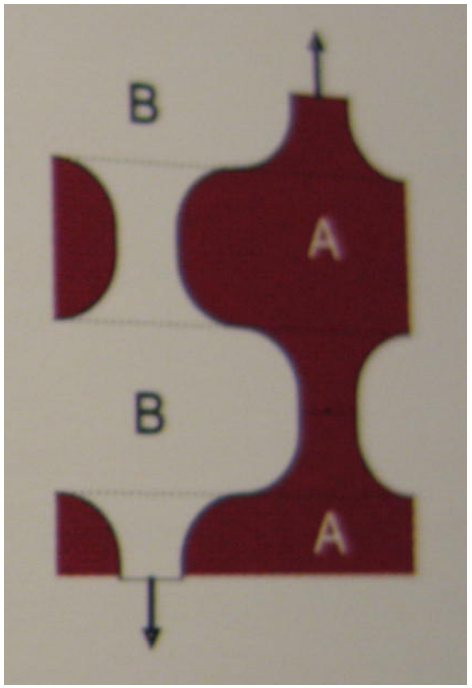

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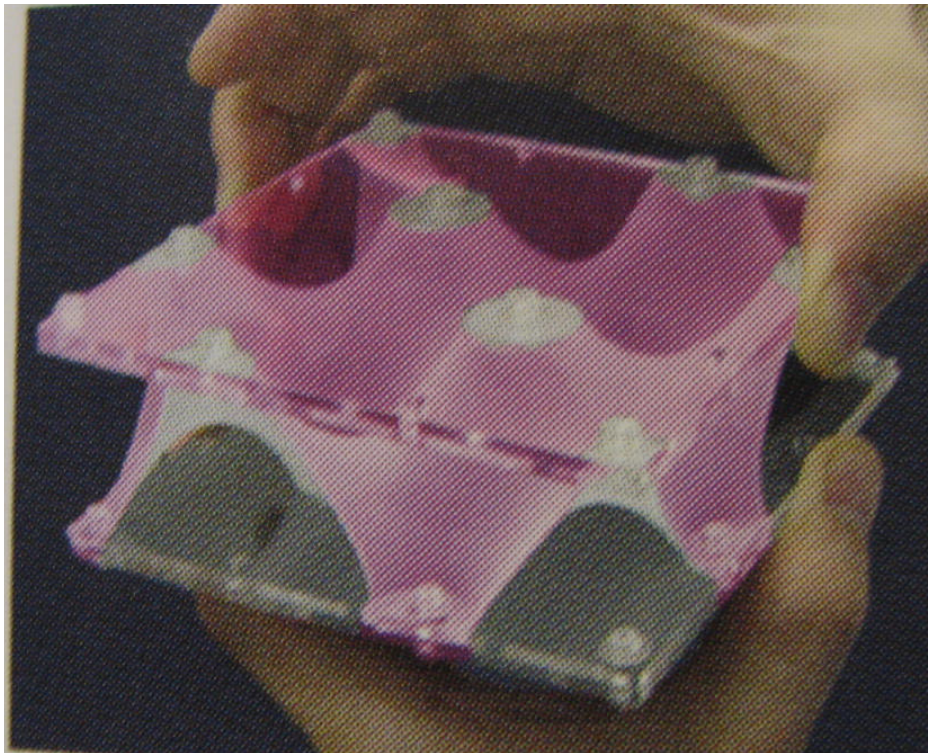

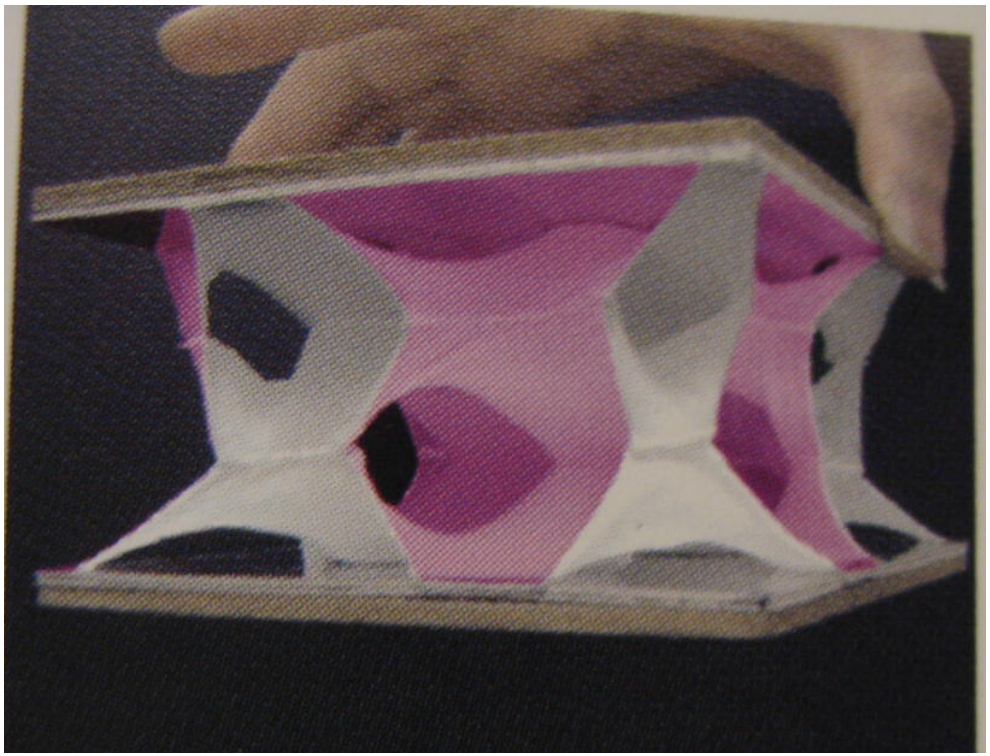

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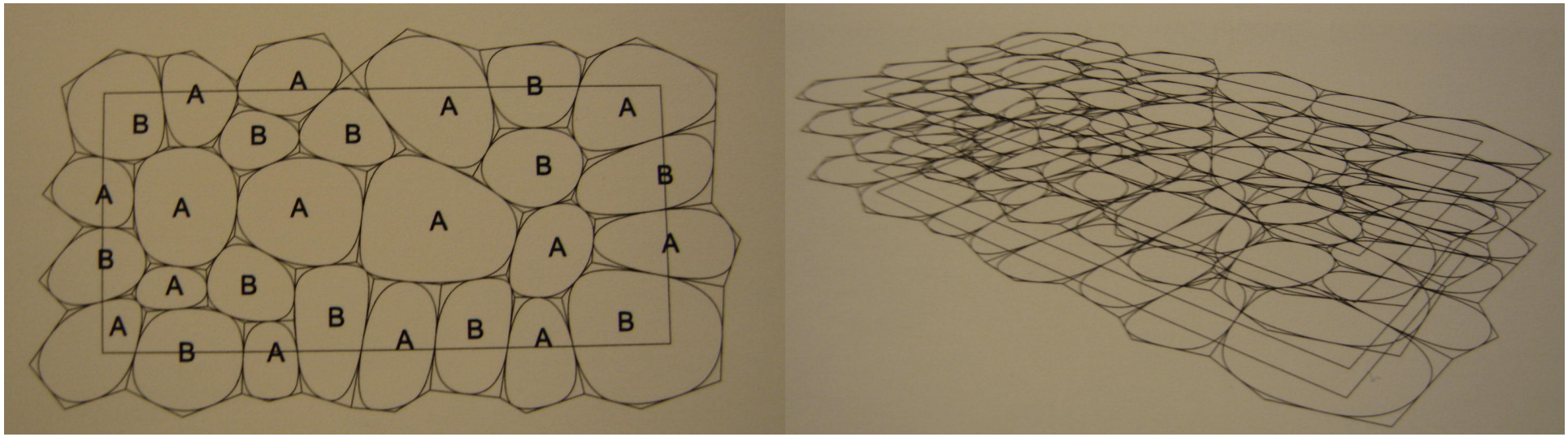

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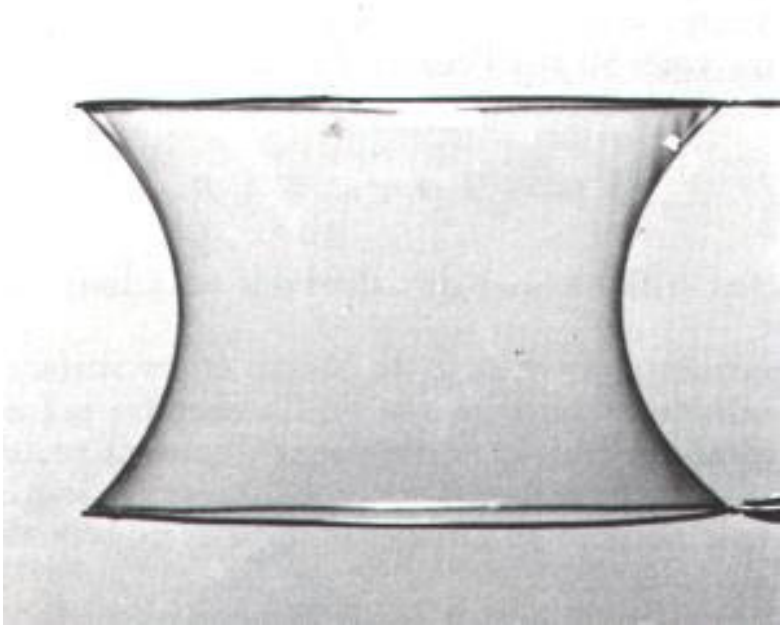
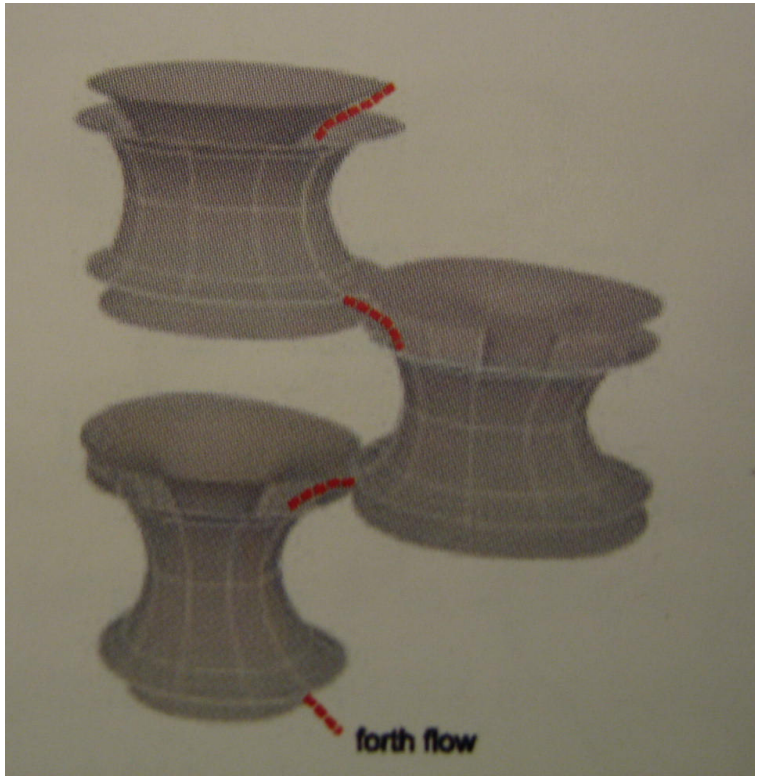
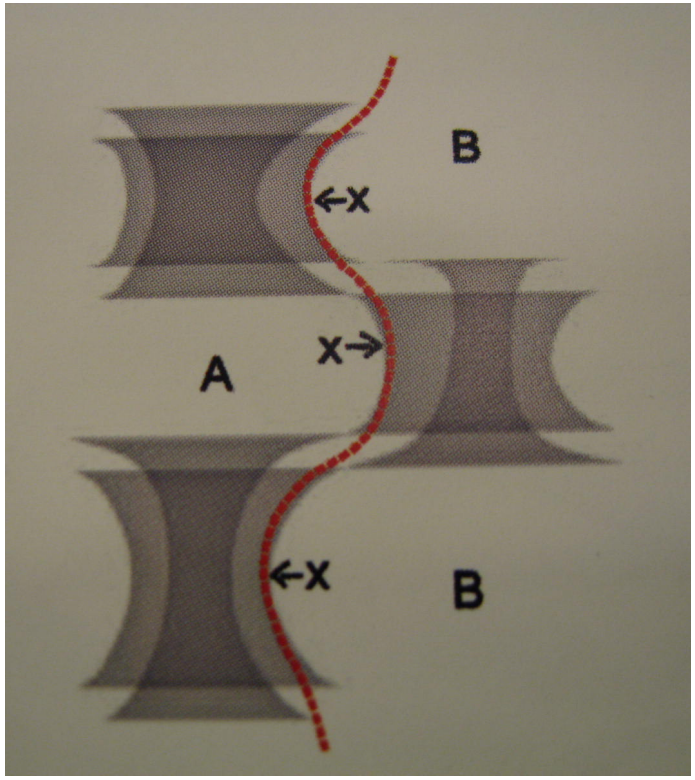


Catenoid – Minimal Surface

- Architectural geometry

  - Cecil Balmond & Arup Advanced Geometry Unit





Degenerated “Catenoid” composition

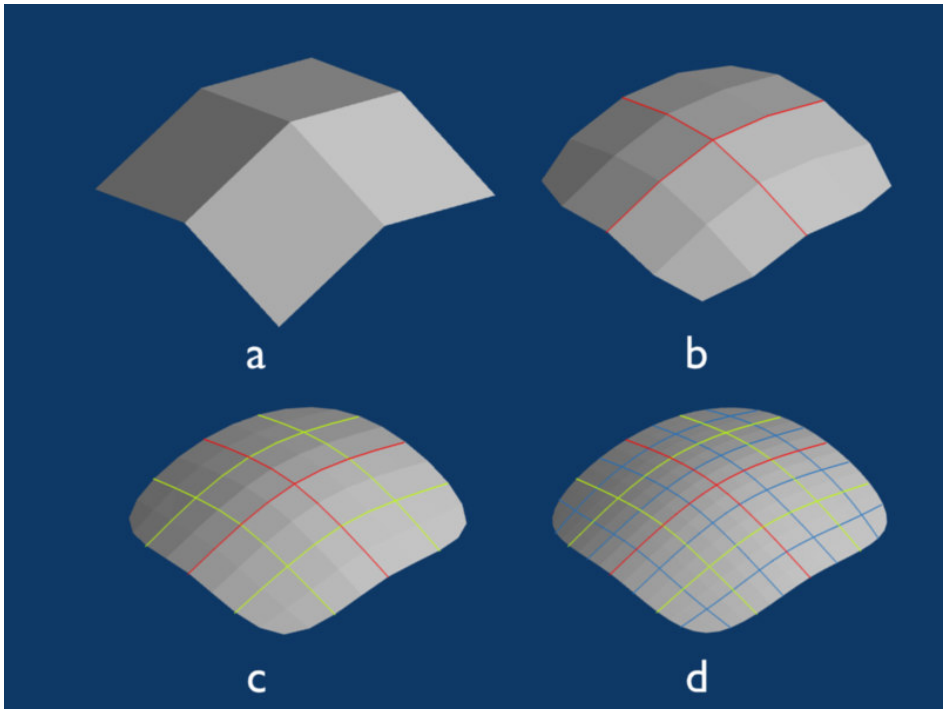
- Architectural geometry

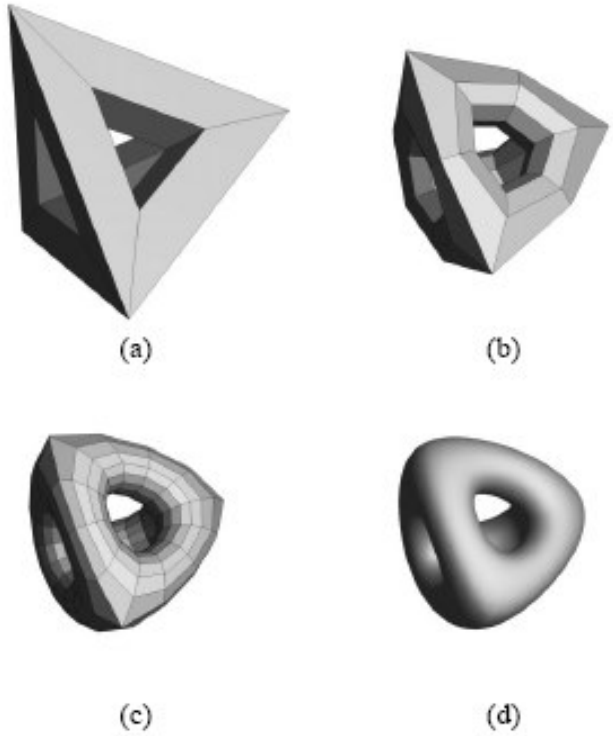
  - Cecil Balmond & Arup Advanced Geometry Unit

Taichung Opera Metropolitan – Toyo Ito –UK – 2005-2009

- Architectural geometry

  - Subdivision surfaces – Catmull-Clark algorithm

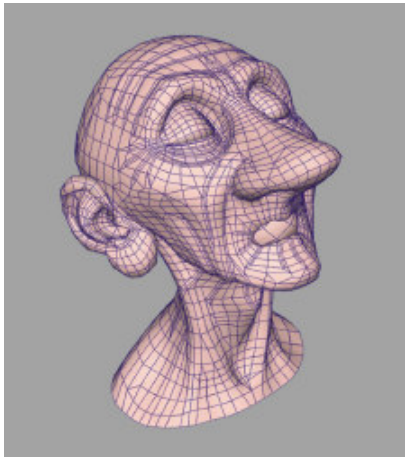




Catmull-Clark subdivision

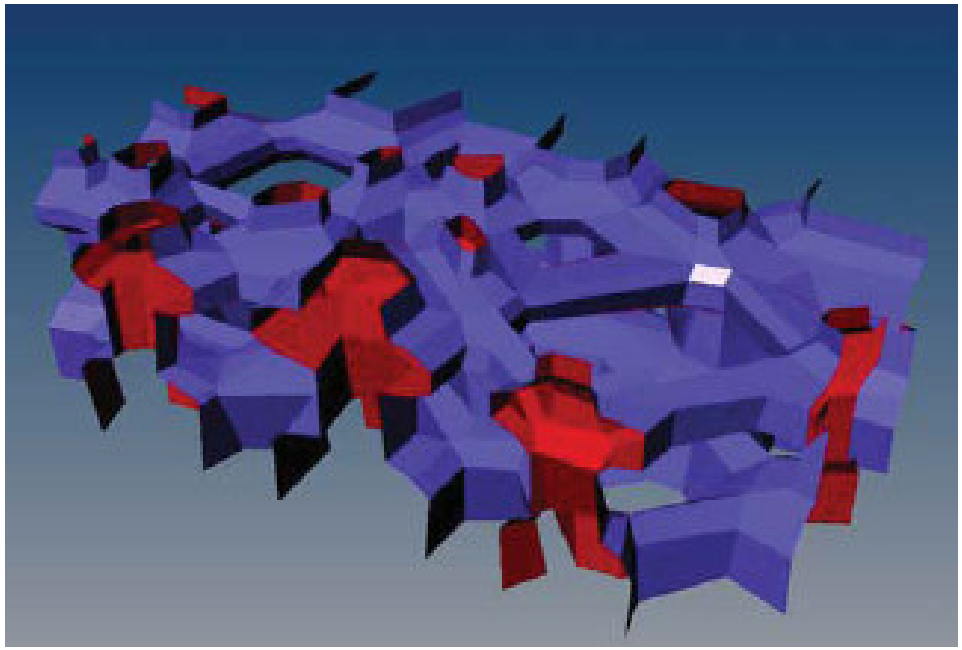
Flexible_Geometrically constrained

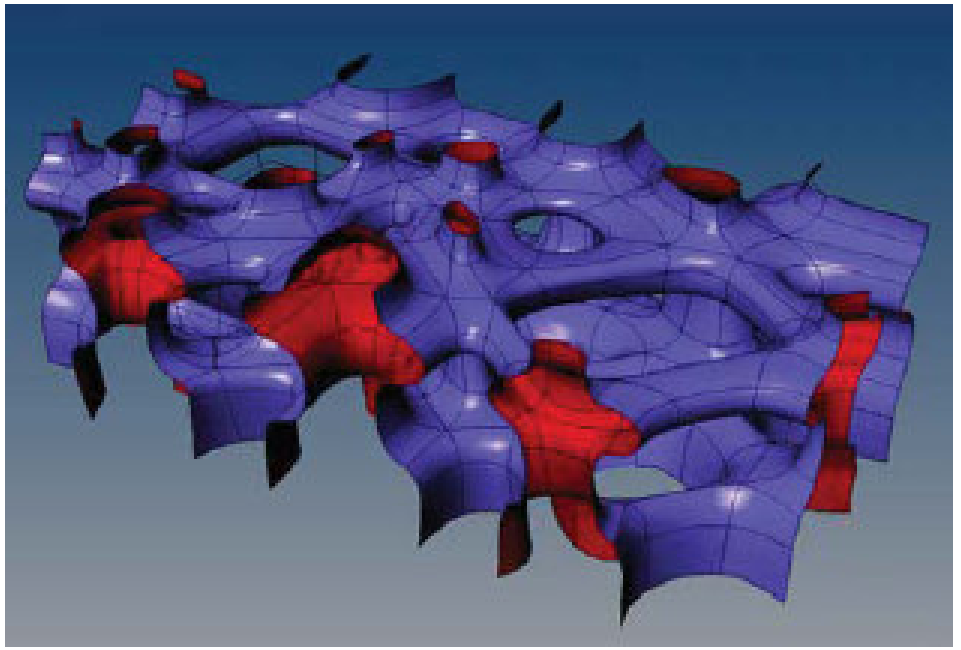
- Algorithmic approach used as a language
  - Subdivision surfaces – Catmull-Clark algorithm



- Architectural geometry

  - Subdivision surfaces – Catmull-clark Scheme





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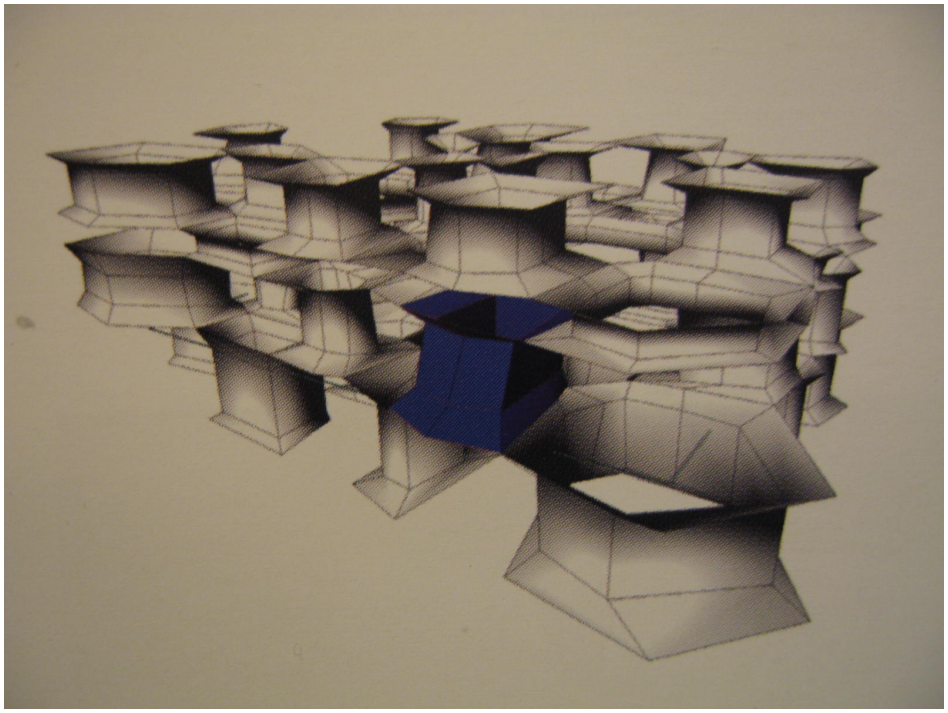

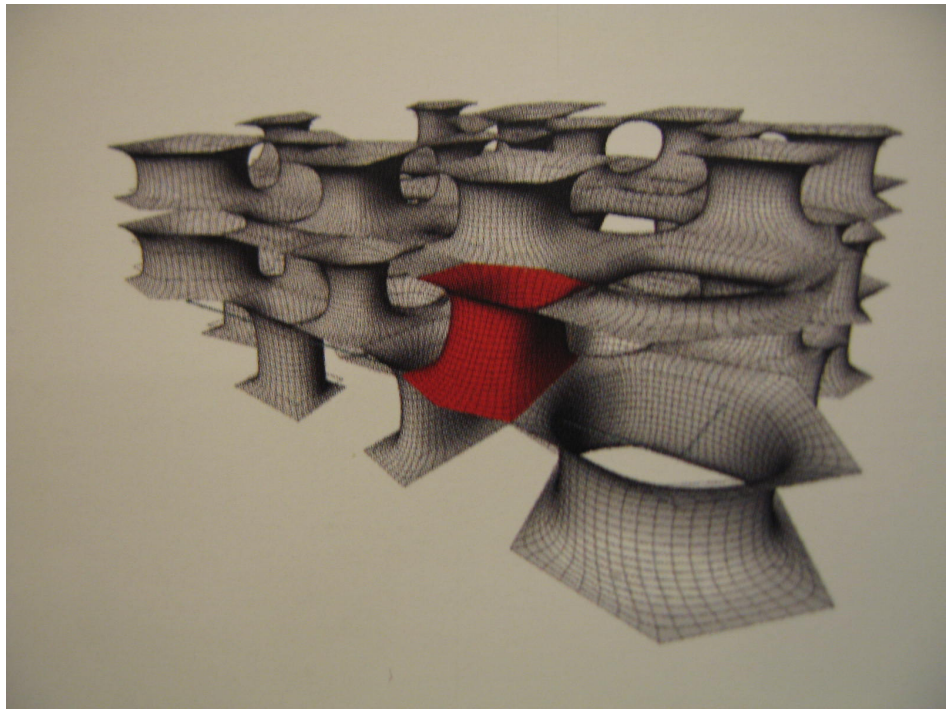

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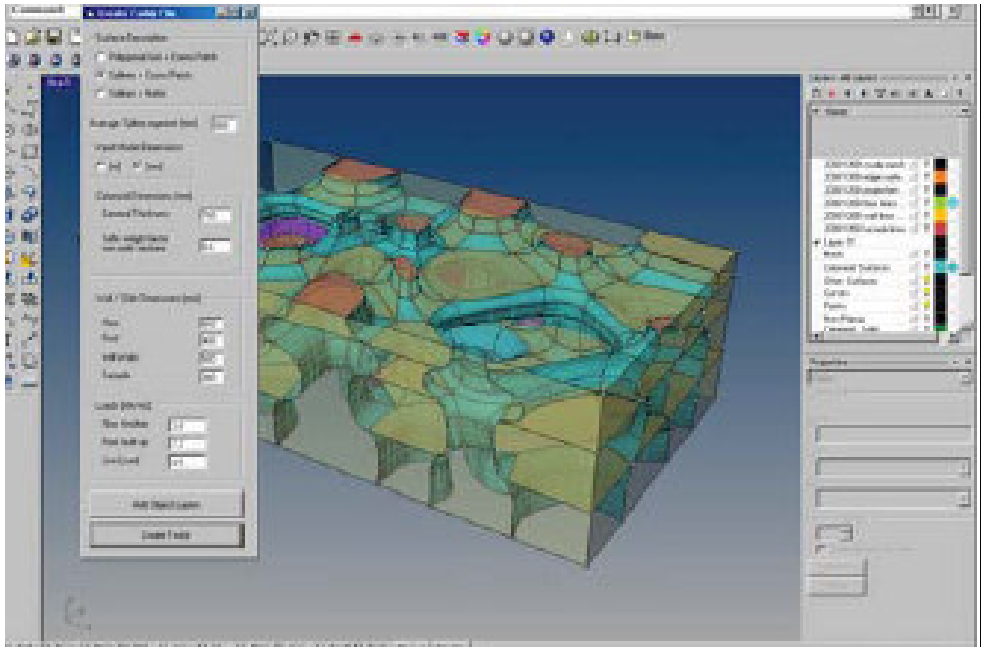
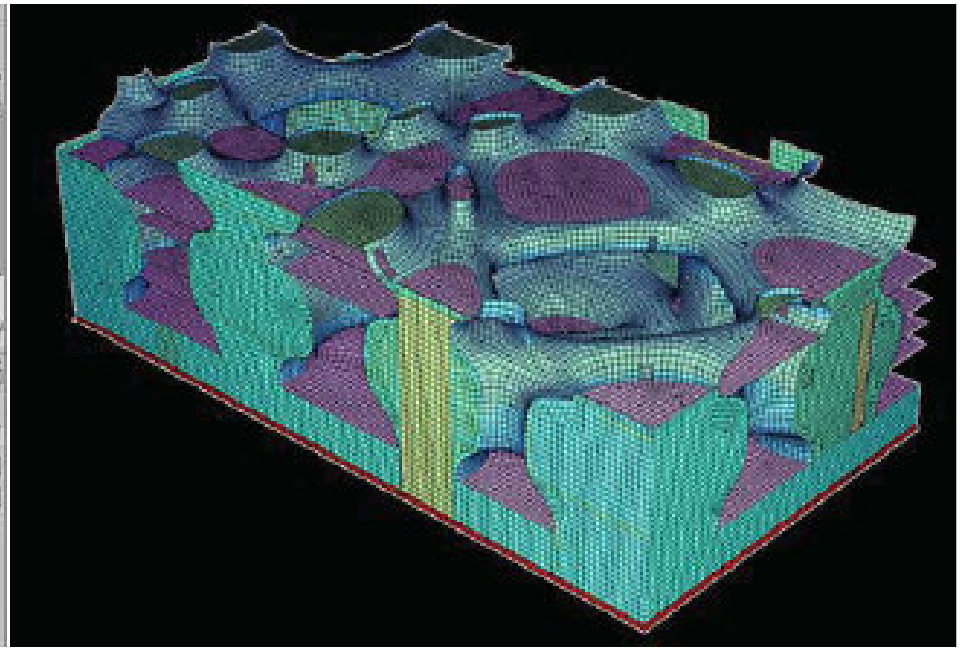
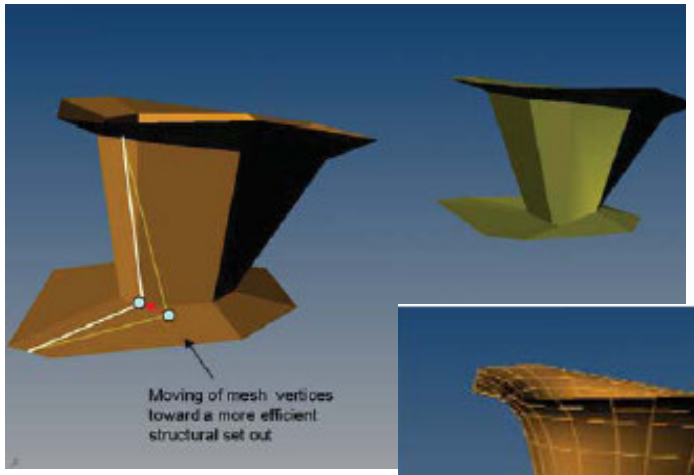
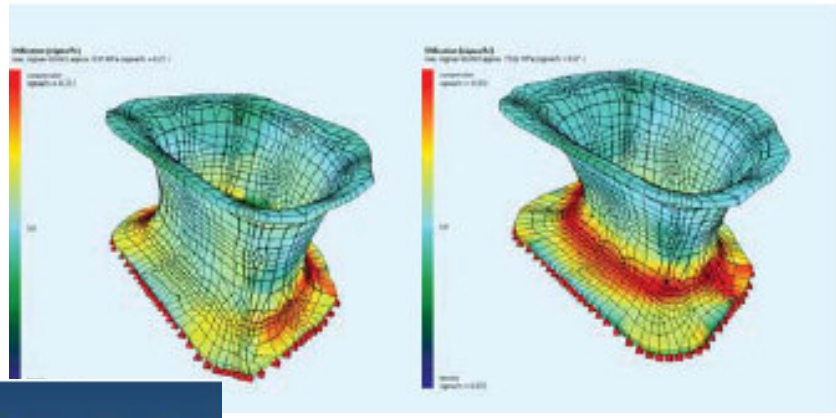


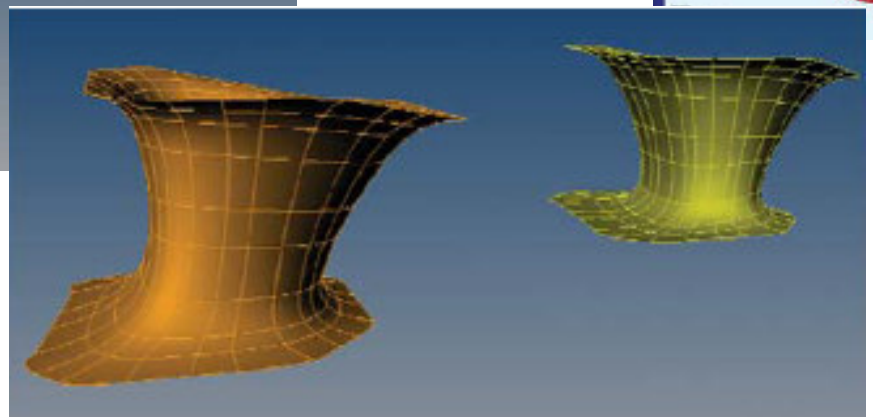


- Architectural geometry

  - As parametric shapes, geometrical information is contained by control points
  - Easy modifications can be done for architectural and structural improvements

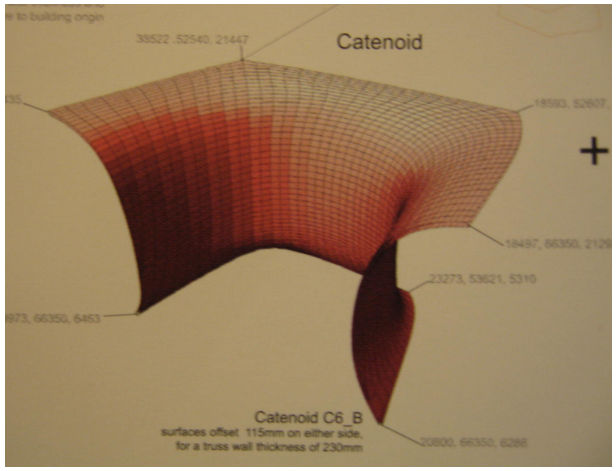


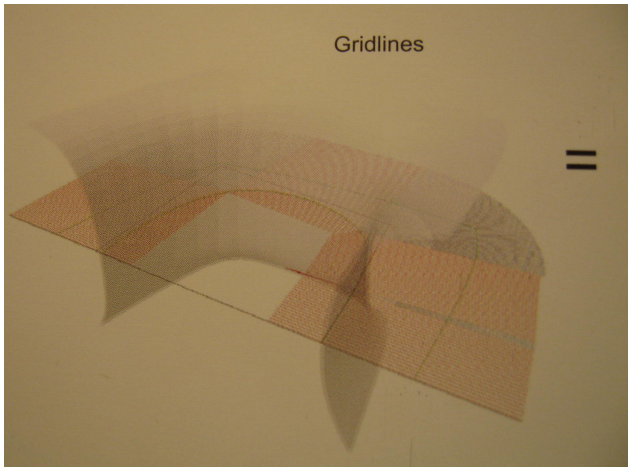


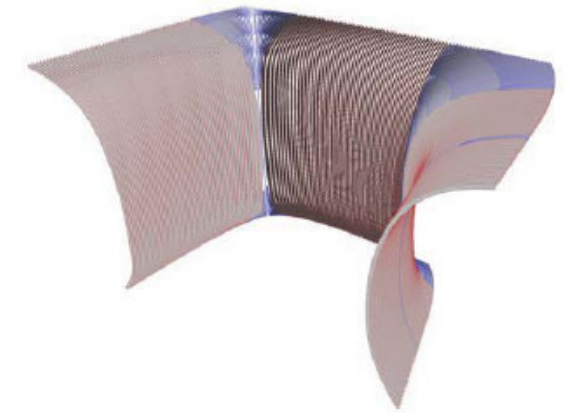


Taichung Opera Metropolitan – Toyo Ito –UK – 2005-2009

- Architectural geometry
  - Construction method
  - Series of parallel 2D form trusses
  - 3D form approximated without expensive 3D tooling such as CNC



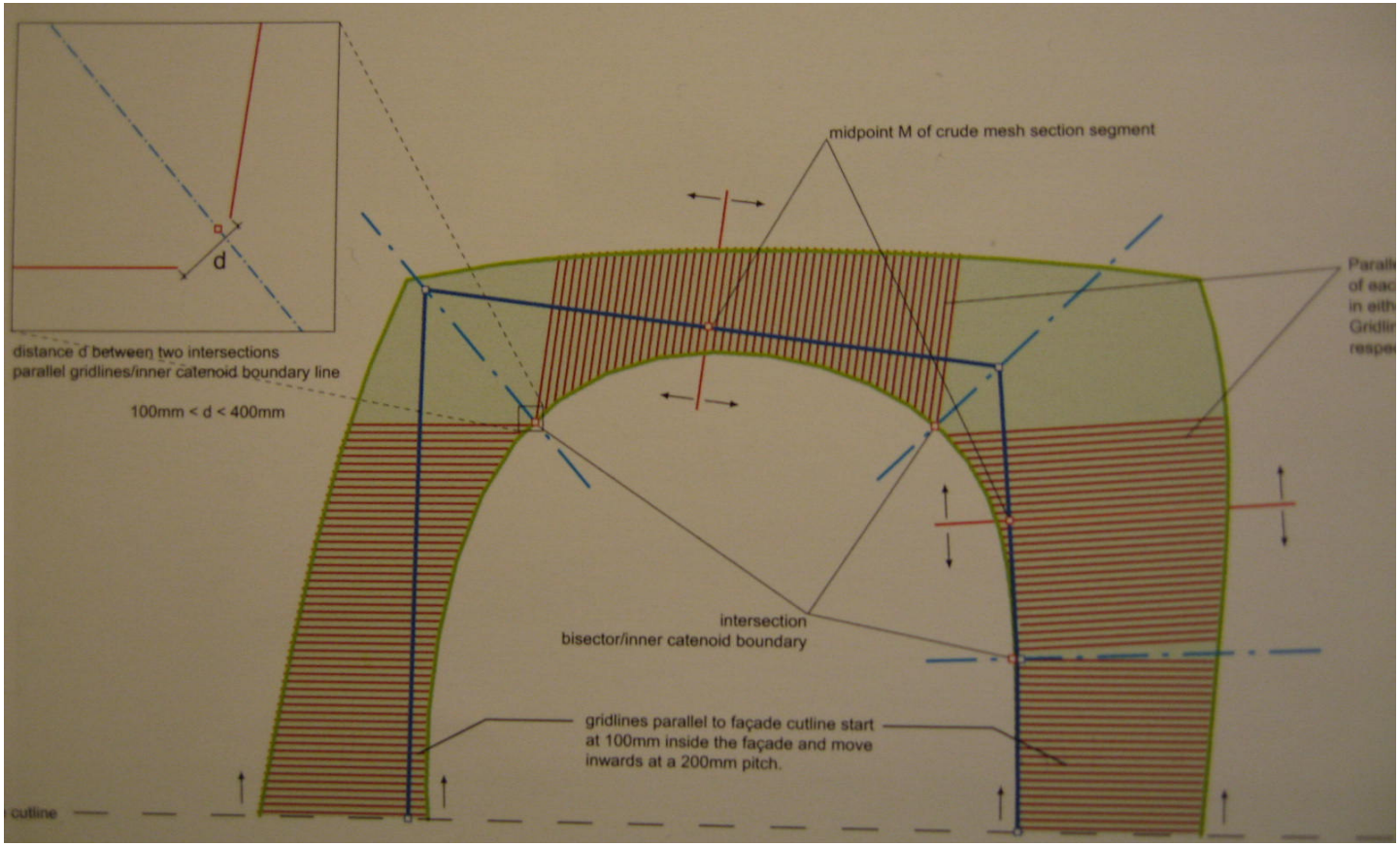




Digital Truss wall stet out

- Architectural geometry

  - Continuous 3D surface divided into parallel and radial zones based on the pre-smoothed crude mesh geometry



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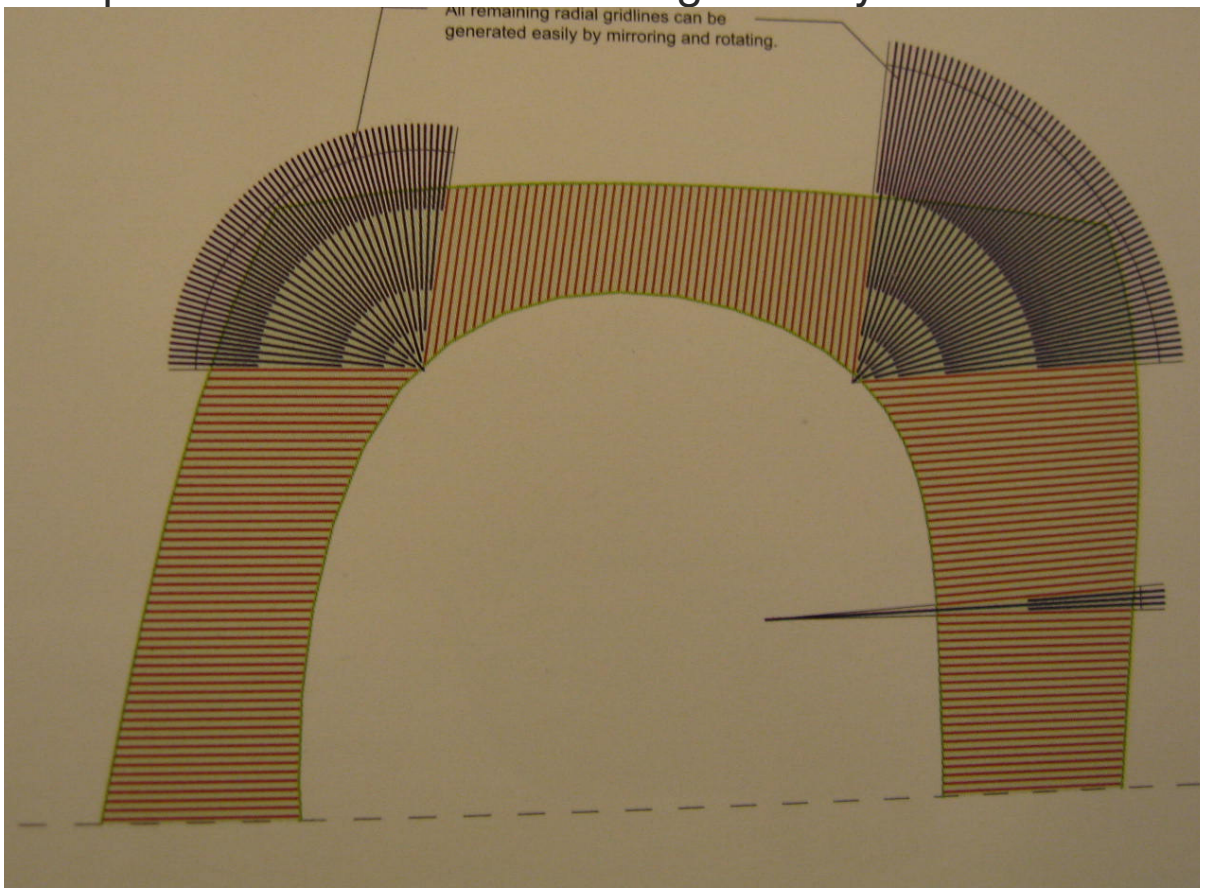

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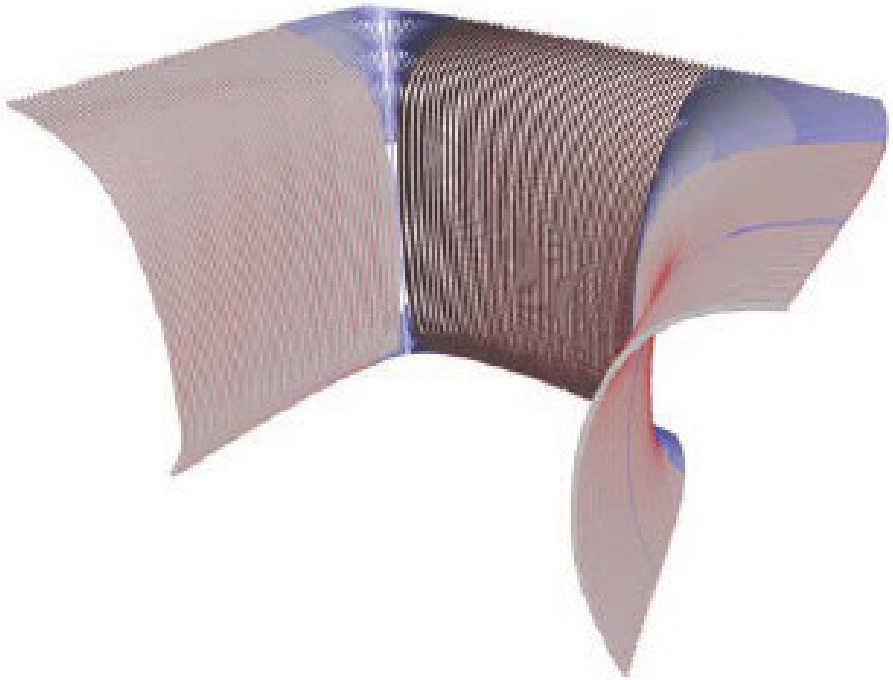

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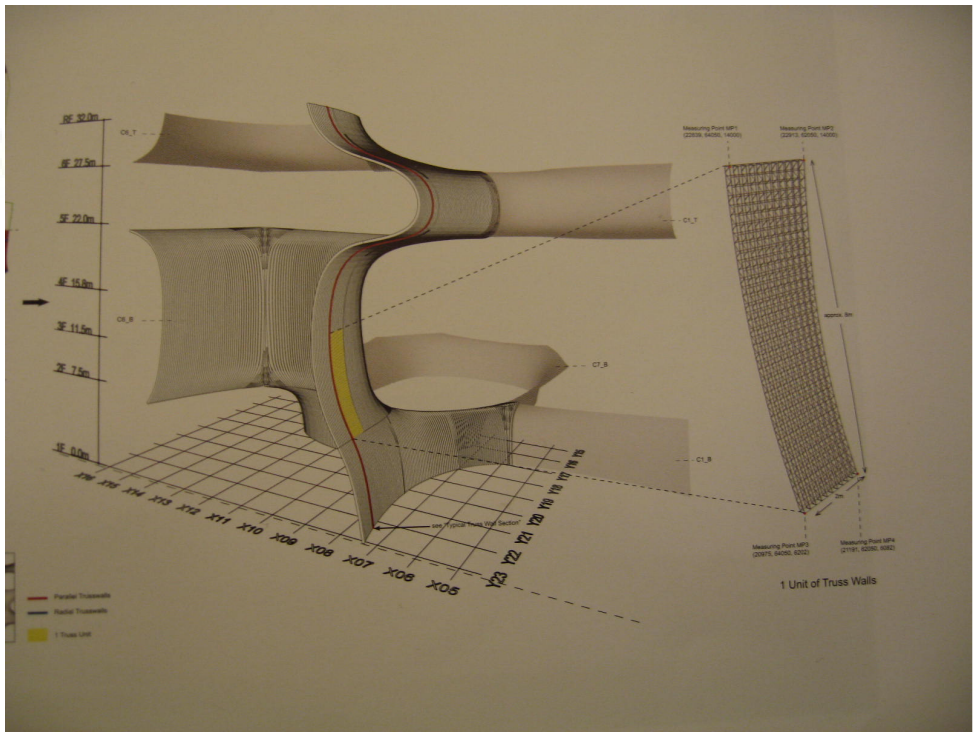


- Architectural geometry

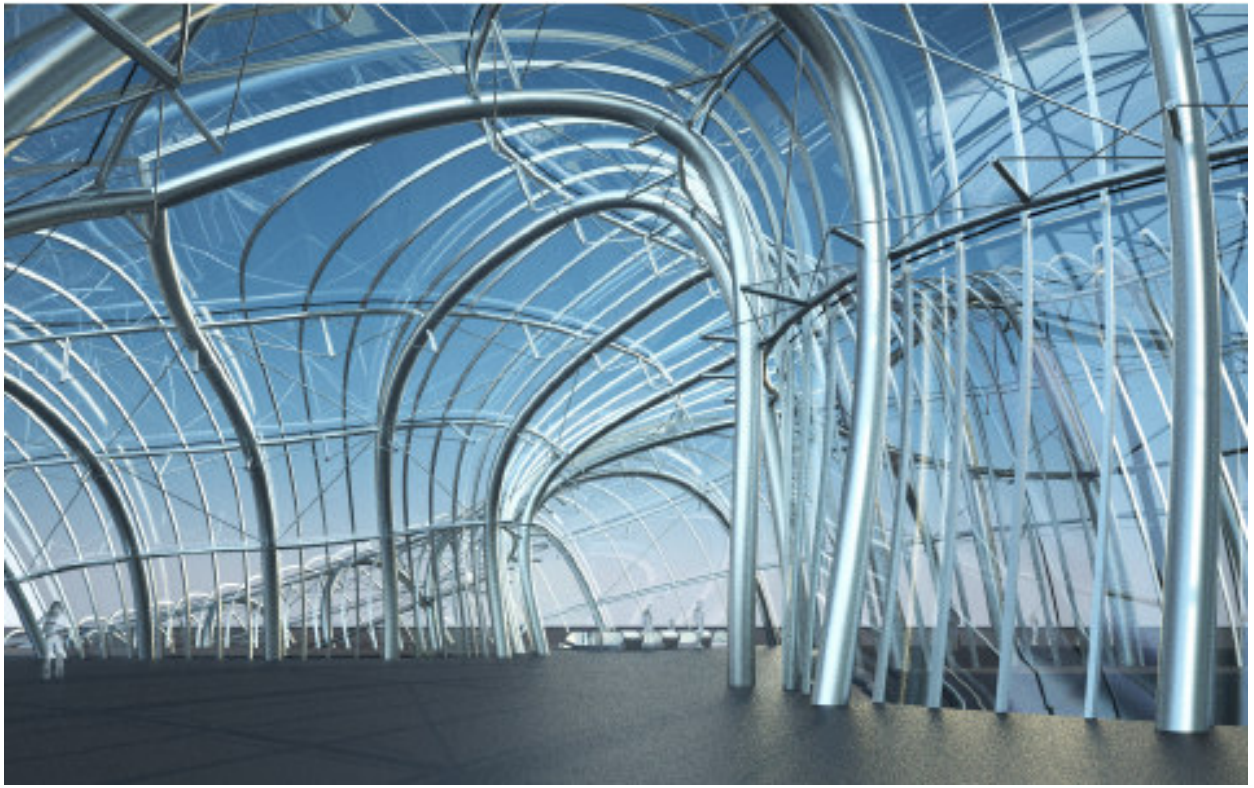
  - Construction method

Pre assembled Truss wall

Welding of reinforcement truss

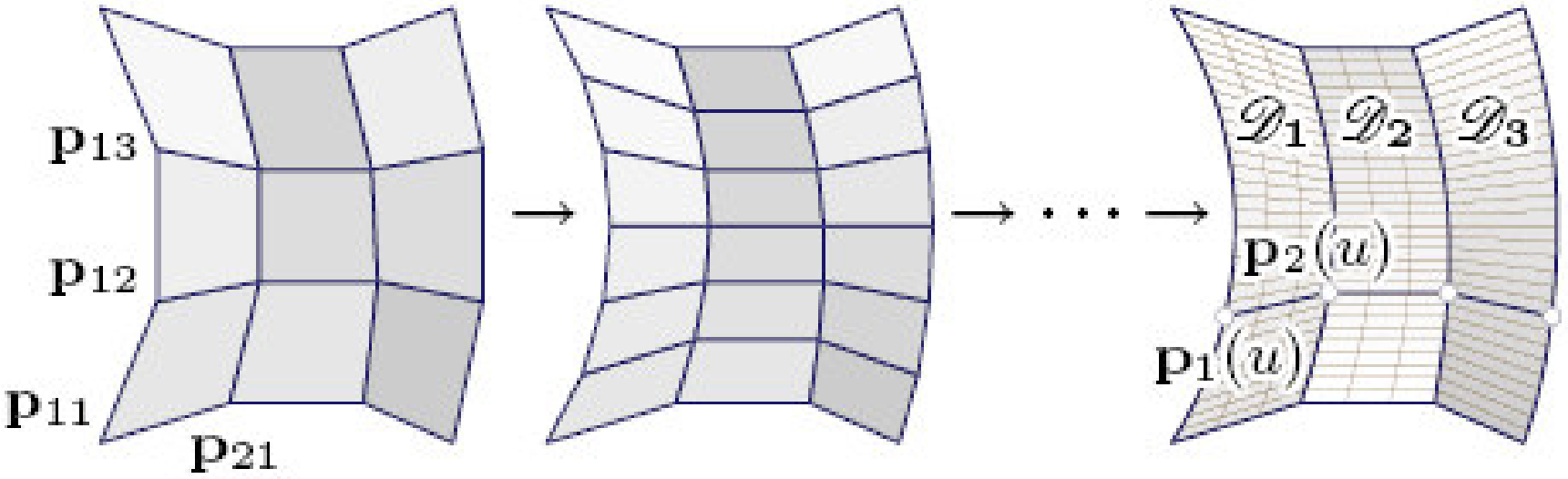
Full scale Mock up after pouring

- Architectural geometry
  - Helmut Pottmann et al.
  - Single curved panels



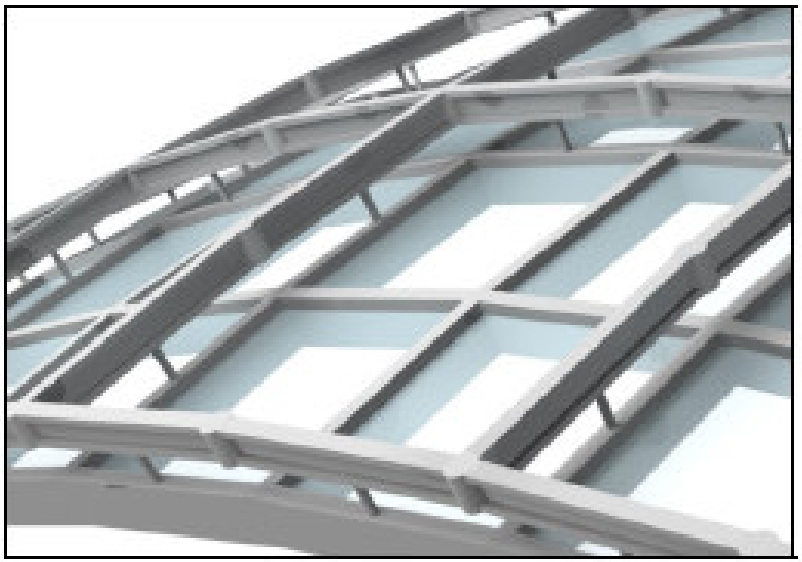
- Architectural geometry

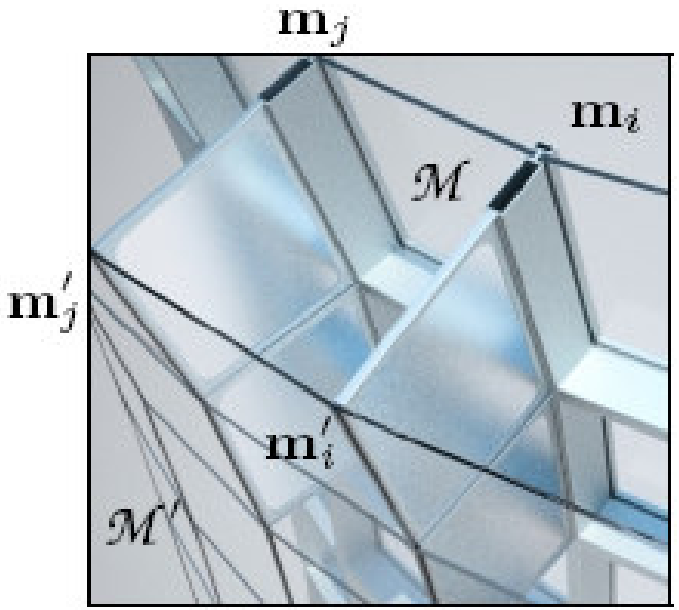
  - Helmut Pottmann et al.
  - Single curved panels
  - Quad planar meshes



- Architectural geometry

  - Helmut Pottmann et al.
  - Single curved panels
  - Quad planar meshes
  - Mesh parallelism for architecture

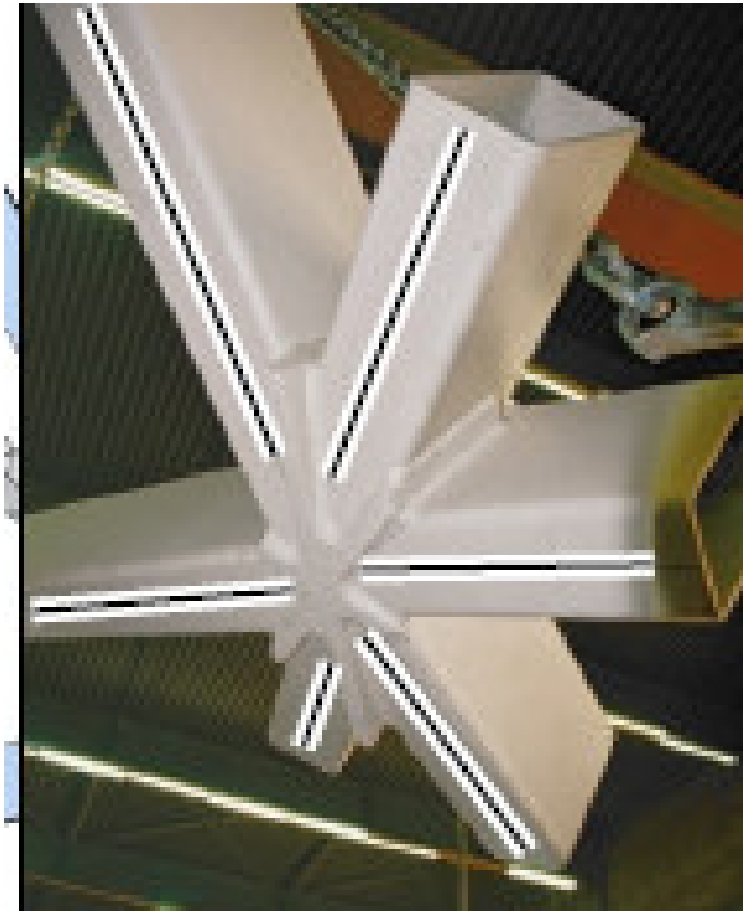




Multi layer construction

- Architectural geometry

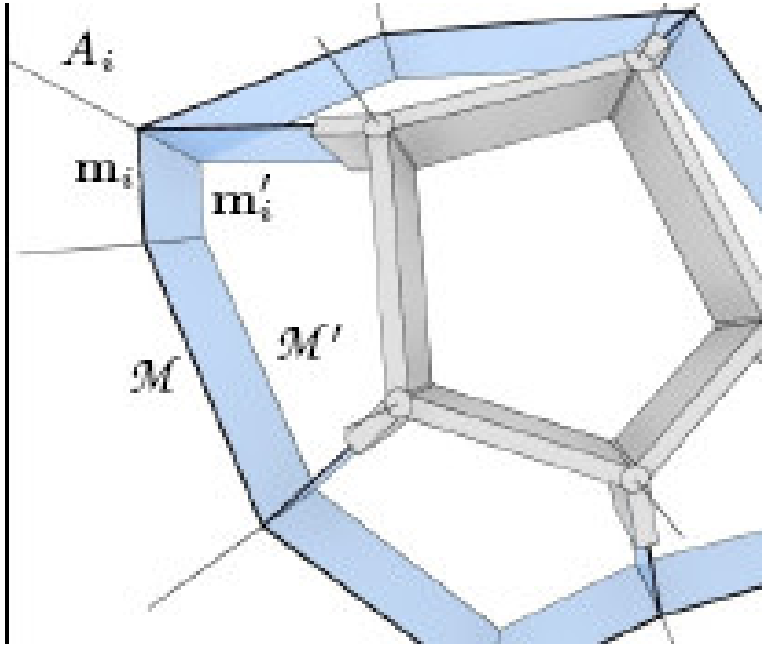
  - Helmut Pottmann et al.
  - Single curved panels
  - Quad planar meshes
  - Mesh parallelism for architecture



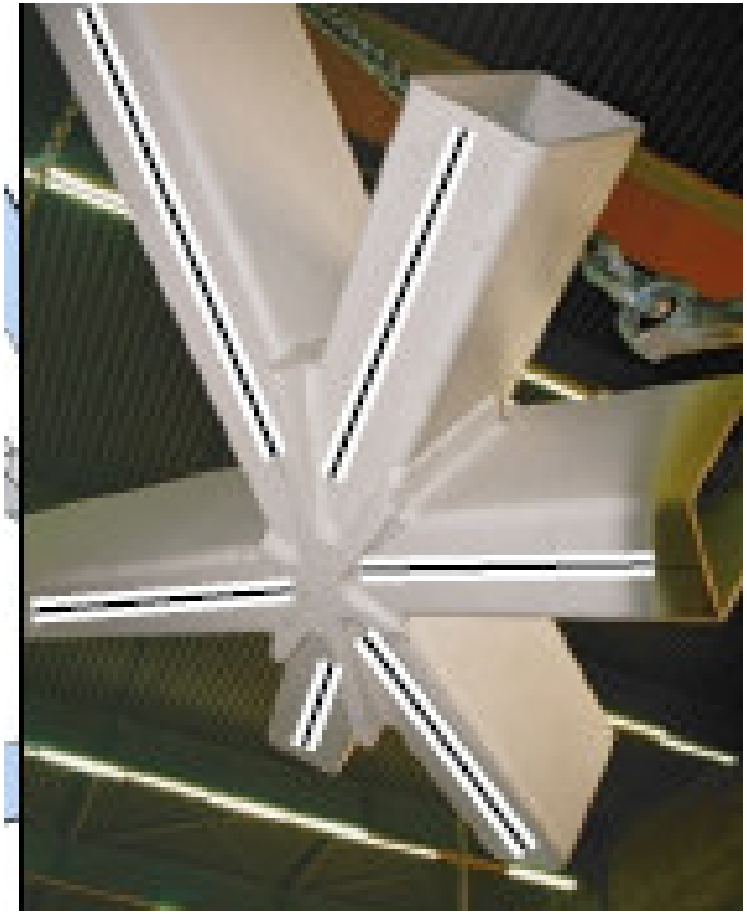
Node without axis and with geometric torsion

- Architectural geometry

  - Helmut Pottmann et al.
  - Single curved panels
  - Quad planar meshes
  - Mesh parallelism for architecture



Torsion free node



Node without axis and with geometric torsion

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  - Helmut Pottmann et al.
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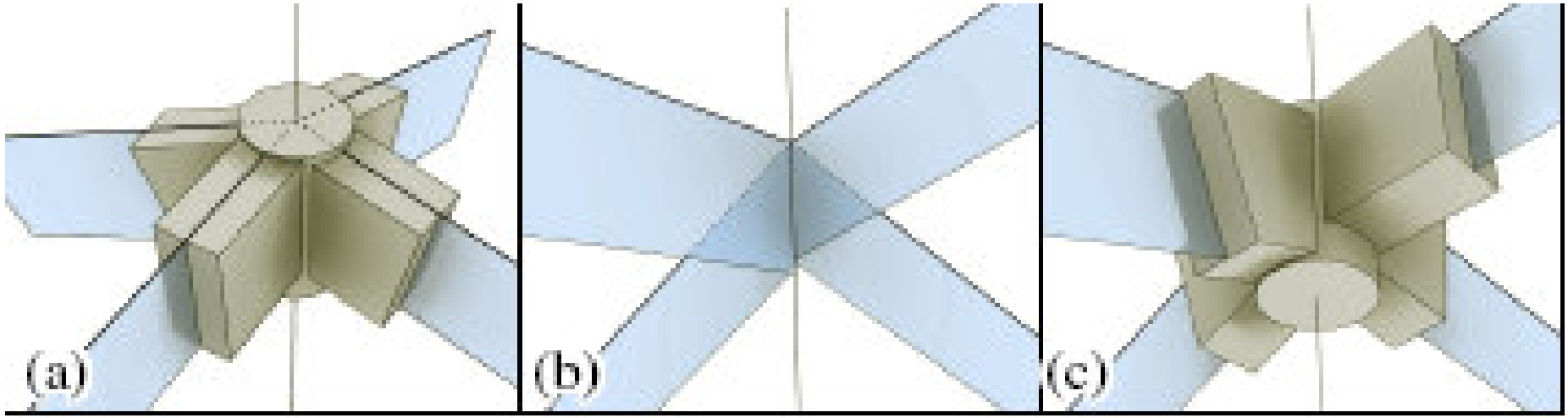
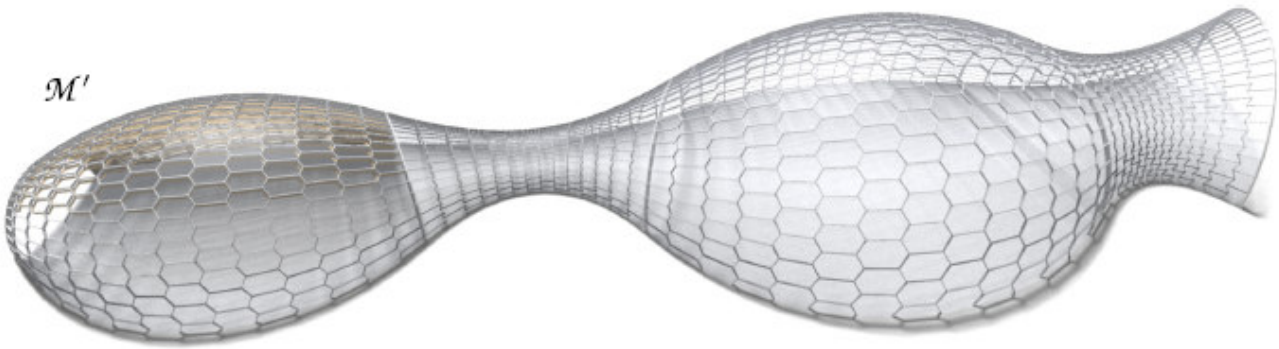
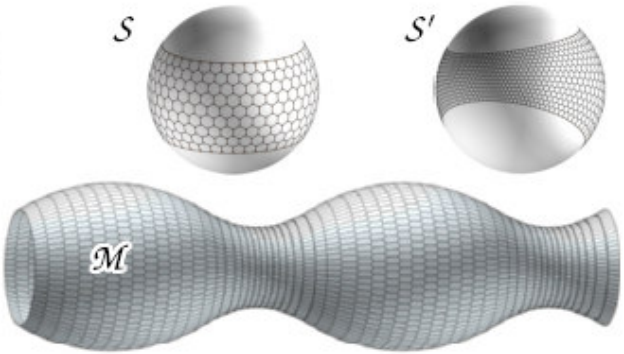


Meshes which are not of constant edge-edge distance

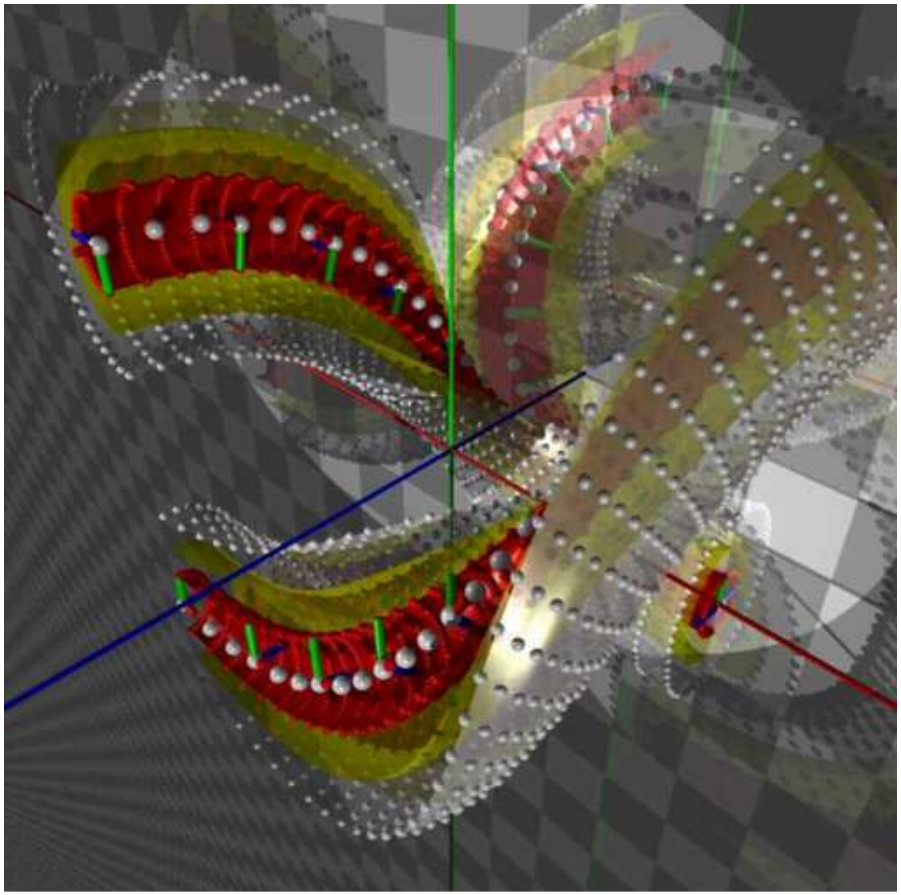
- Architectural geometry
  - Helmut Pottmann et al.
  - Single curved panels
  - Quad planar meshes
  - Mesh parallelism for architecture





- Architectural geometry

  - Alain Marty – Pascalian Forms
  - Geometrical approach of parametrics
    - Algorithmic principle
    - Algebraic abstraction
  - Generative rules
    - Basic operators
    - Recursive process
    - Morphological richness



- Pascalian Forms

  - Principle : get the middle

    - between 2 points

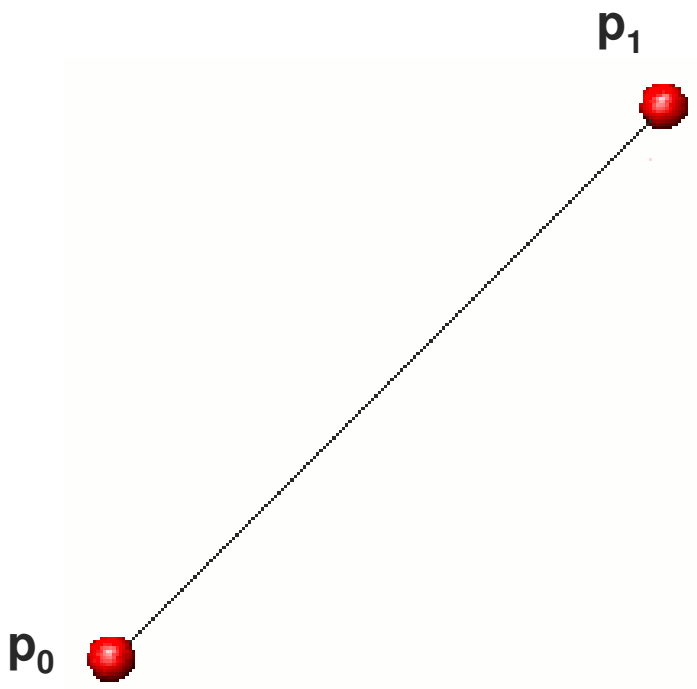
$$p_m = \frac{p_0 + p_1}{2}$$

operator (MI)

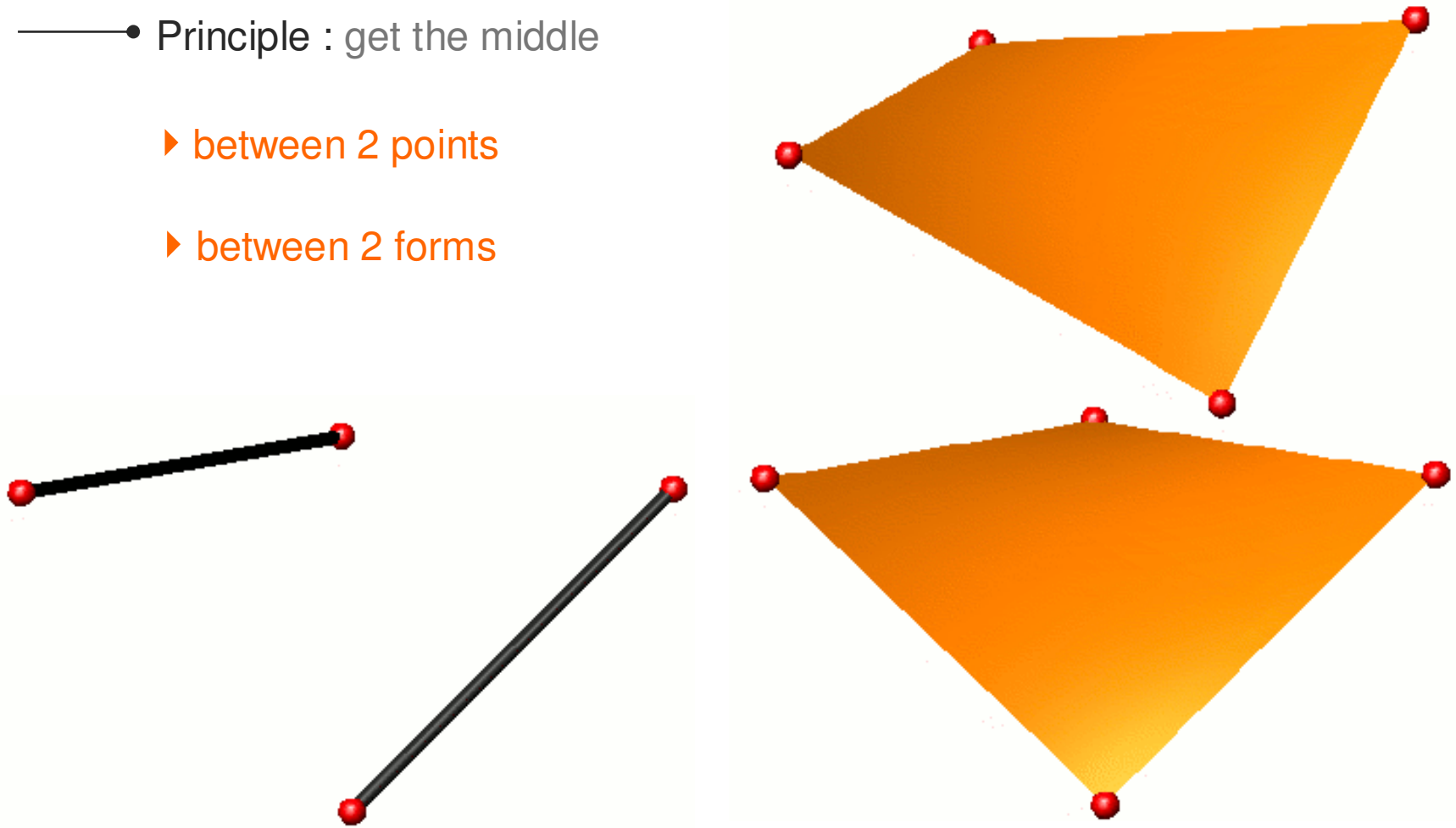
get a point

operator (RMI)

get a segment



- Pascalian Forms
  - Principle : get the middle
    - between 2 points
    - between 2 forms

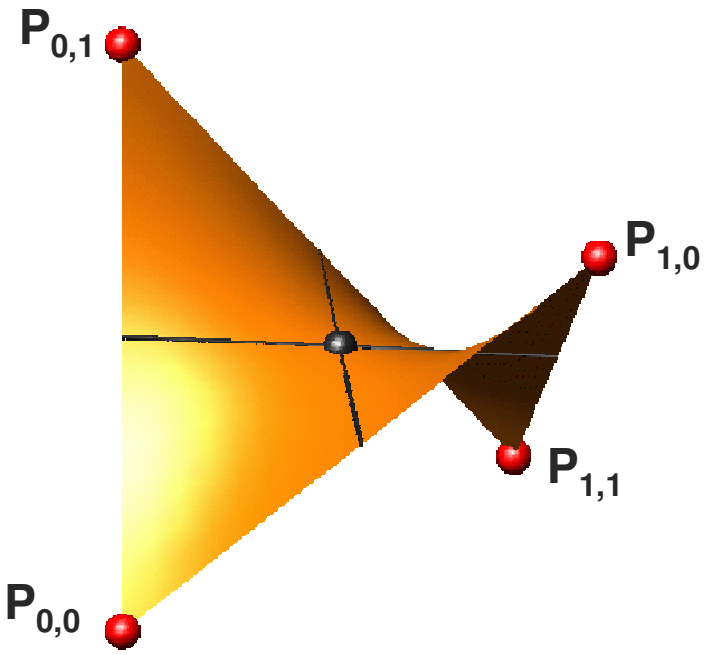


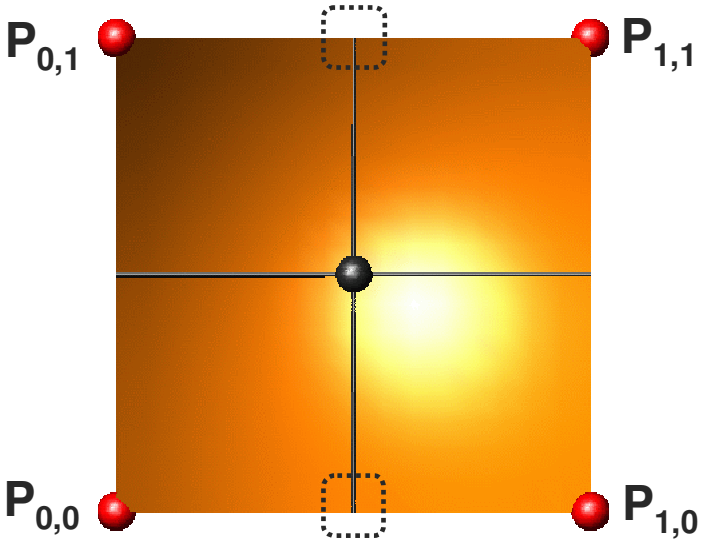
- Pascalian Forms

  - Principle : get the middle

    - Of a facet

$$p_m = \frac{1}{2}\left(\frac{p_{0,0} + p_{1,0}}{2} + \frac{p_{0,1} + p_{1,1}}{2}\right)$$



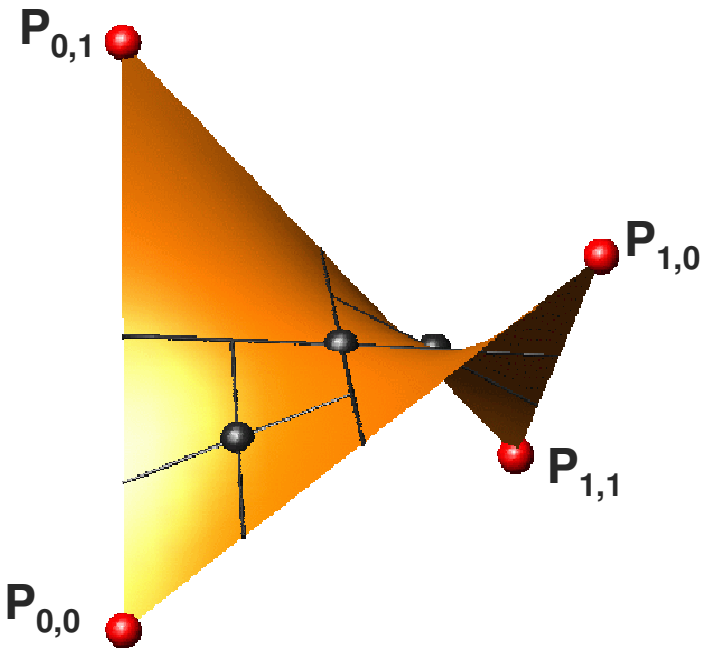


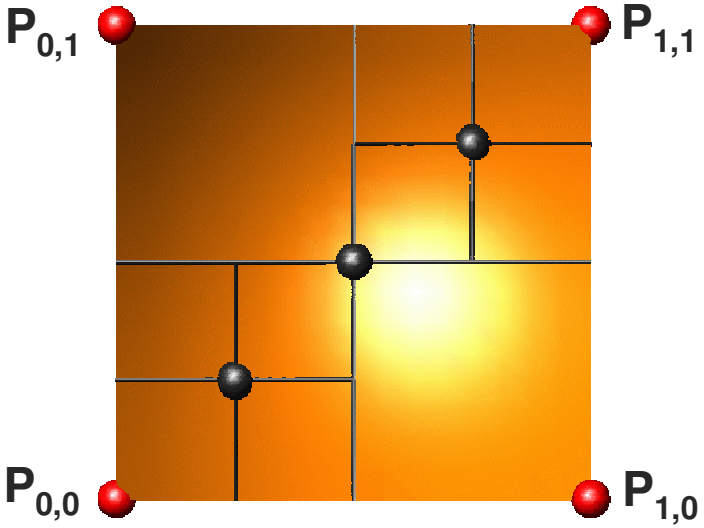
- Pascalian Forms

  - Principle : get the middle

    - Of a facet

$$p_m = \frac{1}{2}\left(\frac{p_{0,0} + p_{1,0}}{2} + \frac{p_{0,1} + p_{1,1}}{2}\right)$$



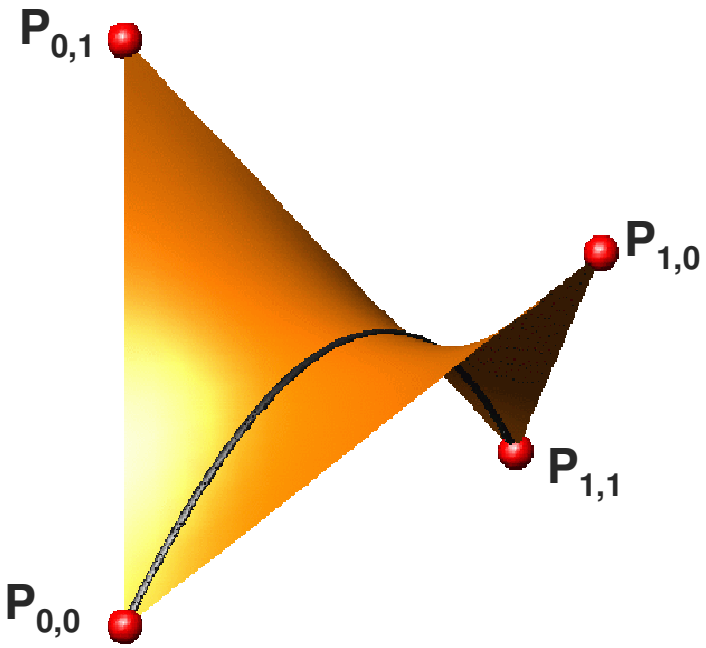


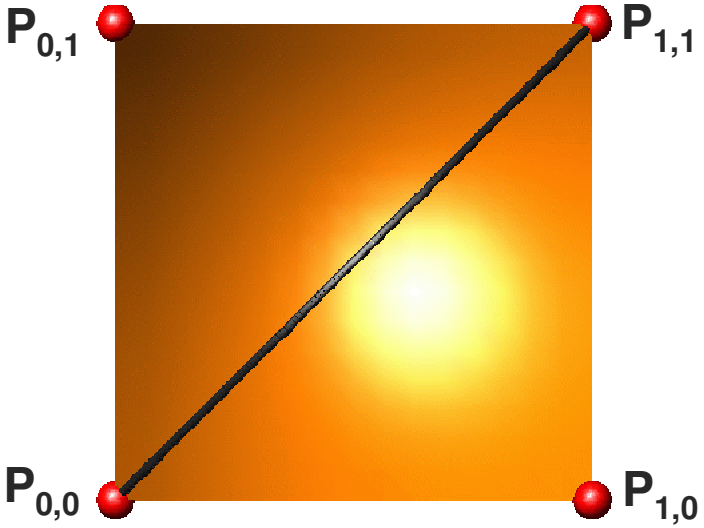
- Pascalian Forms

  - Principle : get the middle

    - Of a facet

$$p_m = \frac{1}{2}\left(\frac{p_{0,0} + p_{1,0}}{2} + \frac{p_{0,1} + p_{1,1}}{2}\right)$$

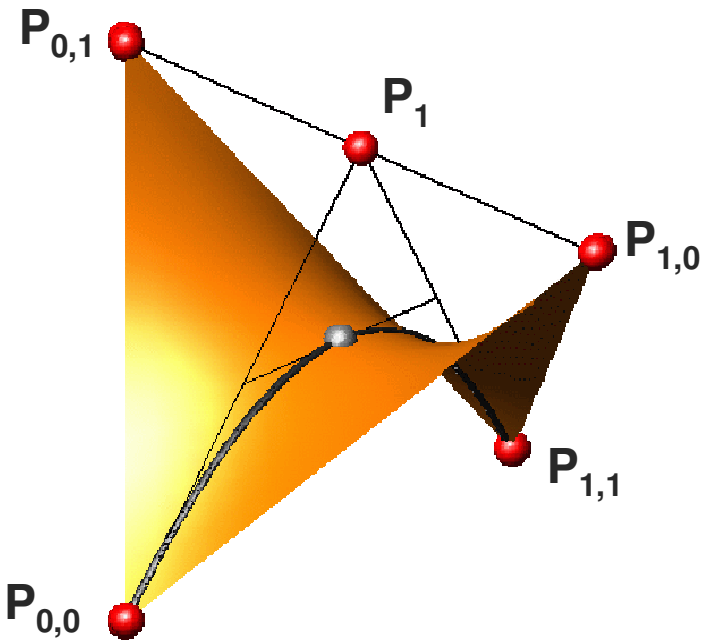




- Pascalian Forms

  - Principle : get the middle

    - Of a facet



$$p_m = \frac{1}{2}\left(\frac{p_{0,0} + p_{1,0}}{2} + \frac{p_{0,1} + p_{1,1}}{2}\right)$$

$$p_m = \frac{1}{4}\left(p_{0,0} + p_{1,0} + p_{0,1} + p_{1,1}\right)$$

$$p_m = \frac{1}{4}\left(p_0 + 2p_1 + p_2\right)$$

operator (Diag)

Diagonal curve

- Pascalian Forms

  - Principle : get the middle

    - Of a facet

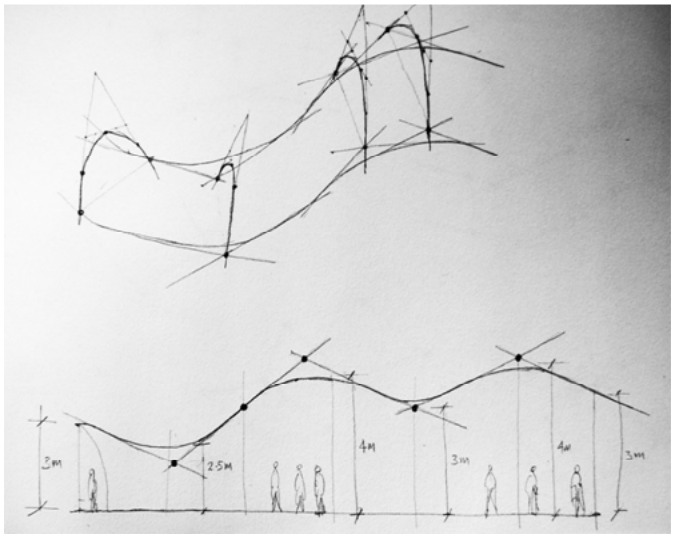
$$p_m = \frac{1}{2}\left(\frac{p_{0,0} + p_{1,0}}{2} + \frac{p_{0,1} + p_{1,1}}{2}\right)$$

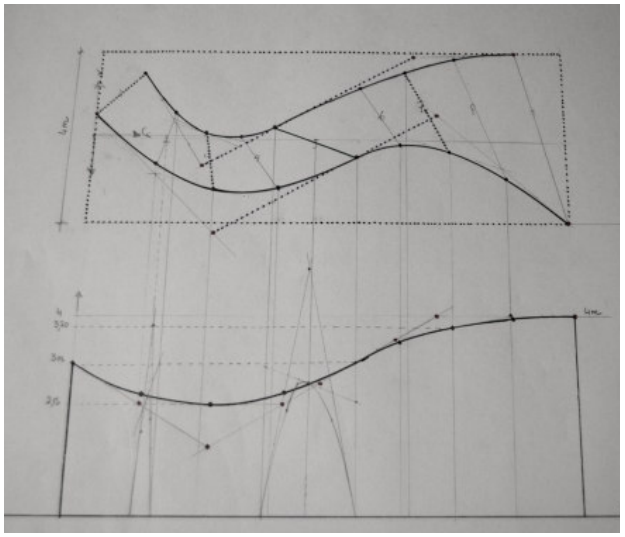
$$p_m = \frac{1}{4}\left(p_{0,0} + p_{1,0} + p_{0,1} + p_{1,1}\right)$$

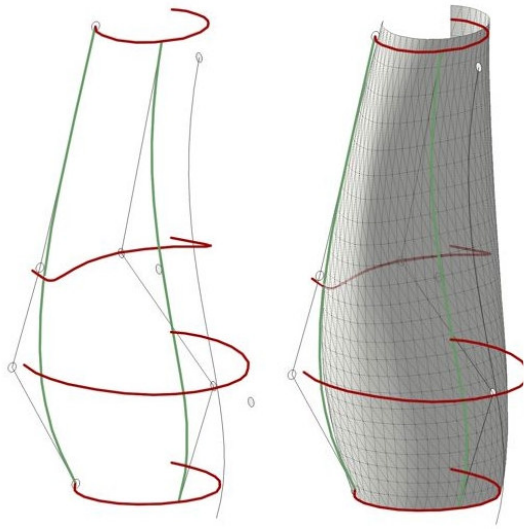
$$p_m = \frac{1}{4}\left(p_0 + 2p_1 + p_2\right)$$

- Pascalian Forms

  - 3 geometrical operators
  - Lead to Bezier, rational Bezier, Splines and Nurbs representations
  - Same generative process from sketches, numerical code and physical construction

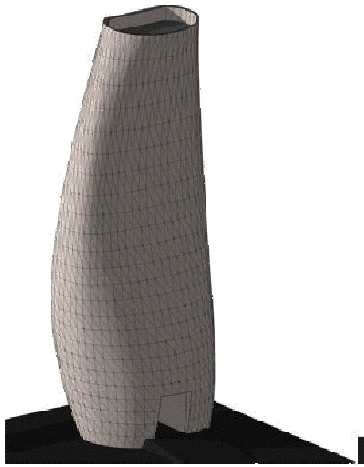




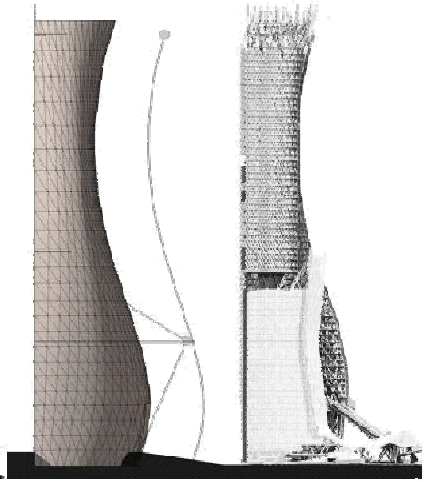


- Pascalian Forms

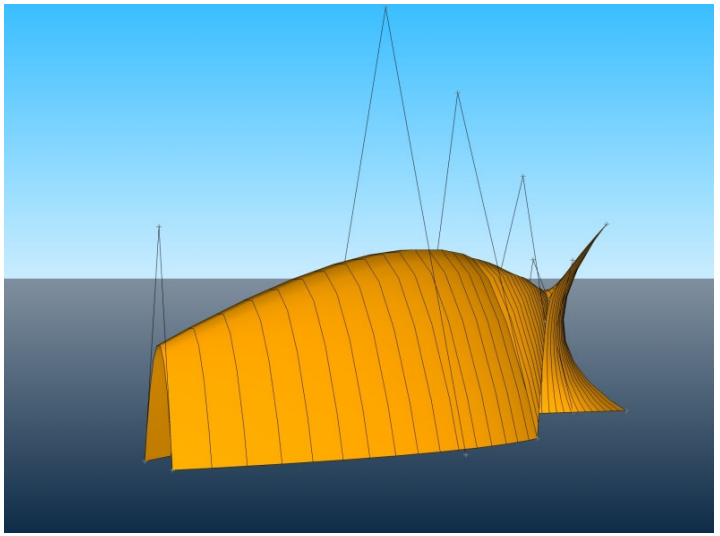
  - 3 geometrical operators
  - Lead to Bezier, rational Bezier, Splines and Nurbs representations
  - Same generative process from sketches, numerical code and physical construction



Ajout d'épaisseur et extrusion



Comparaison du profil Est



- Pascalian Forms
  - 3 geometrical operators
  - Lead to Bezier, rational Bezier, Splines and Nurbs representations
  - Same generative process from sketches, numerical code and physical construction

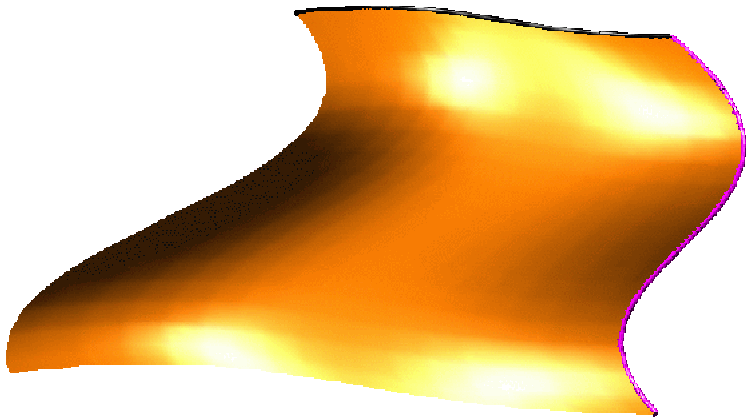
- Pascalian Forms

  - 3 geometrical operators
  - Lead to Bezier, rational Bezier, Splines and Nurbs representations
  - Same generative process from sketches, numerical code and physical construction

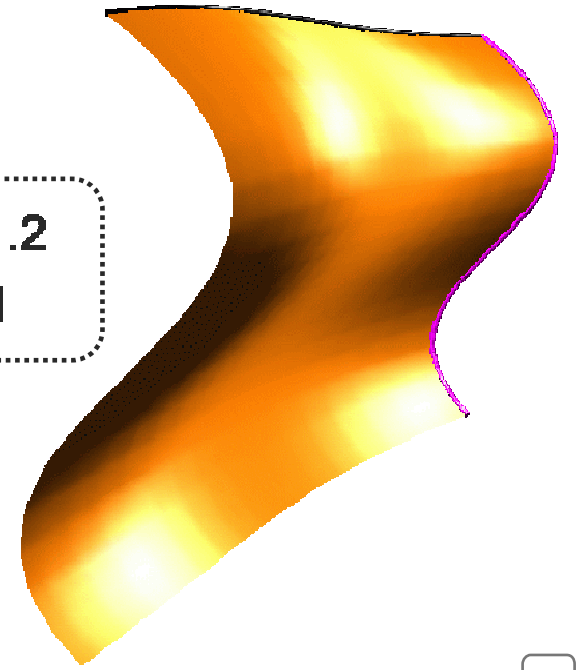
- Pascalian Forms and further developments – Bagneris' PhD

  - Understand the underlying geometry leads to communicate on more elaborated concepts
  - Reach information inside complex forms for structural and technical improvements

$\lambda = 1$
$\mu = 1.2$

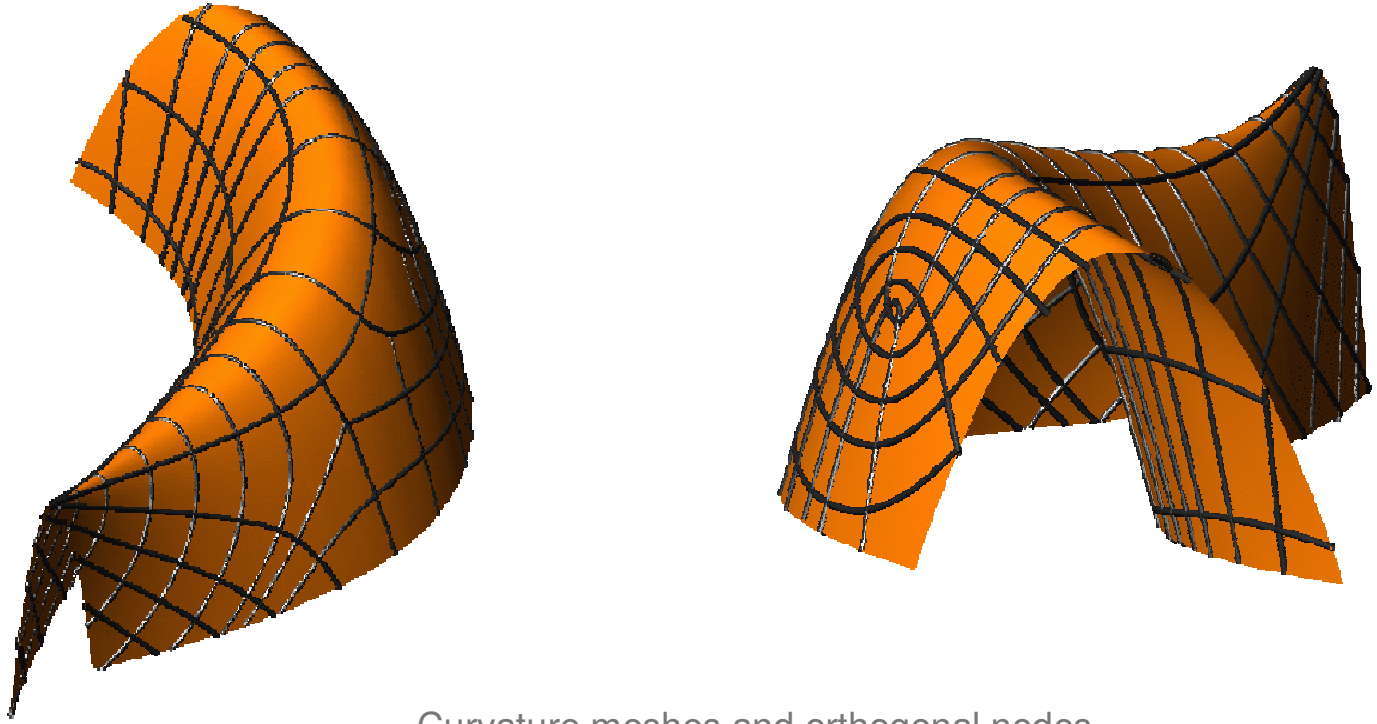


$\lambda = 1.2$
$\mu = 1$



- Pascalian Forms and further developments – Bagneris' PhD

  - Understand the underlying geometry leads to communicate on more elaborated concepts
  - Reach information inside complex forms for structural and technical improvements



- Pascalian Forms and further developments – Bagneris' PhD

  - Understand the underlying geometry leads to communicate on more elaborated concepts
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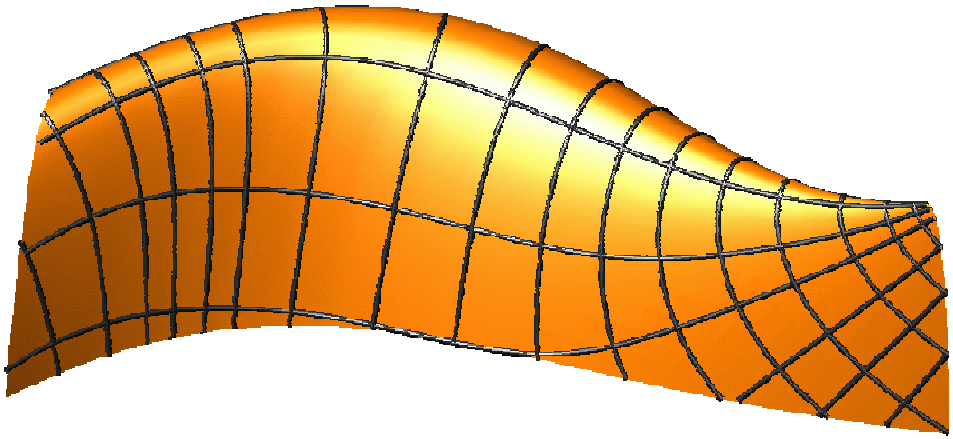
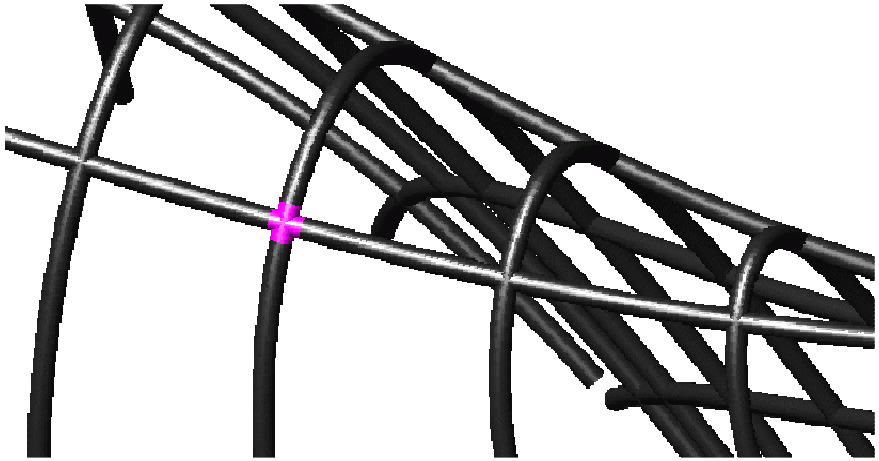
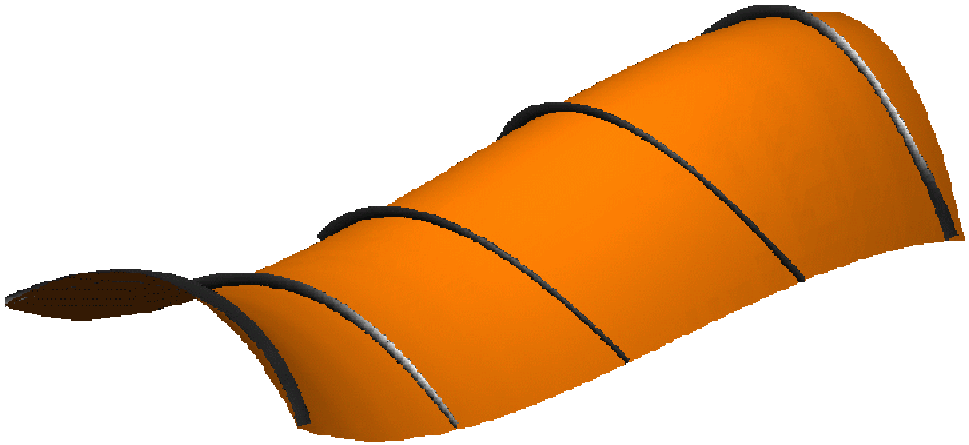




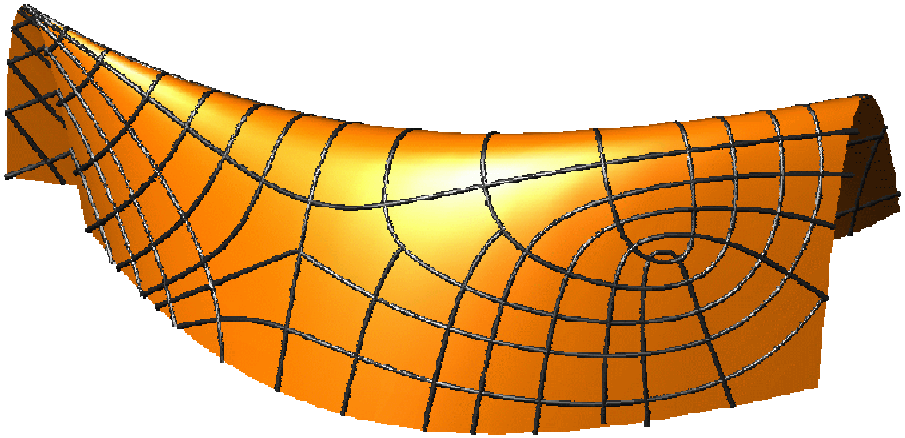
developable surfaces generated from the normals of curvature lines

- Pascalian Forms and further developments – Bagneris' PhD

  - Understand the underlying geometry leads to communicate on more elaborated concepts
  - Reach information inside complex forms for structural and technical improvements



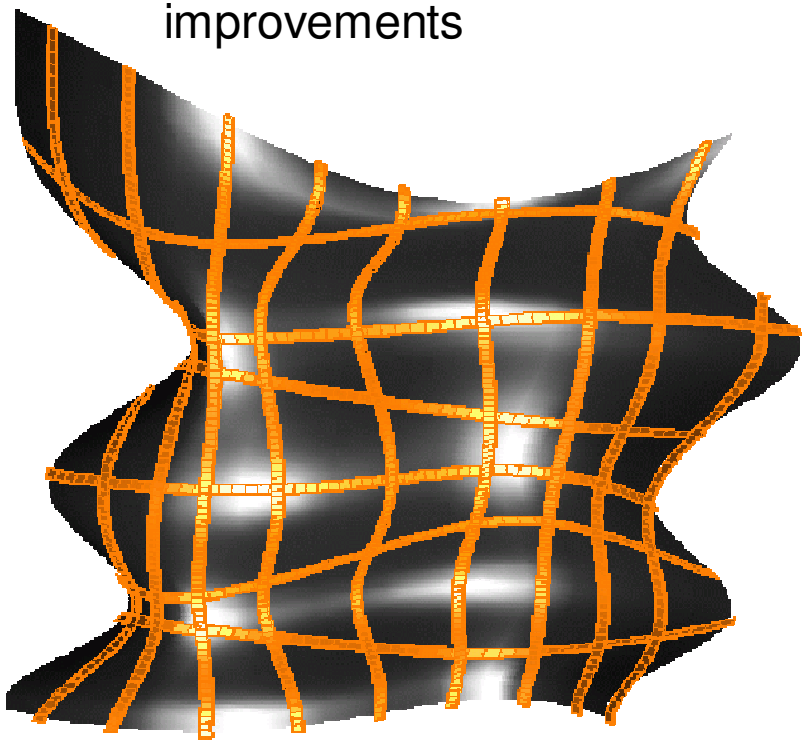
Developable ribs



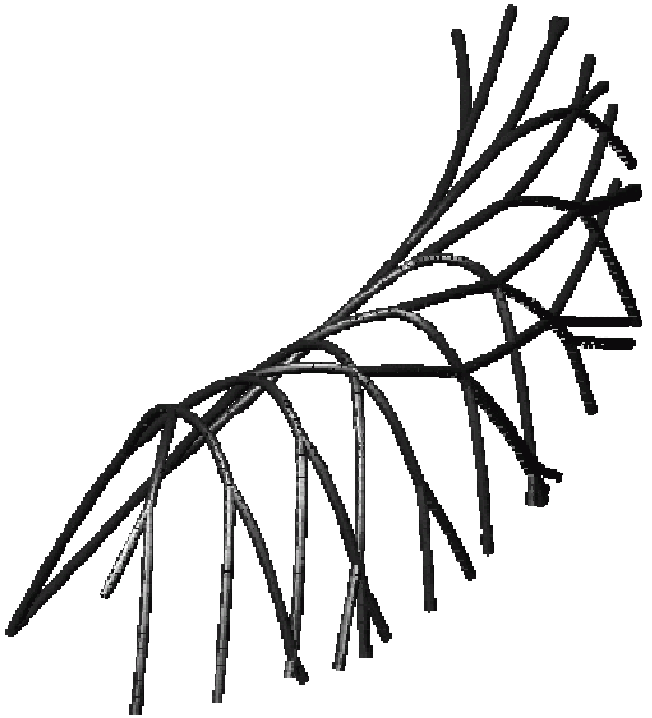
Ombilic points

- Pascalian Forms and further developments – Bagneris' PhD

  - Understand the underlying geometry leads to communicate on more elaborated concepts
  - Reach information inside complex forms for structural and technical improvements



Geodesic

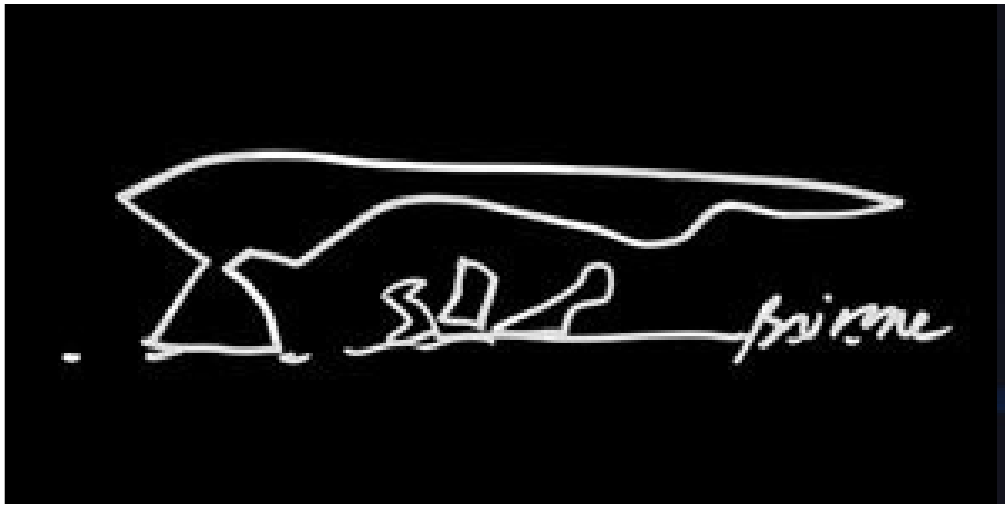


Fractal patterns

Flexible_Mechanically constrained

- Computational morphogenesis _____ Step 1

  - “More is More”
  - Bollinger & Grohmann

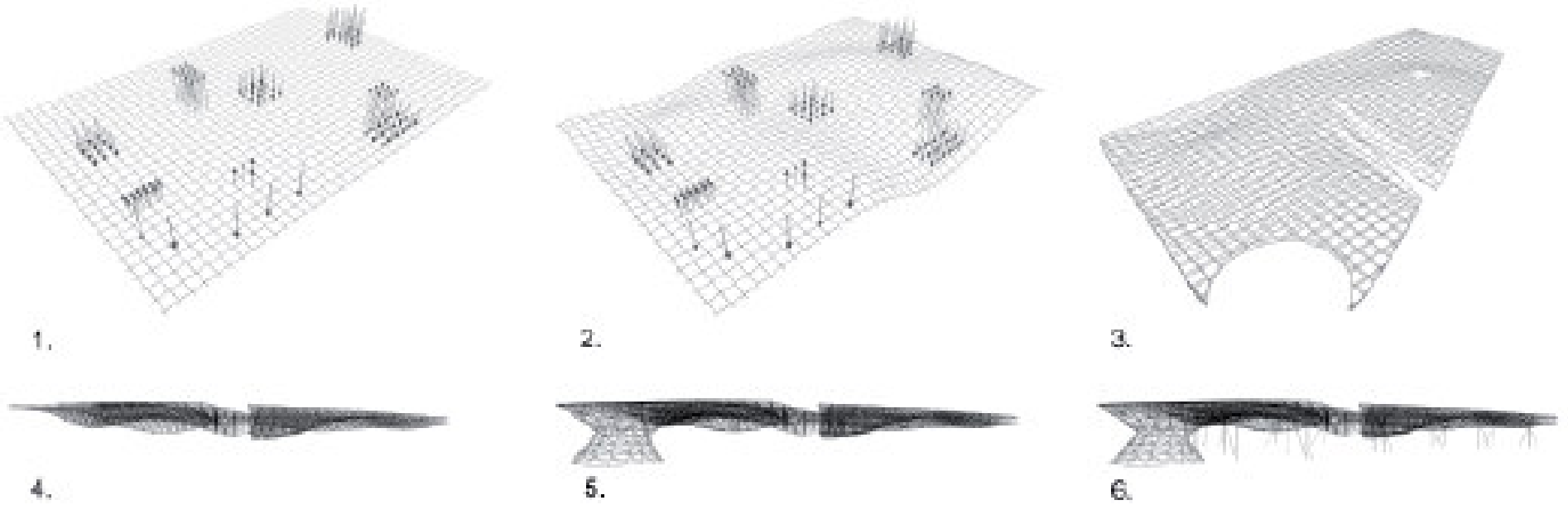


- Computational morphogenesis _____ Step 1

  - “More is More”
  - Bollinger & Grohmann

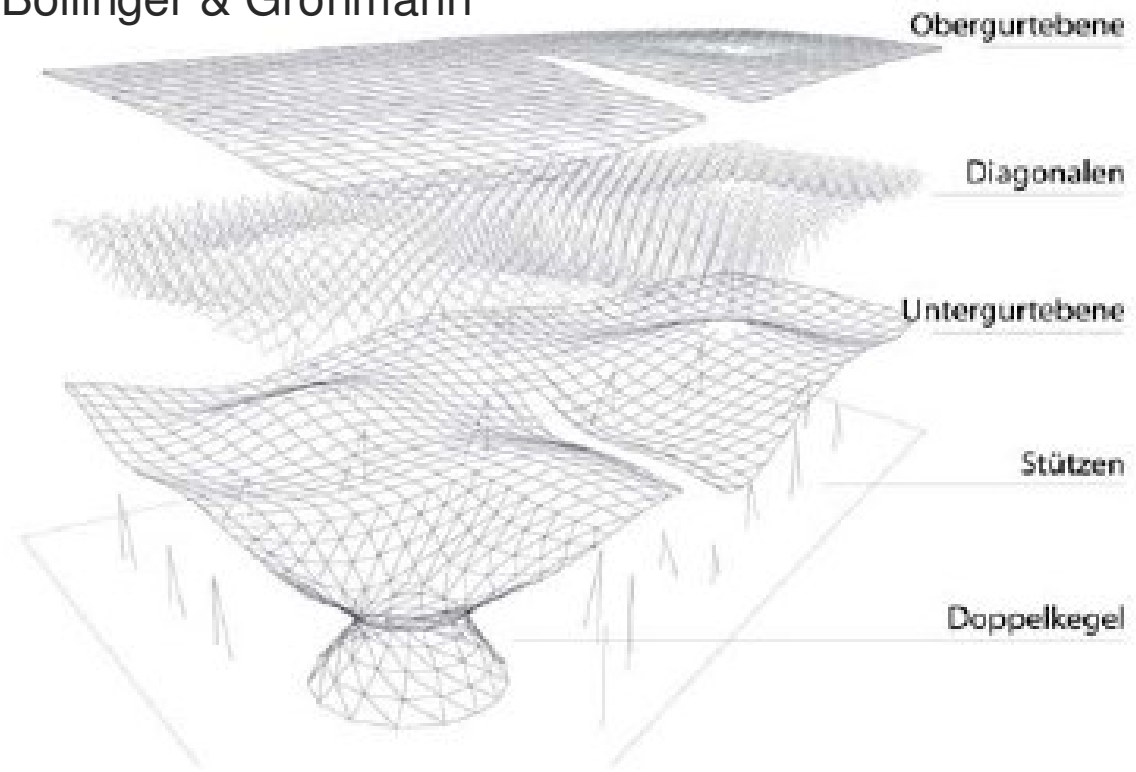
- Computational morphogenesis _____ Step 1

  - “More is More”
  - Bollinger & Grohmann



- Computational morphogenesis _____ Step 1

  - “More is More”
  - Bollinger & Grohmann



- Computational morphogenesis _____ Step 1

  - “More is More”

  - Bollinger & Grohmann

BMW Welt – Coop Himmelb(l)au – Germany – 2001/2007

- Computational morphogenesis _____ Step 1

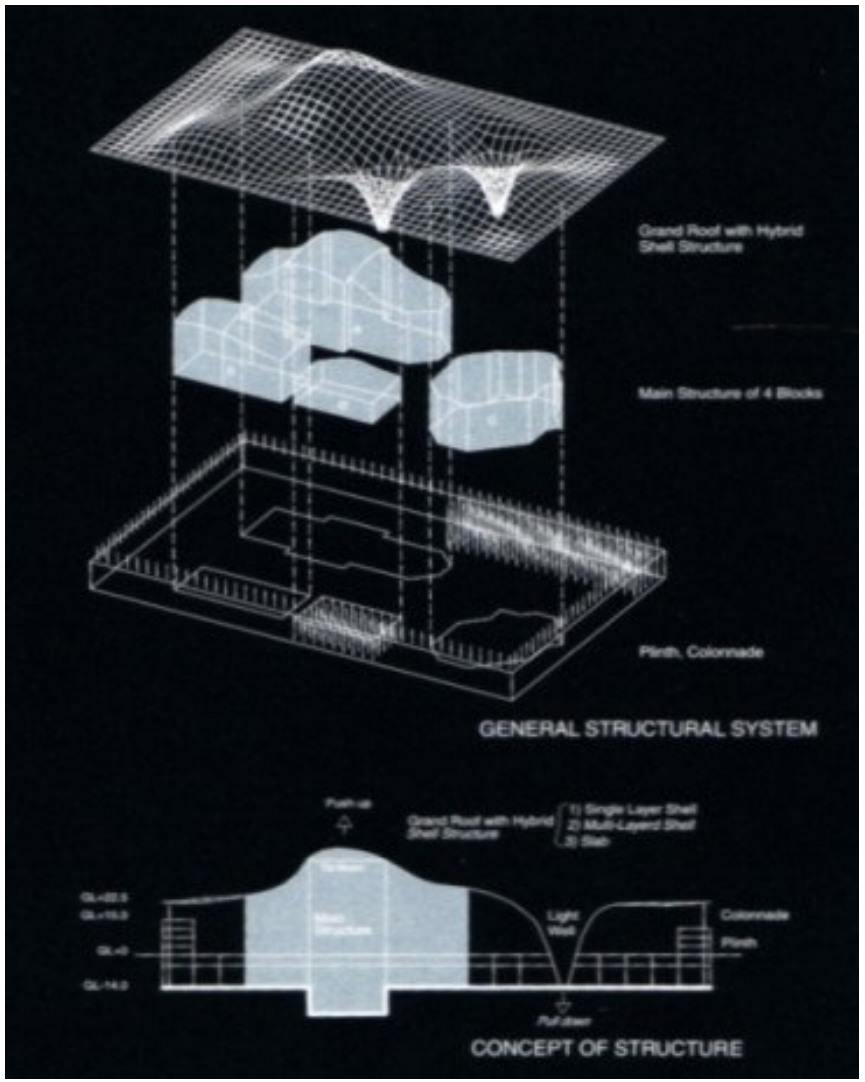
  - “More is More”

  - Bollinger & Grohmann

BMW Welt – Coop Himmelb(l)au – Germany – 2001/2007

- Computational morphogenesis _____ Step 1

  - “More is More”
  - Sasaki & partners



Beijing Opera – Isozaki – 1999 – Competition

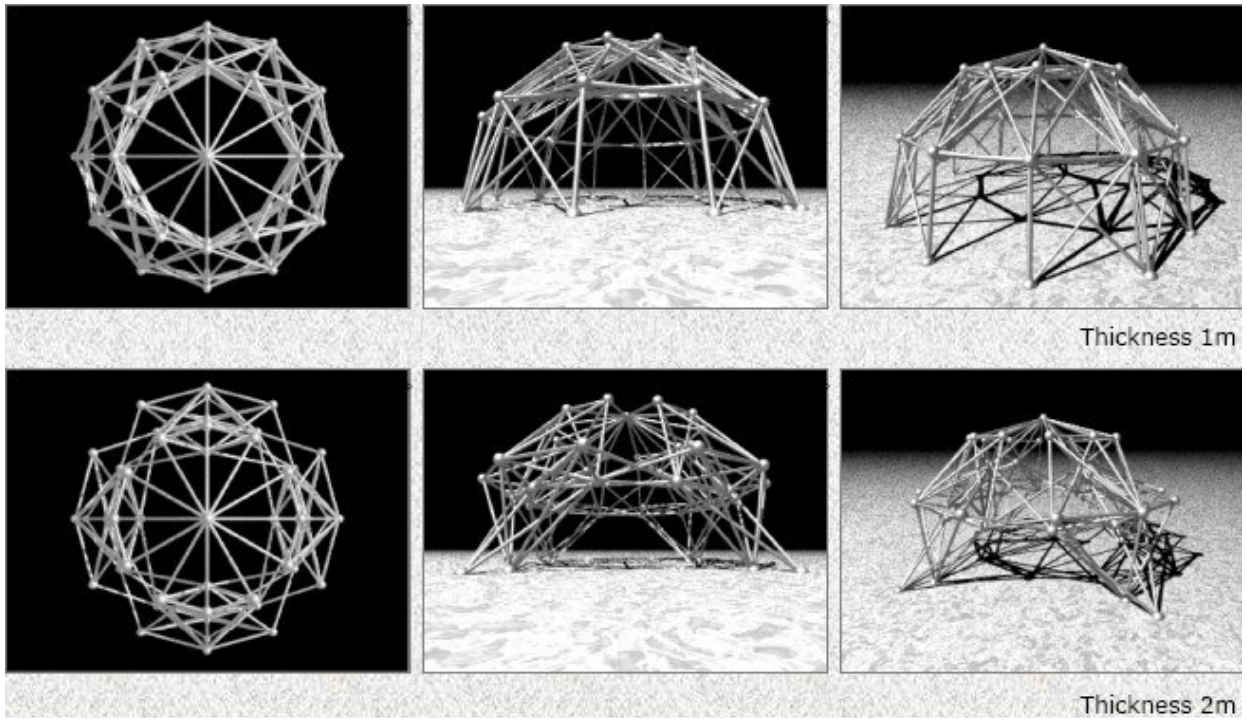
- Computational morphogenesis____ Step 2
  - 2D & 3D Truss and frame topology creation

    Evaluation by finite element analysis

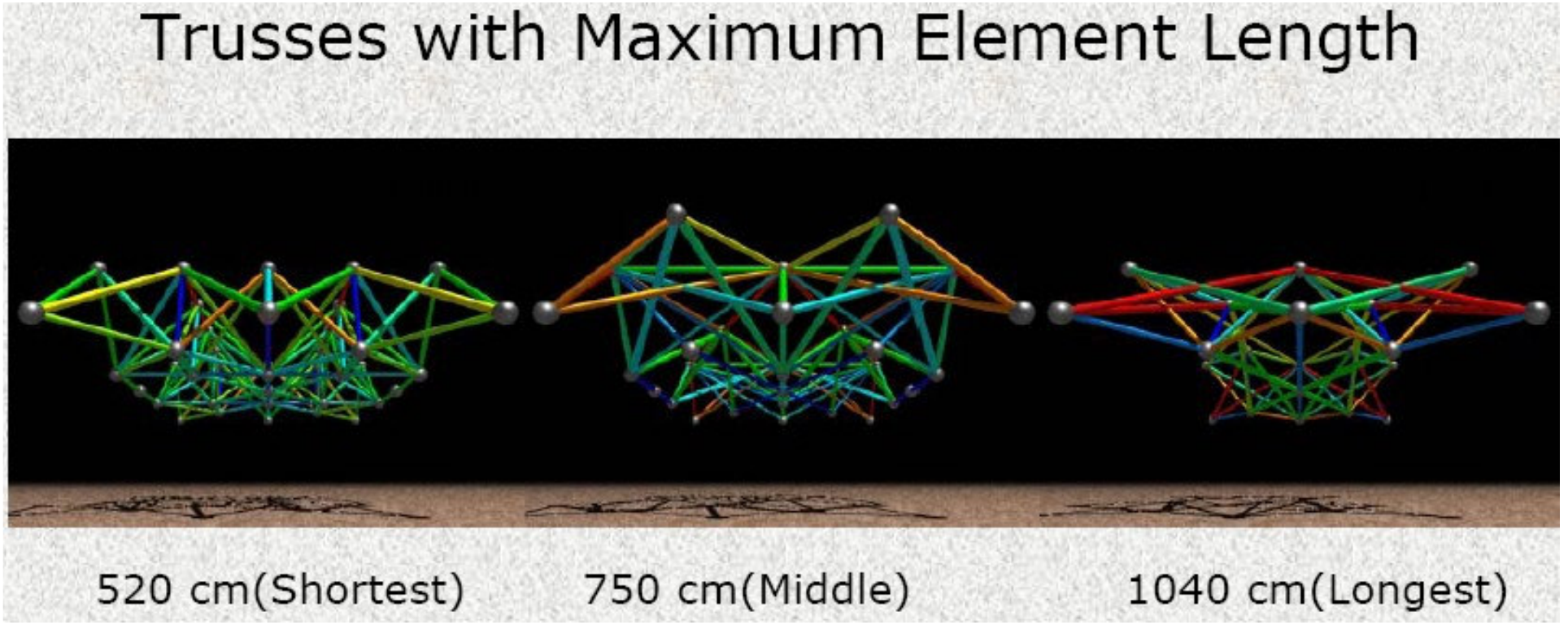
    Genetic Algorithm (selection, cross over, mutation)

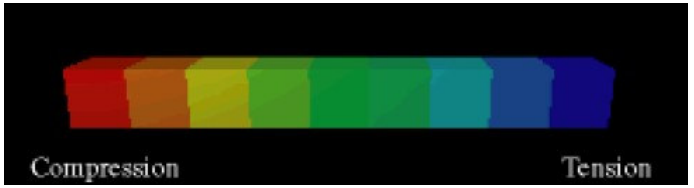
    Constrains on node displacements and axial stress with buckling consideration

H.Ohmori

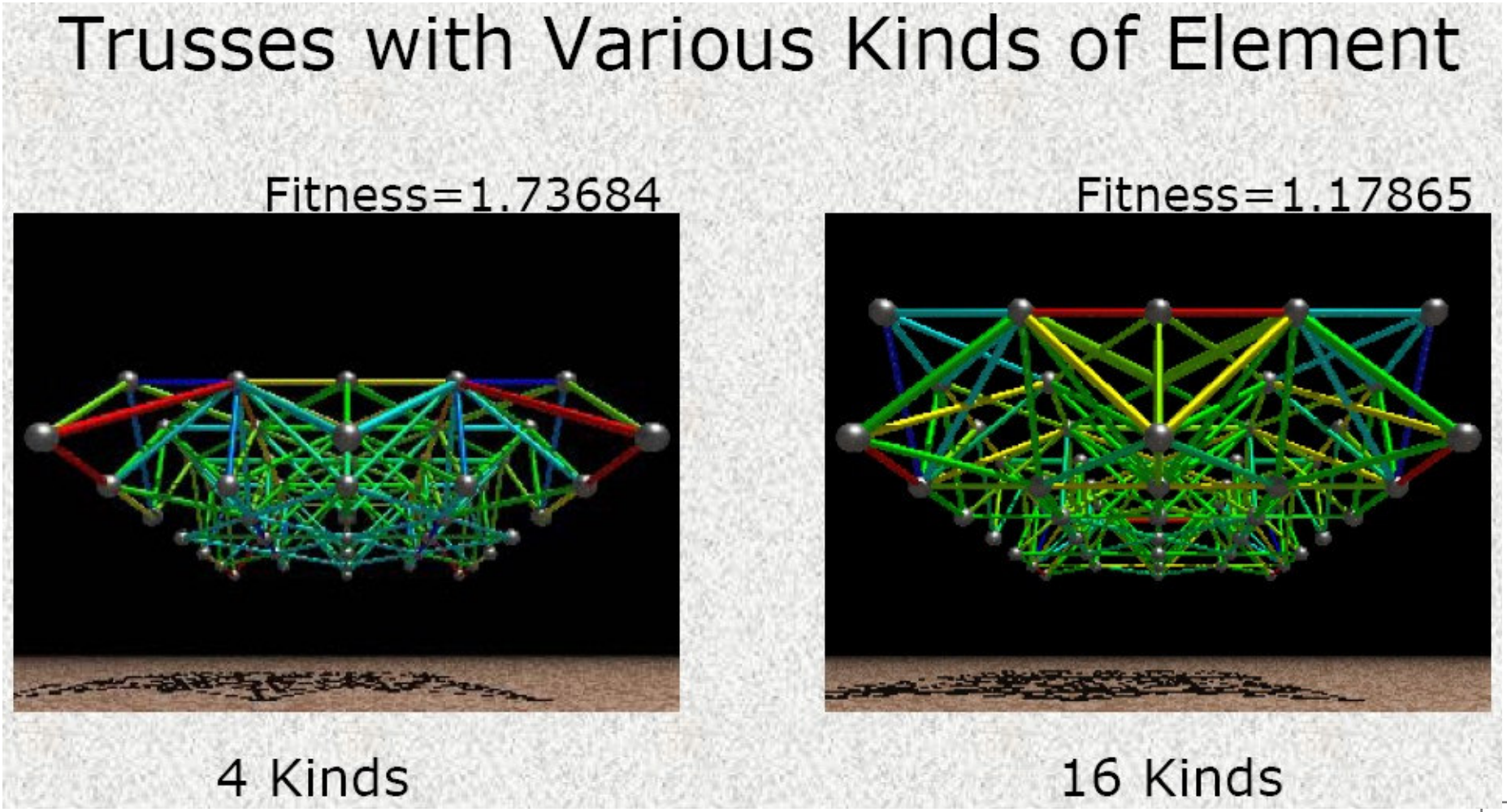


- Computational morphogenesis____ Step 2
  - 2D & 3D Truss and frame topology creation

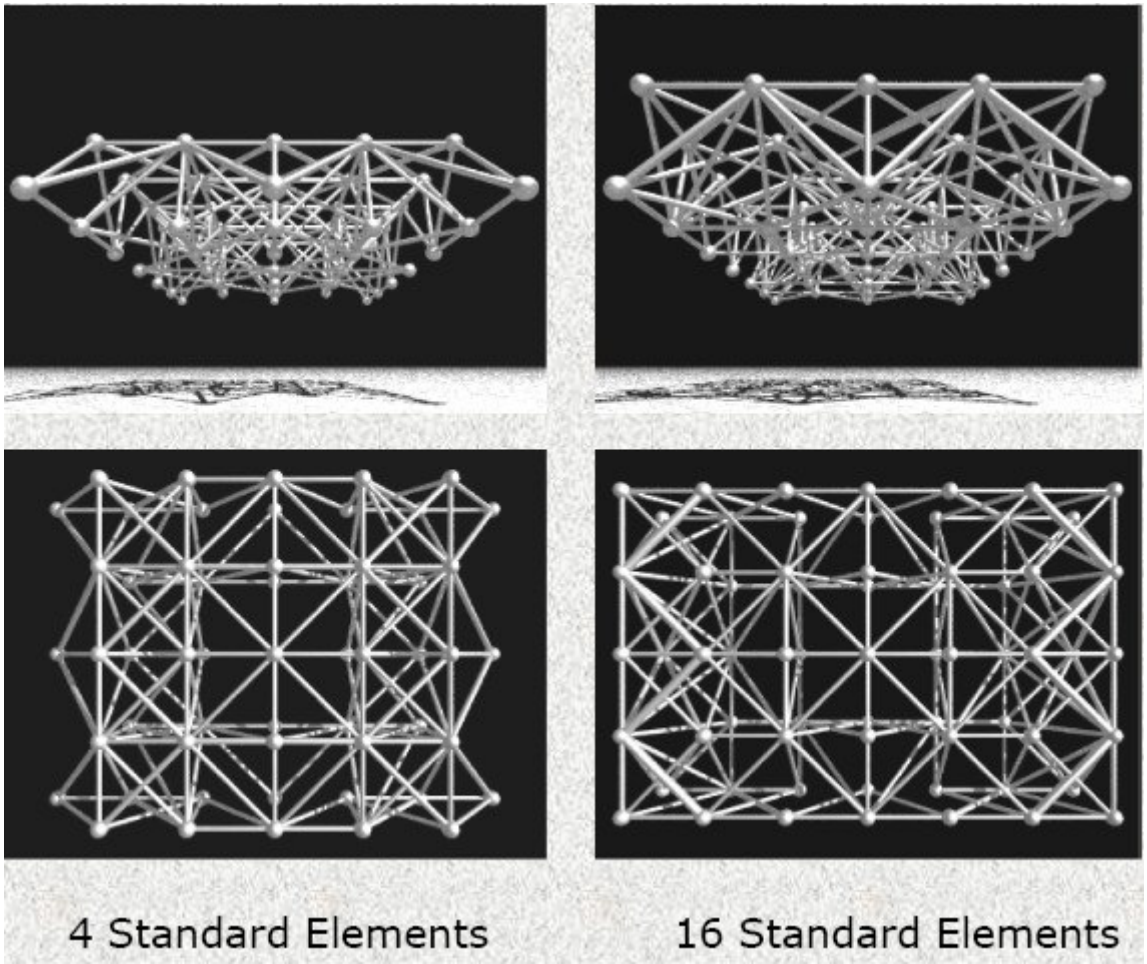




- Computational morphogenesis____ Step 2
  - 2D & 3D Truss and frame topology creation



- Computational morphogenesis____ Step 2
  - 2D & 3D Truss and frame topology creation

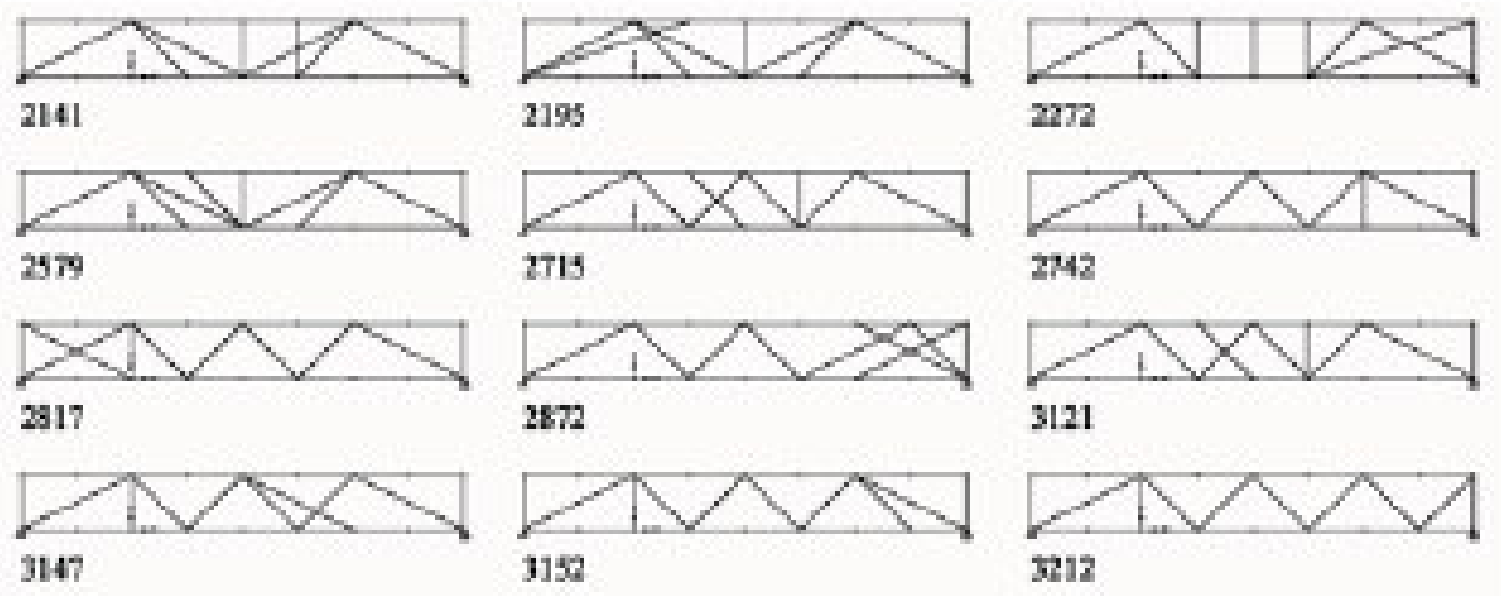


- Computational morphogenesis____ Step 2

  - Bollinger & Grohmann

    Automatic design of lattice girders and lattice girder grids

    Geometrical irregularity & structural efficiency

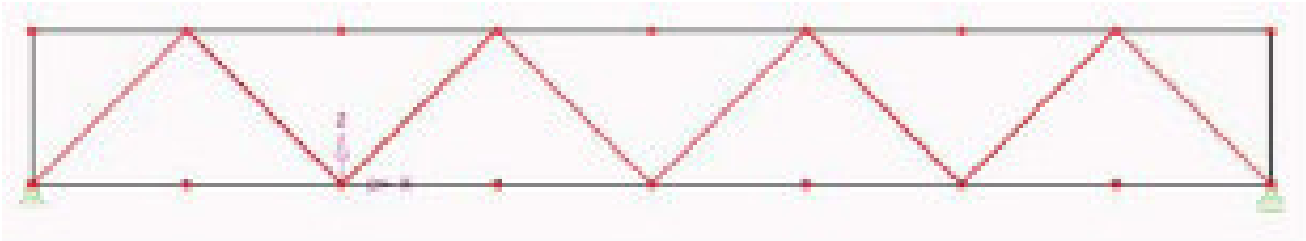


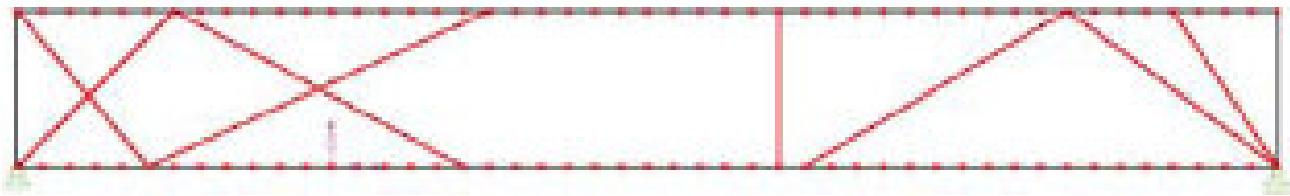
- “Computational morphogenesis_____ Step 2

  - Bollinger & Grohmann

    Automatic design of lattice girders and lattice girder grids

    Geometrical irregularity & structural efficiency





- Computational morphogenesis____ Step 2

  - Bollinger & Grohmann

    Automatic design of lattice girders and lattice girder grids

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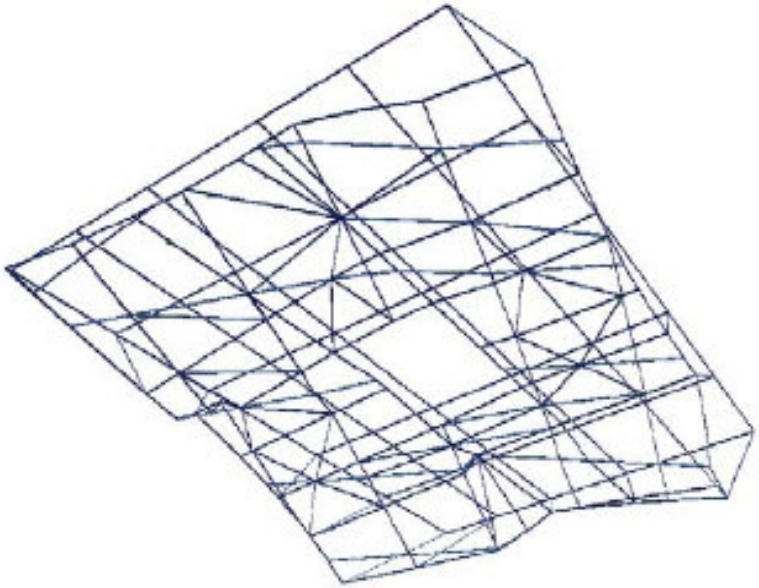


Figure 9: Given Girder Grid

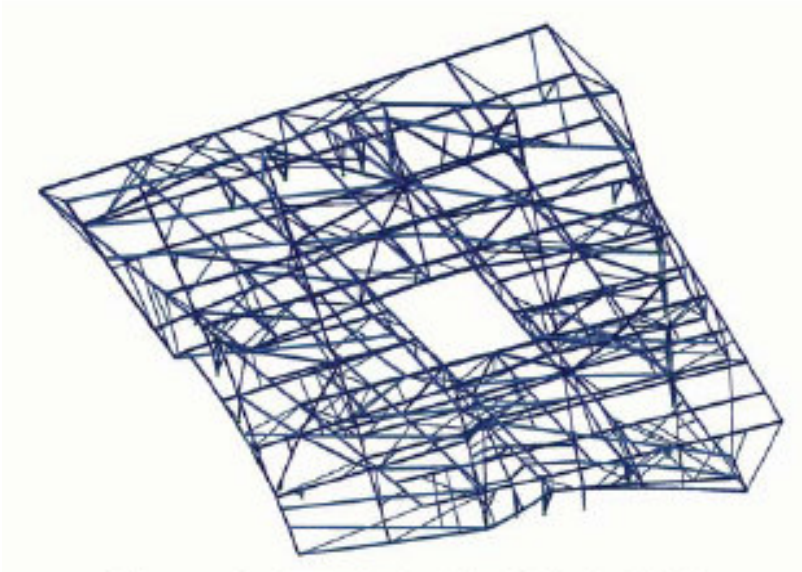


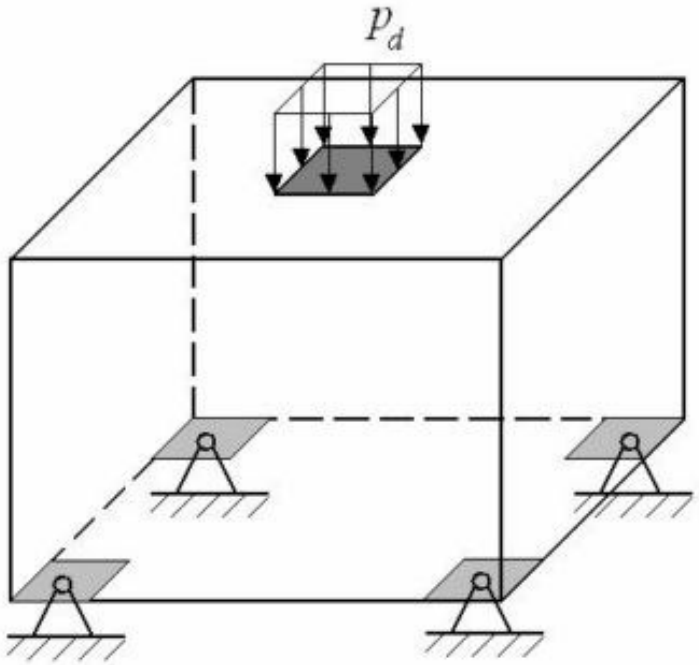
Figure 10: Irregular Latticed Girder Grid

- Computational morphogenesis____ Step 3

  - Creation of 2D and 3D structures from continuum

    Evolutionary Structural Optimisation (ESO) method

    - Deletion of unnecessary portion



- Computational morphogenesis____ Step 3

  - Creation of 2D and 3D structures from continuum

    Evolutionary Structural Optimisation (ESO) method

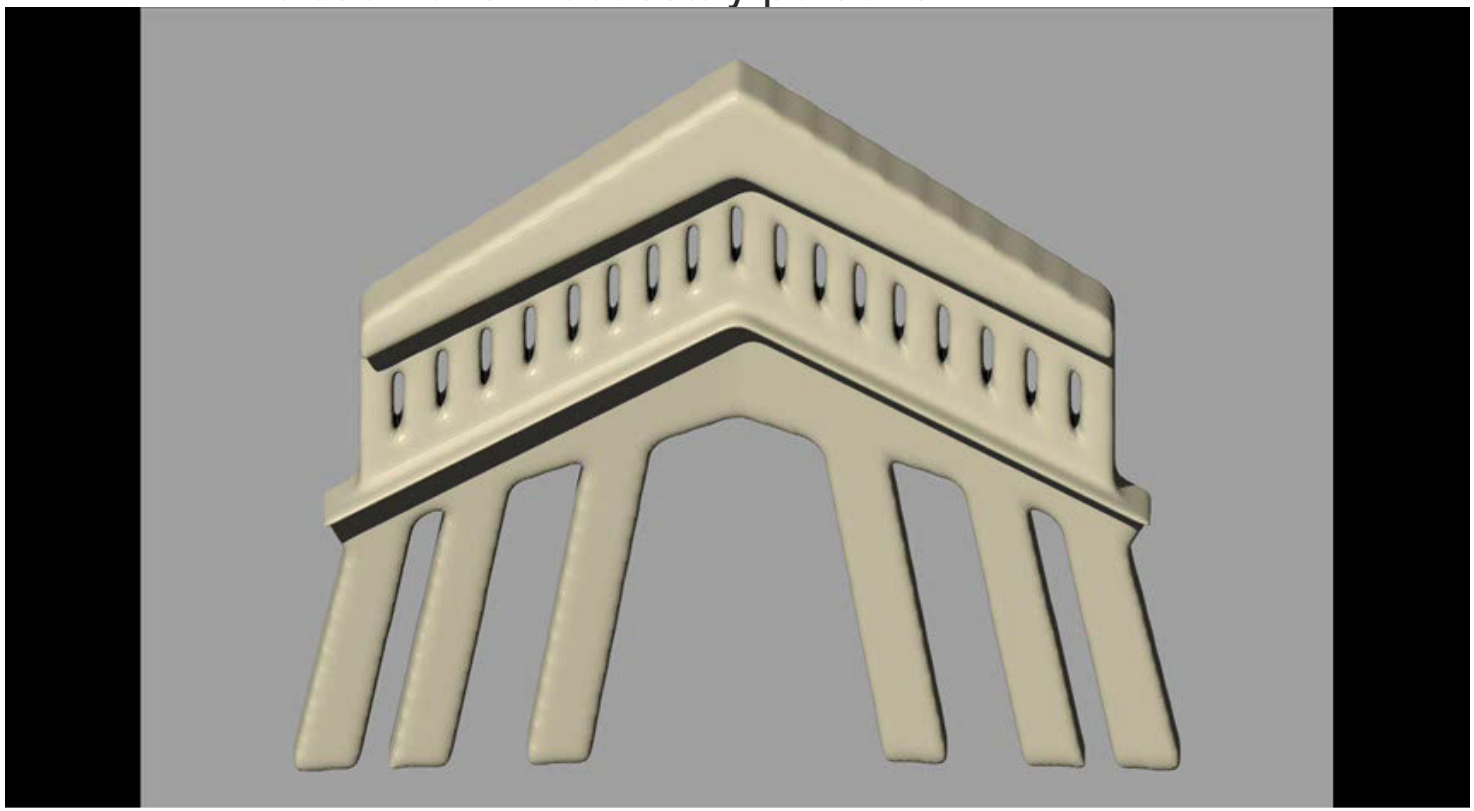
    - Deletion of unnecessary portions

- Computational morphogenesis____ Step 3

  - Creation of 2D and 3D structures from continuum

    Evolutionary Structural Optimisation (ESO) method

    - Deletion of unnecessary portions



- Computational morphogenesis____ Step 4

  - Creation of 2D and 3D structures from continuum

    Evolutionary Structural Optimisation (ESO) method

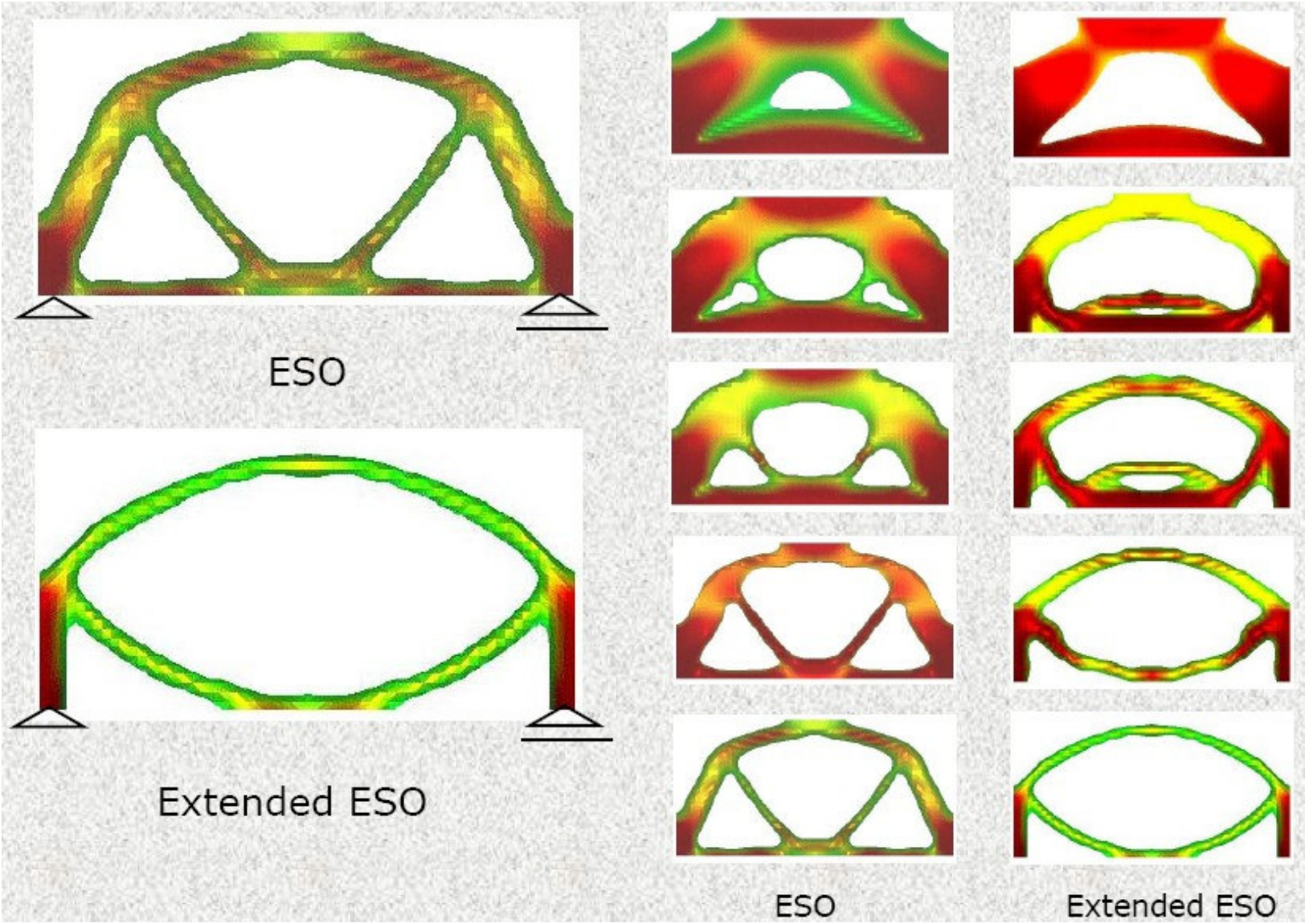
    - Deletion of unnecessary portions

    Extended Evolutionary Structural Optimisation (ESO) method

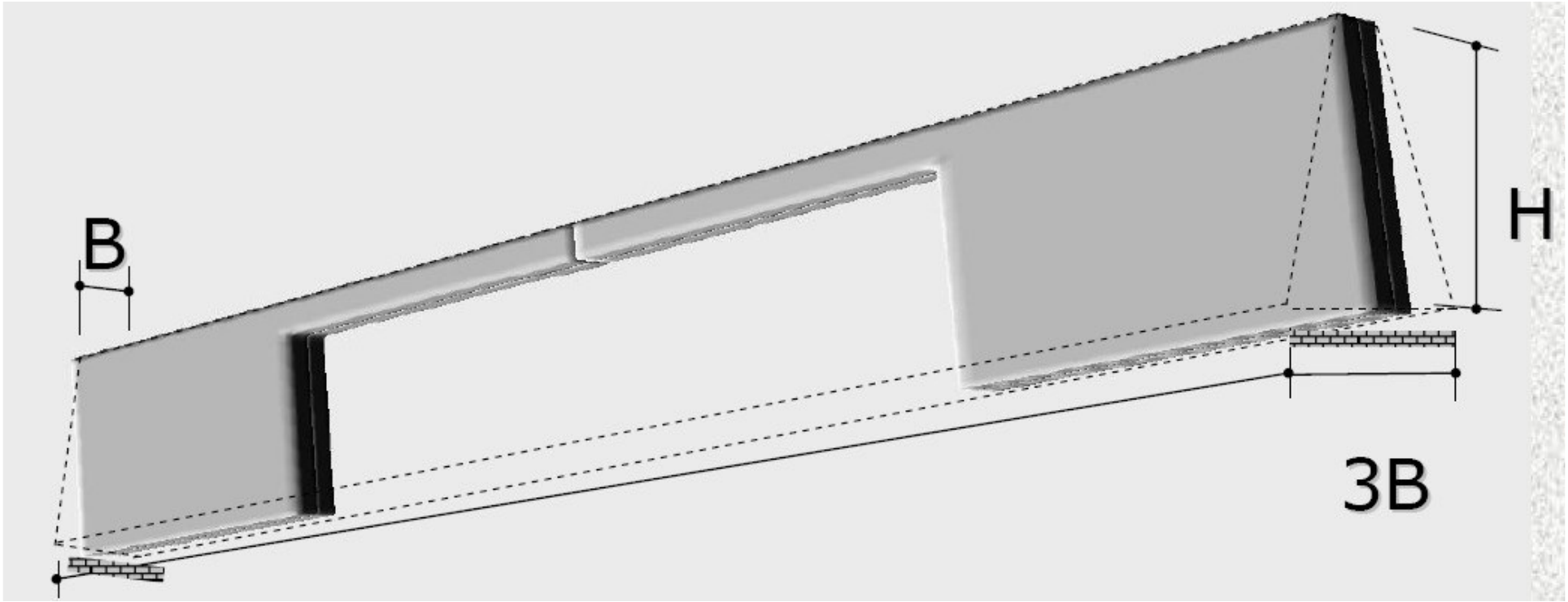
    - Deletion of unnecessary portion
    - Addition of necessary portion
    - Equi-stress contour lines

- Comparison

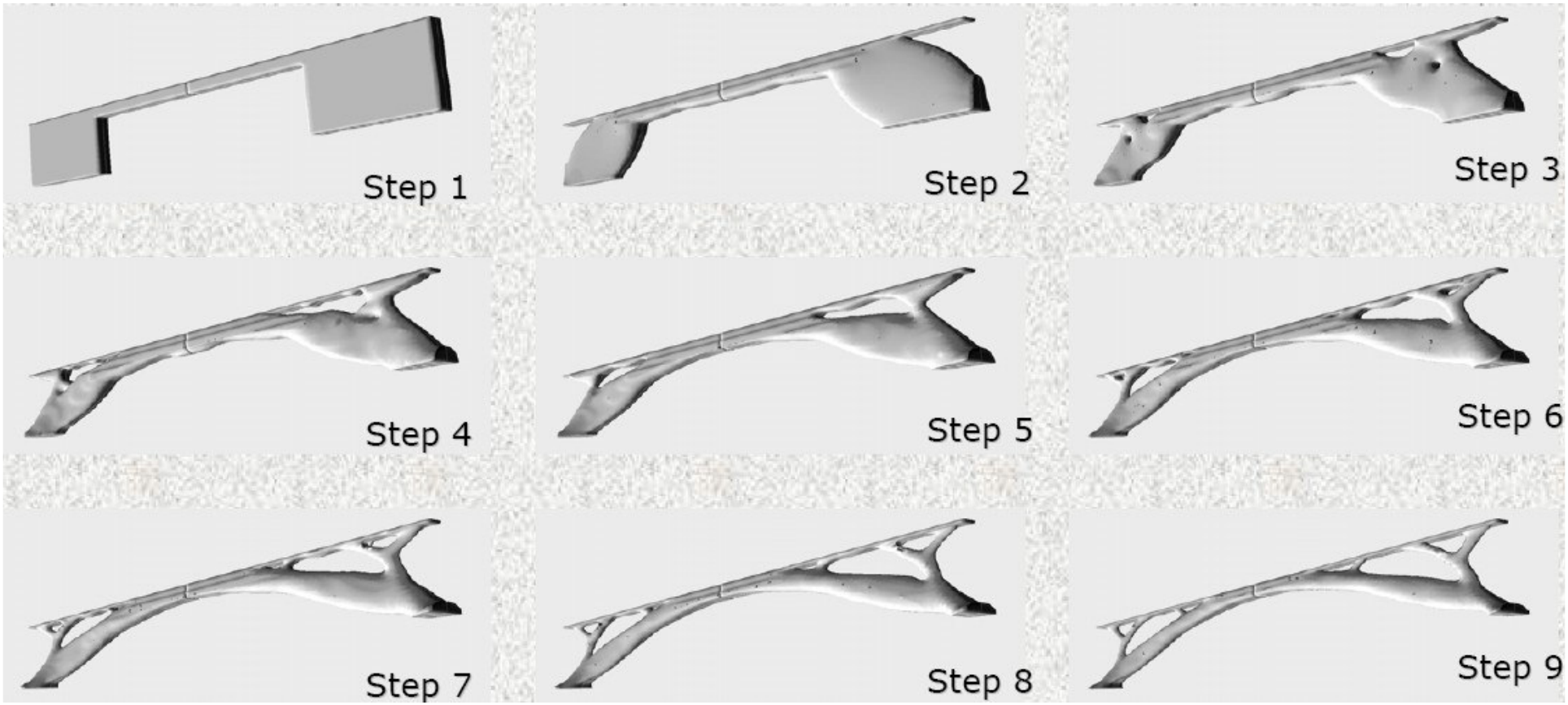
H.Ohmori



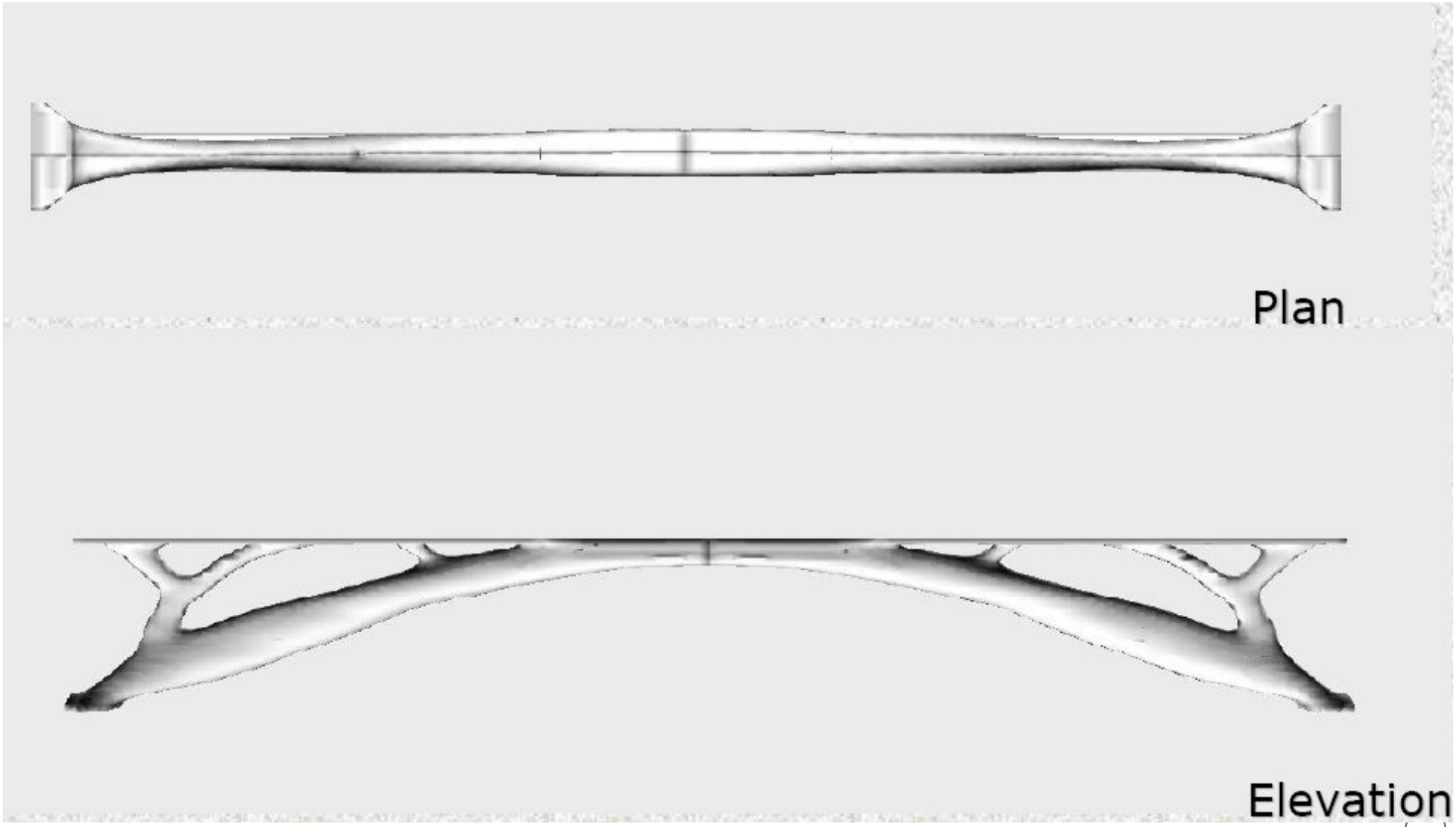
- 3D structure bridge with Extended ESO



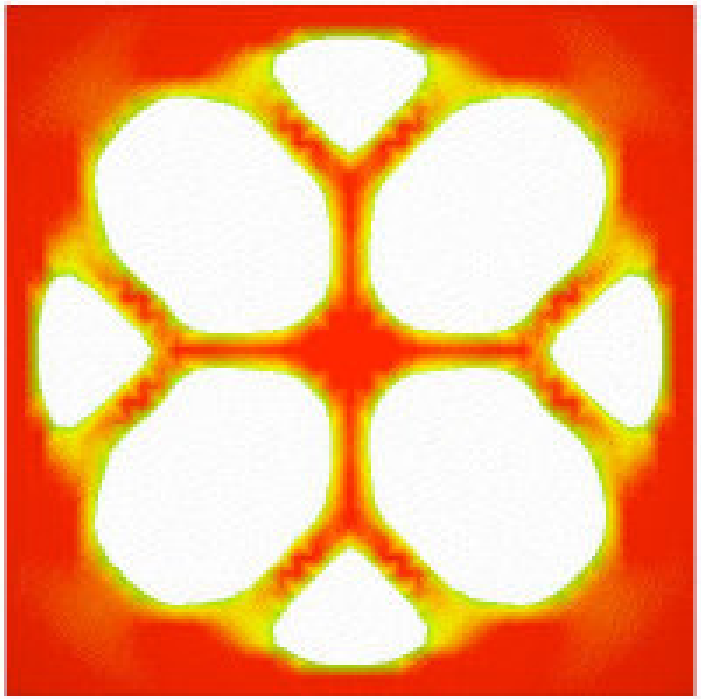
- 3D structure bridge with Extended ESO

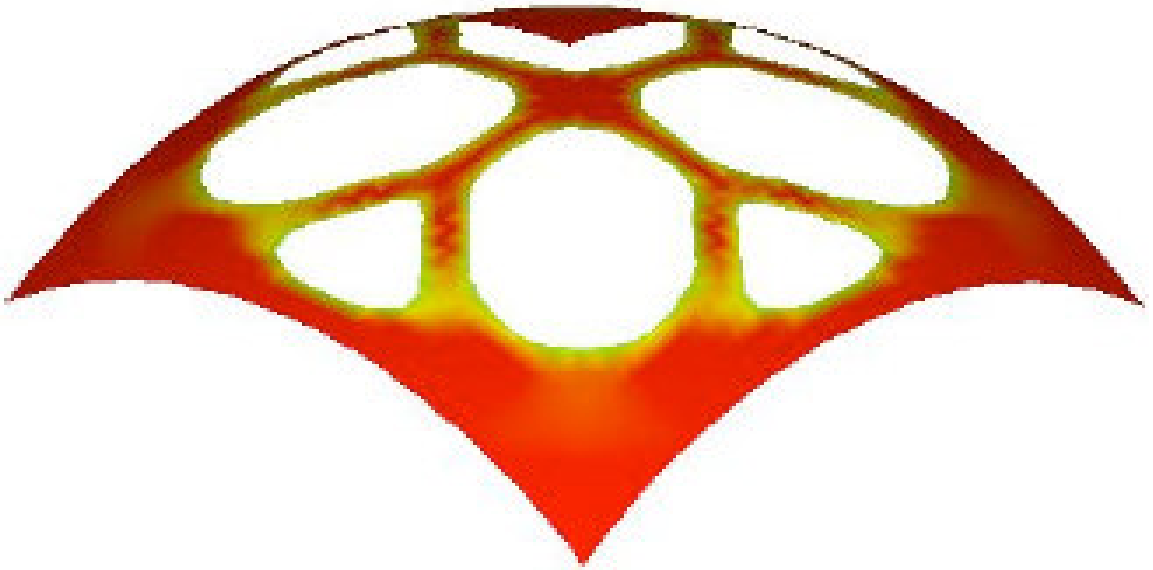


- 3D structure bridge with Extended ESO

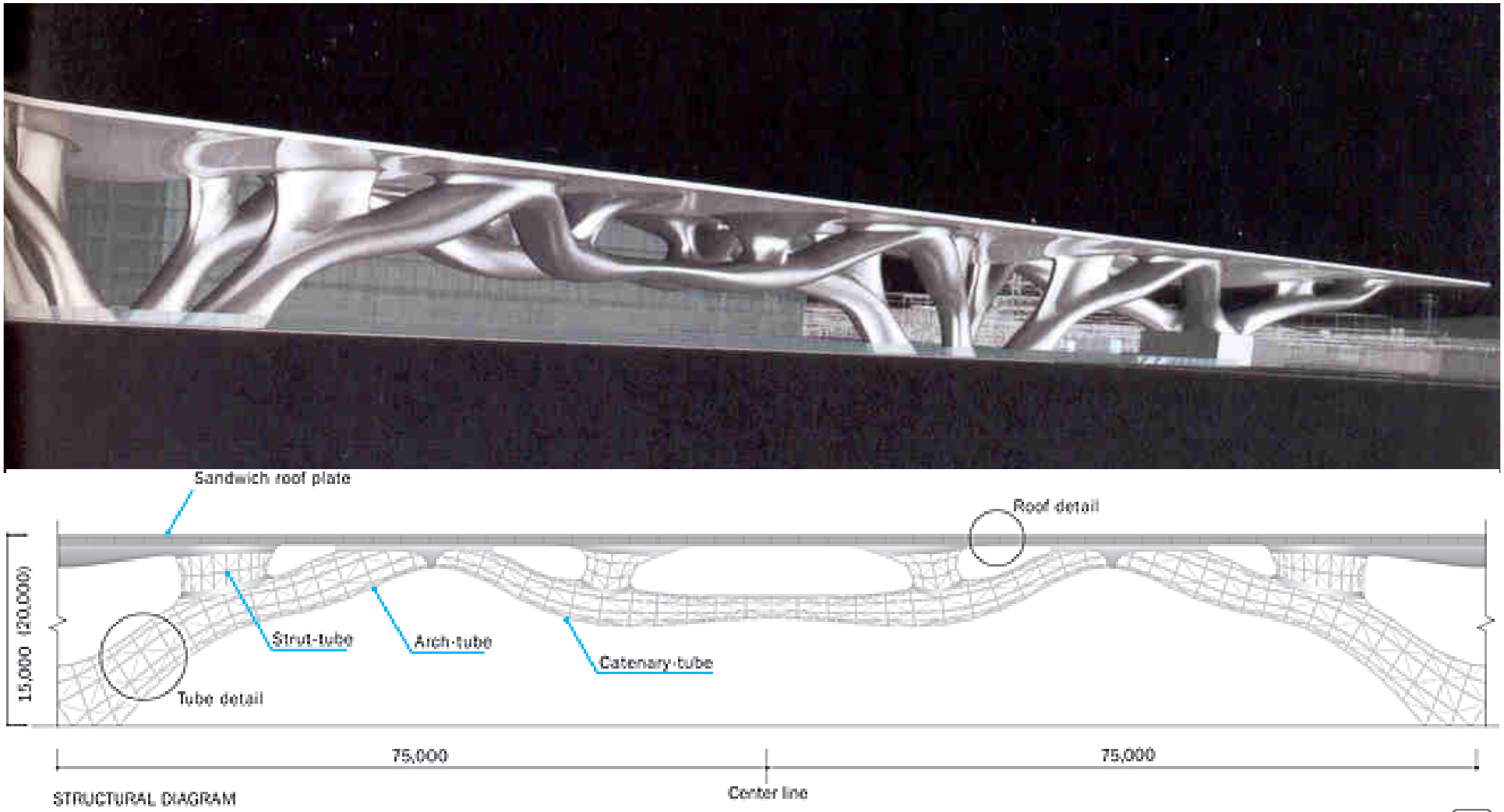


- Shell design with Extended ESO



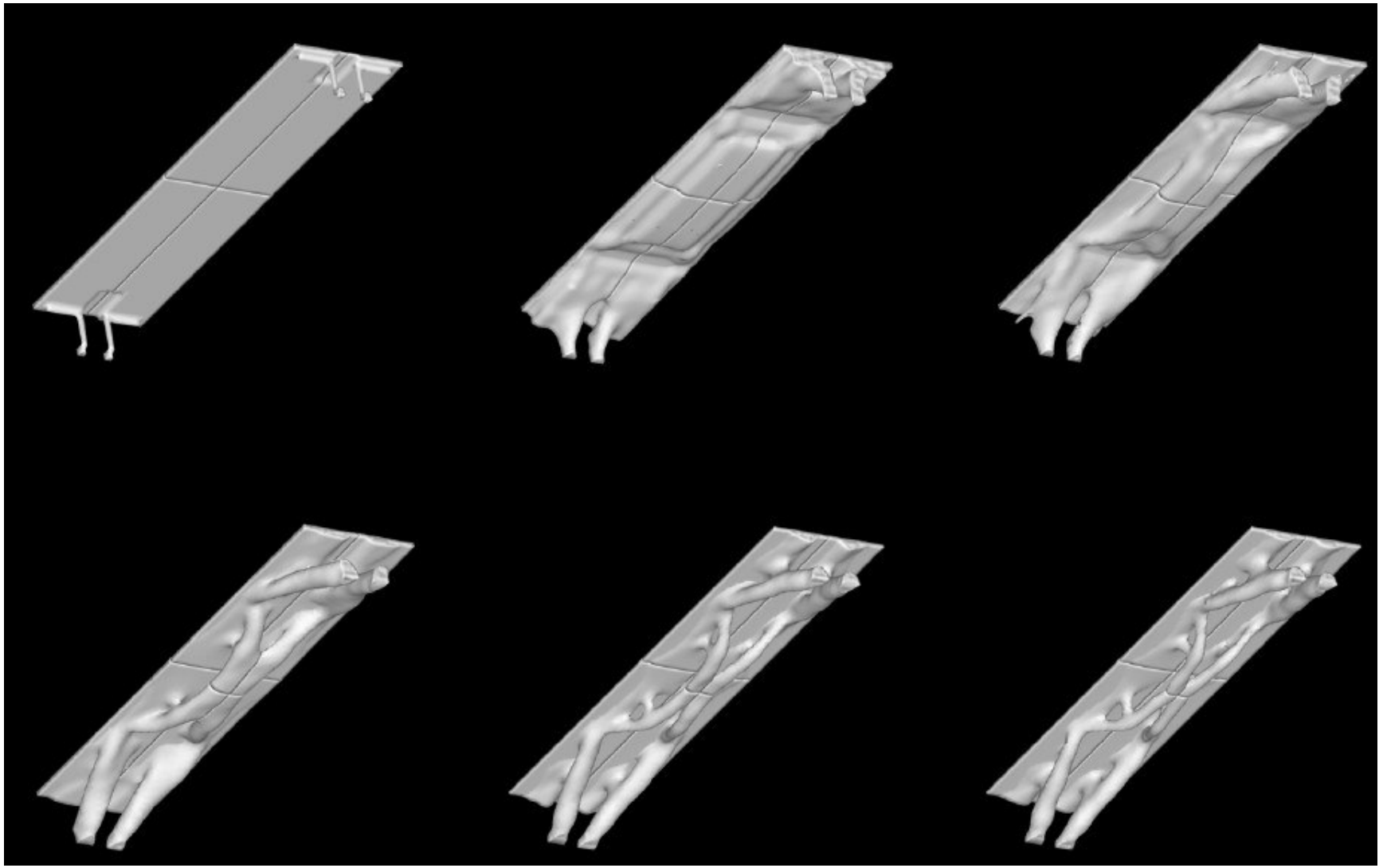


- Architectural competition



Firenze New station building project – A. Isozaki with M.Sasaki

- Architectural competition

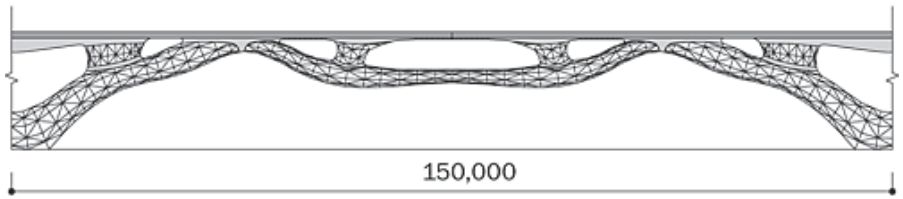


Firenze New station building project – A. Isozaki with M.Sasaki

Construction

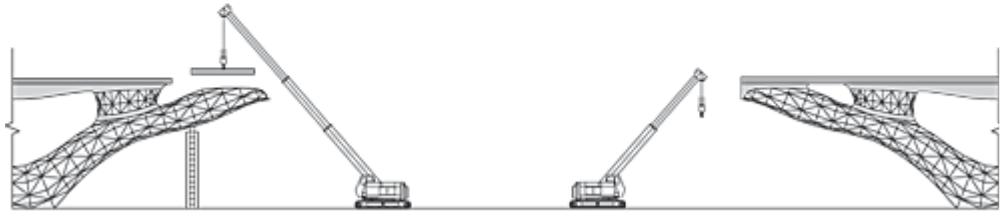
Firenze New station building project

– A. Isozaki with M.Sasaki

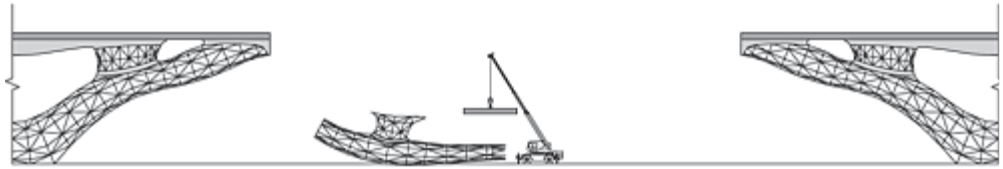


FEM Analysis

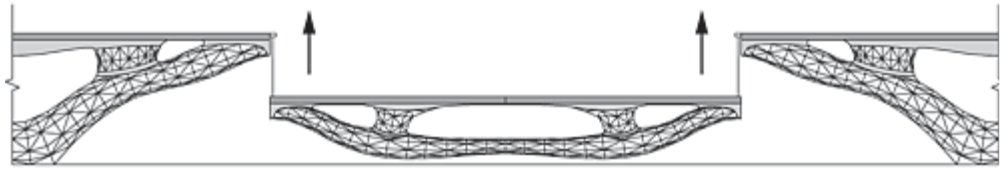
Step 1: Assembly of the Arch-Tube
Assembled units are prefabricated in factory and transported to the site. The sizes of each unit are defined by the size of trailer and other transportation equipments.



Step 2: Arch-Tube and Sandwich Roof Plate
Canitlevered truss construction. The sandwich roof plates are set on the arch-tube.

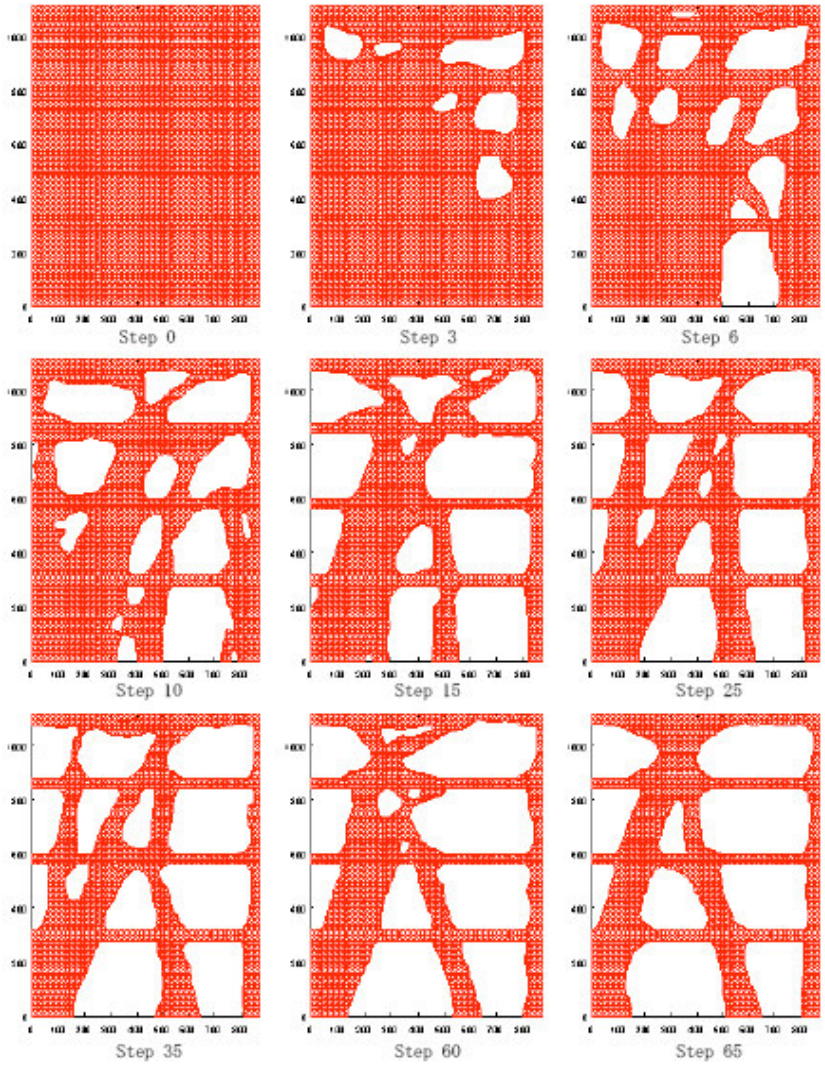


Step 3: Catenary-Tube and Sandwich Roof Plate
Center part is preassembly. Catenary-tube and sanwich roof plate are assembed on the ground.



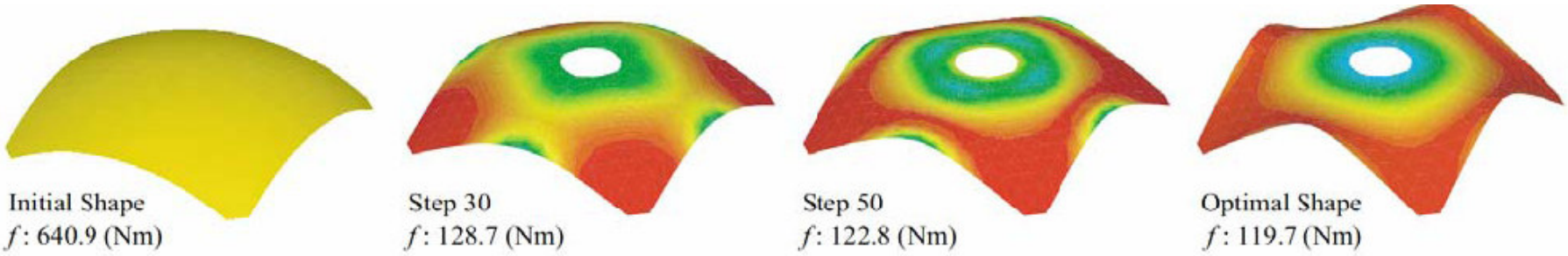
Step 4: Center part is lifted up and connected to both sides.

- Structural design : Application to office building



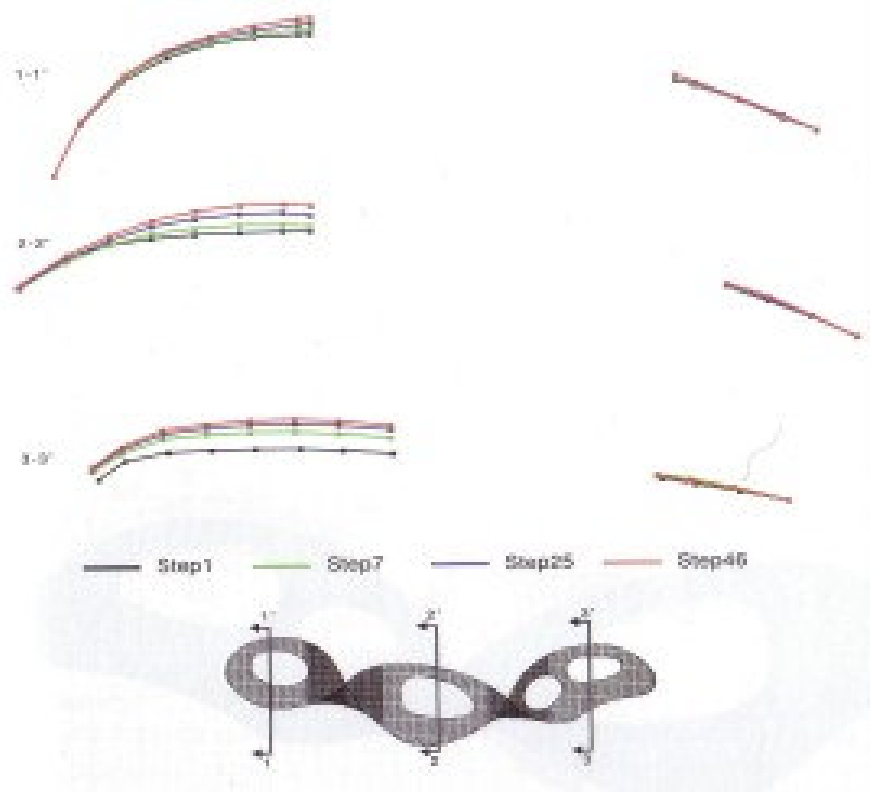
- Computational morphogenesis____ Step 5

  - Creation of shell structures as example of multi-objective optimization
  - No perfect solution exists
  - Several solutions



- Computational morphogenesis____ Step 5

  - Creation of shell structures as example of multi-objective optimization
  - Sasaki & partners



I project – Japan – Toyo Ito – 2005 – 40cm thick

- Computational morphogenesis____ Step 5

  - Creation of shell structures as example of multi-objective optimization
  - Sasaki & partners



I project – Japan – Toyo Ito – 2005 – 40cm thick

- Computational morphogenesis____ Step 5

  - Creation of shell structures as example of multi-objective optimization

  - Sasaki & partners

Kakamigahara crematorium – Japan – Toyo Ito – 2004-2006

Conclusion

- New design tools aiming at improving interoperability between partners
- Specially dedicated to architectural design
- Just a beginning …more constrains should be considered in the future to reach sustainable designs
- Don’t be fascinated by powerful tools…human brain is sill the best designer