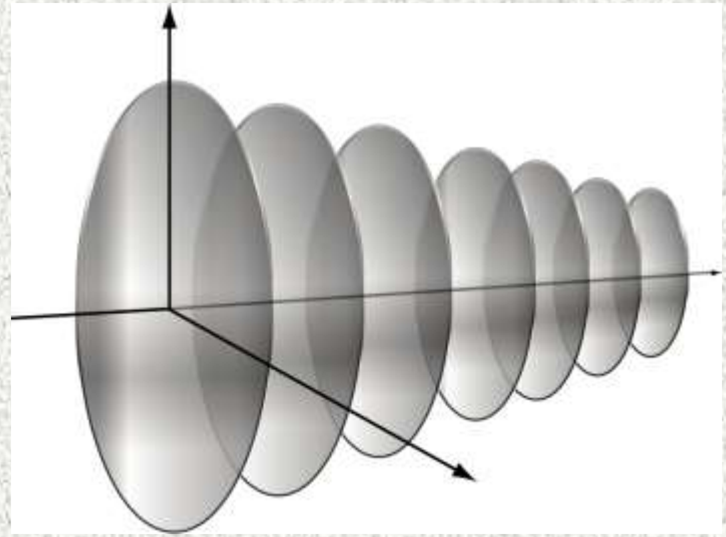
Computational Morphogenesis

- Its Current State and Possibility for the Future -



Hiroshi Ohmori
Nagoya University, Japan

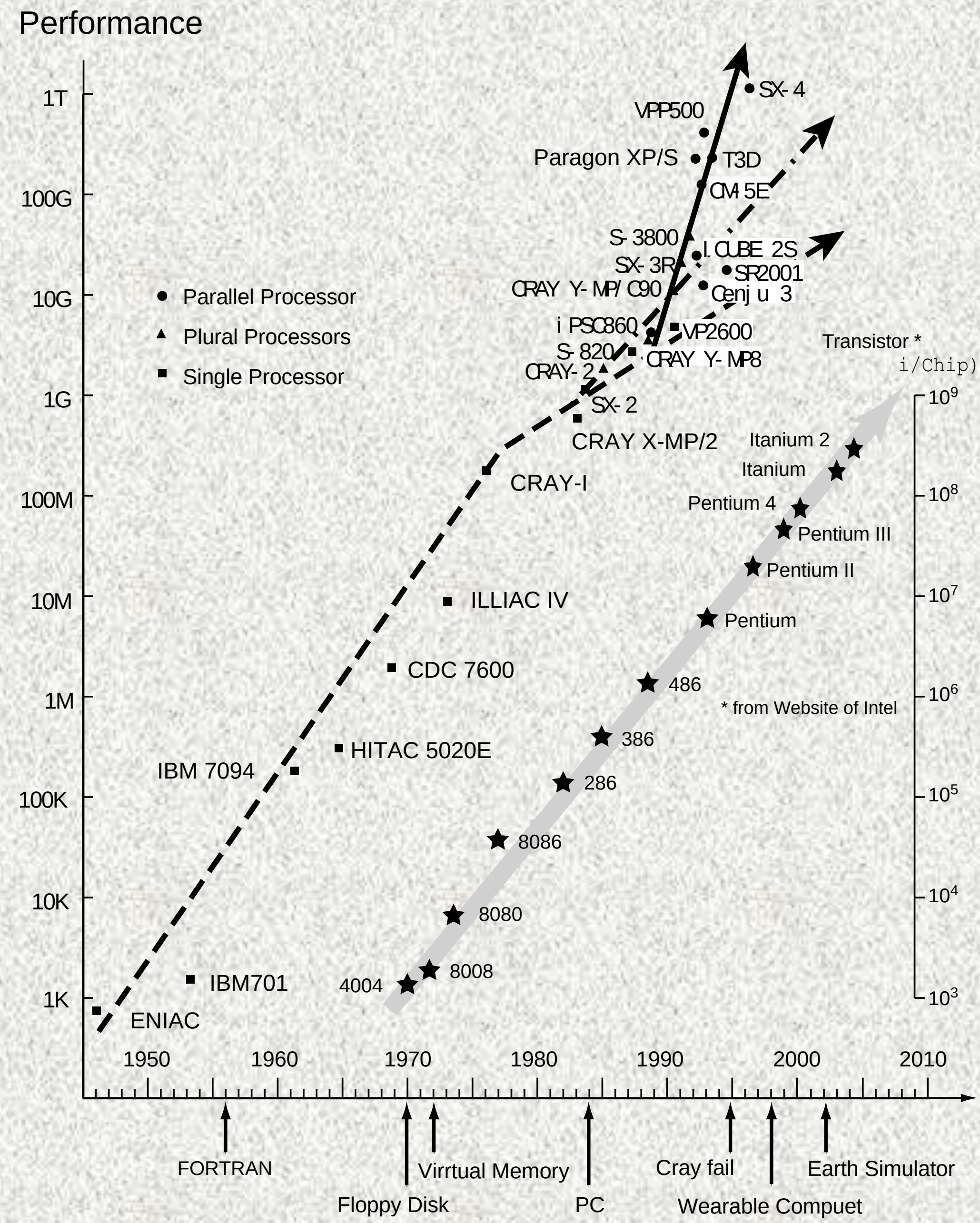
Finite Element Method

- 1956 M. J. Turner, R. W. Clough, H. C. Martin and L. J. Topp: "Stiffness and Deflection Analysis of Complex Structures"
- Early 60s Infant Period - Vast Numbers of Application to Structural Problems
- Late 60s Mathematical Proofs of Convergence
- 70s Application to Non-Structural Problems - Fluid, Heat, Sound, Soil and Electro-Magnetic Problems
- After 80s Visualization, Virtual Reality, Super High Degree-of-Freedom Problem....

Structural Optimization

- 1900 Michel Truss Problem - Truss Topology Problem
- 60s Size Optimization Problem - Section Area of Truss Structures, Linear Programming Scheme
- 70s Size Optimization - Section Area of Beam, Linear Programming Scheme
- 80s - 90s Size Optimization - Shell Form, Shape of Rigid Frames, Nonlinear Programming Scheme
- 1995 Truss Topology Optimization - Homogenization Design Method, Genetic Algorithms

Computer



History of Computer Performance

Truss Optimization

- Evaluation : Finite Element Analysis
- Genetic Algorithm (Selection, Crossover, Mutation)

Fitness Function

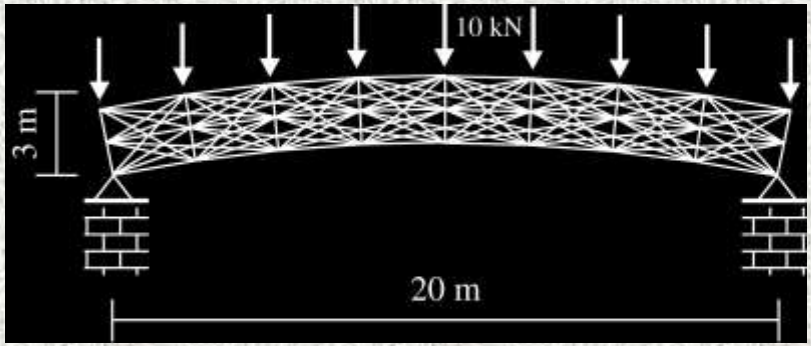
$$f = \frac{1}{W(\boldsymbol{x}, \boldsymbol{A})} \prod_i g_i$$

- Constraints

  on Nodal Displacement

  on Axial Stress with Buckling Consideration

Truss Optimization

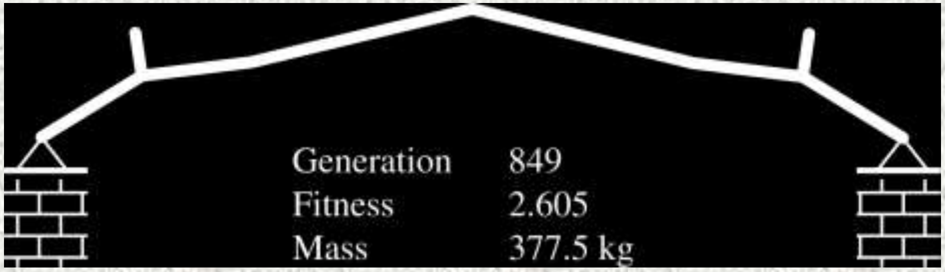


Variables
- Element Arrangement
- Sectional Area

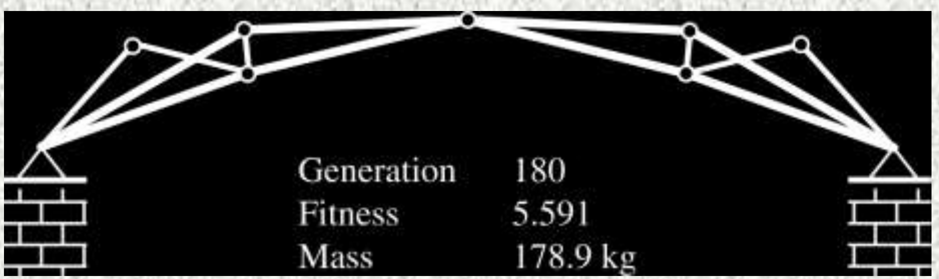
Constraints
- Nodal Displacement
- Stress Resultant

Young's Modulus	210 GPa
Population	20
Elite	2
Generation for Layout	200
Generation for Sectional Area	200
Generation for Material	100
Generation for Connection	200
Displacement Limit	70 mm
Stress Limit (Tension)	160 MPa
(Compression)	Buckling Stress

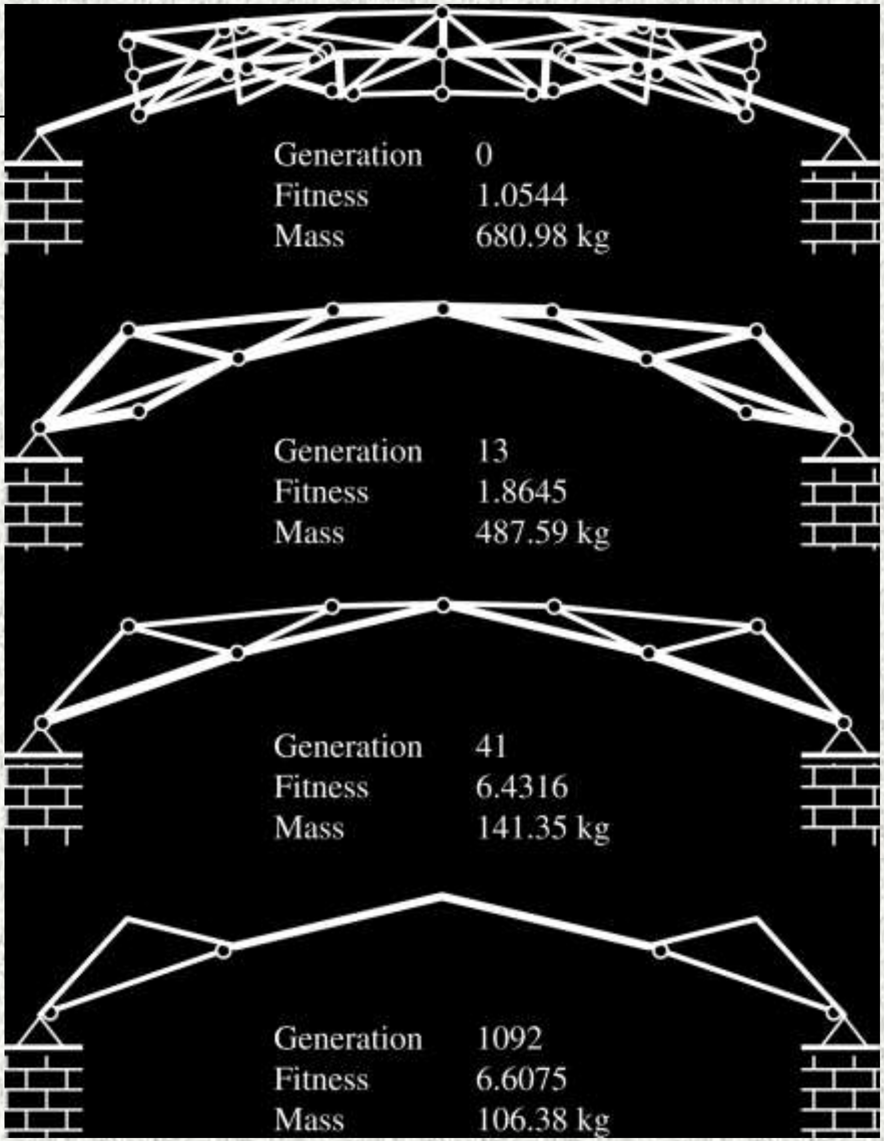
Truss Optimization



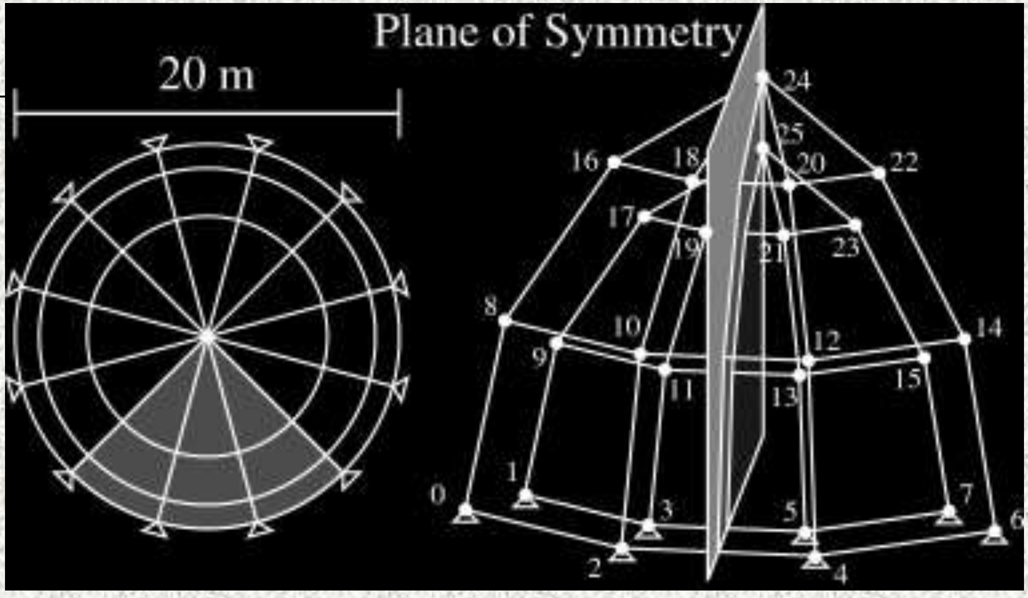
Frame Structure



Truss Structure



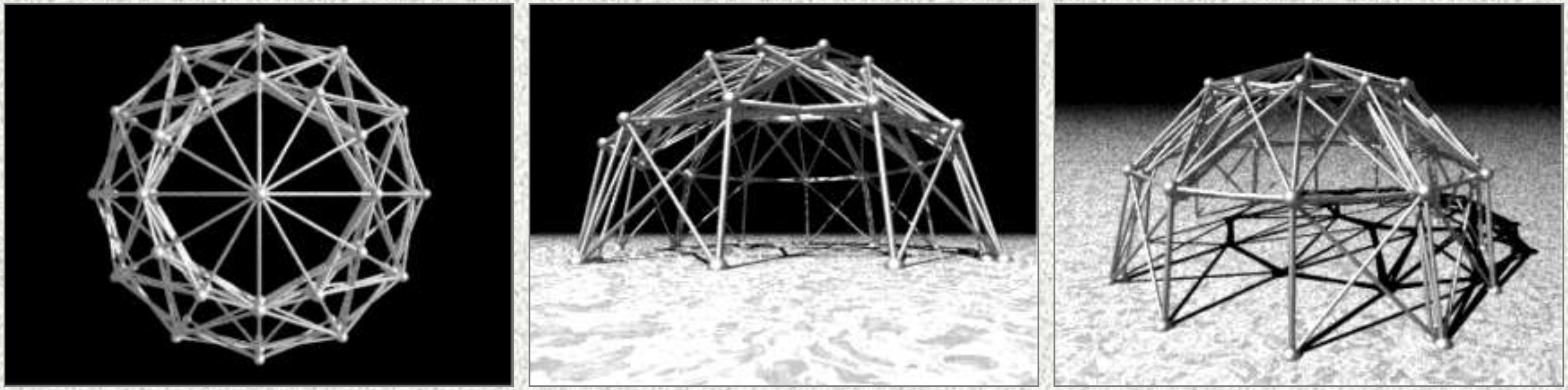
Truss Optimization



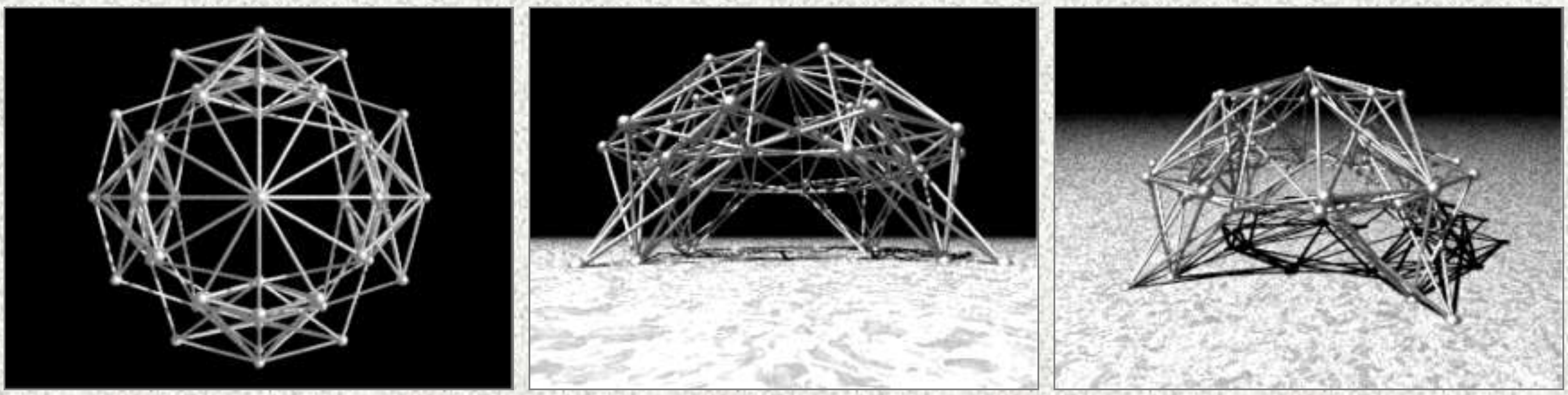
- Layer Thickness
- Rise

Population	20
Elite	2
Generation for Layout	500
Generation for Sectional Area	500
Generation for Material	50
Displacement Limit	20 mm
Stress Limit (Tension)	160 MPa
Stress (Compression)	Buckling

Truss Domes

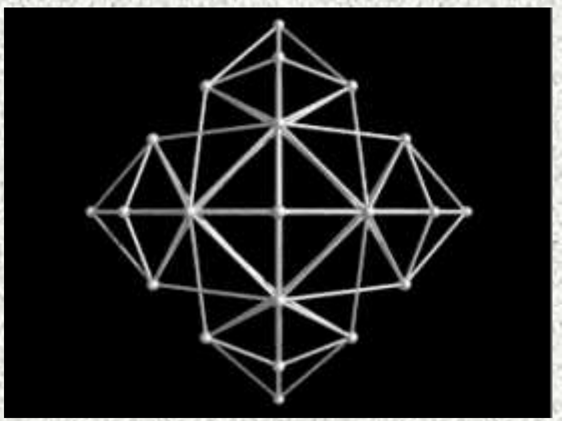
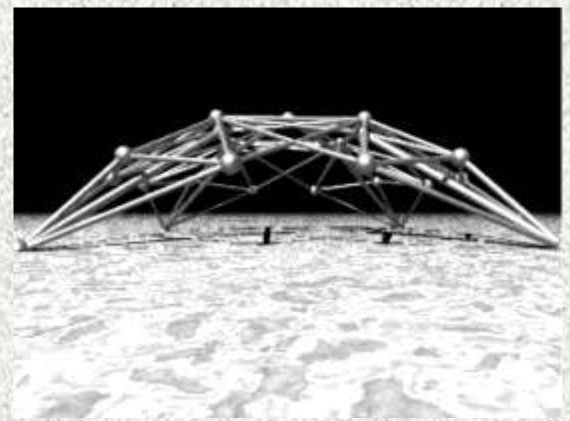
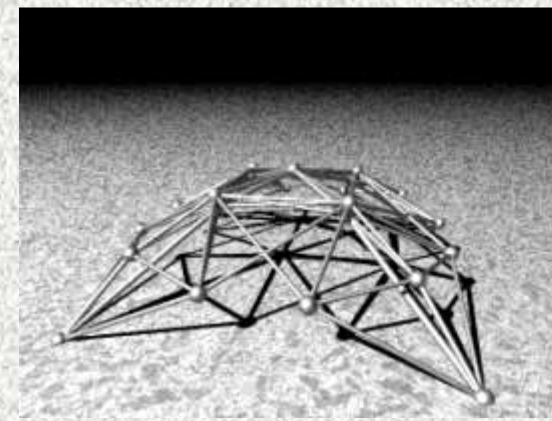


Thickness 1m

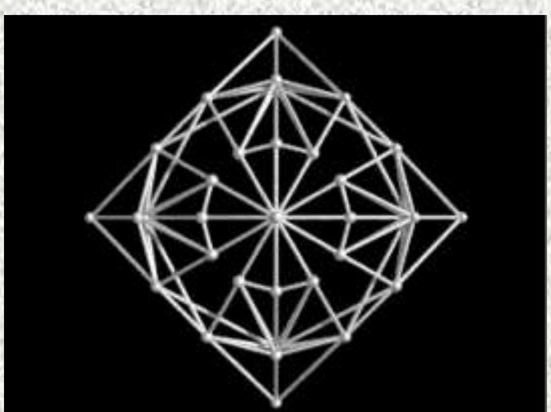
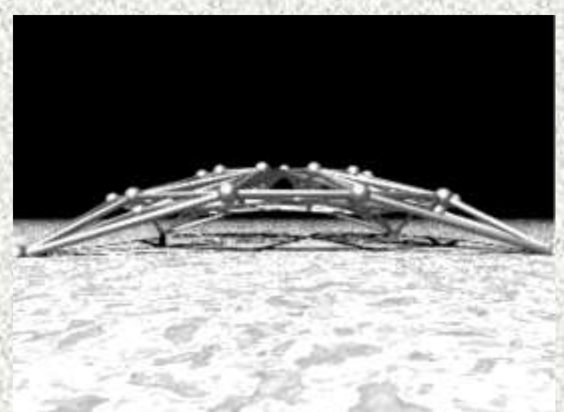
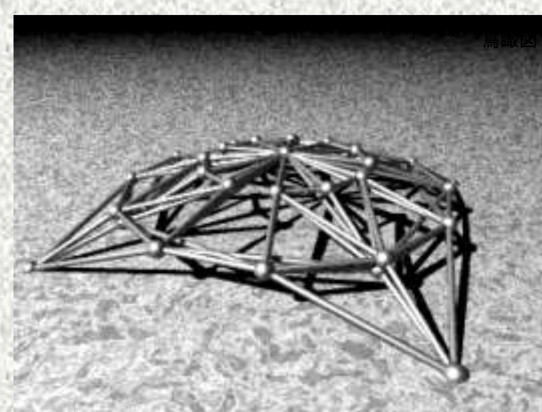


Thickness 2m

Truss Domes

Rise 5m

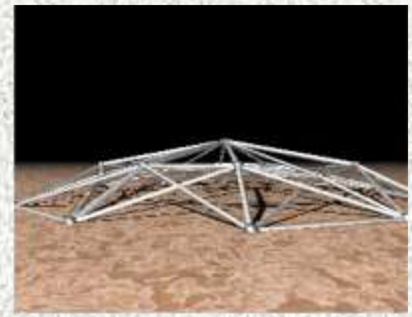




Rise 3m

Hybrid System Domes

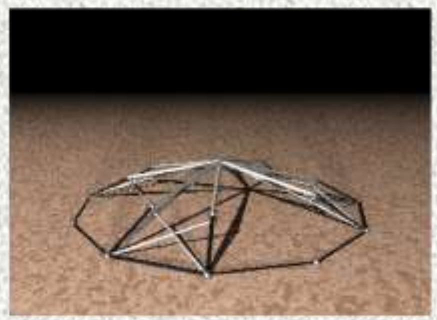
Horizontal View

Bird's Eye View



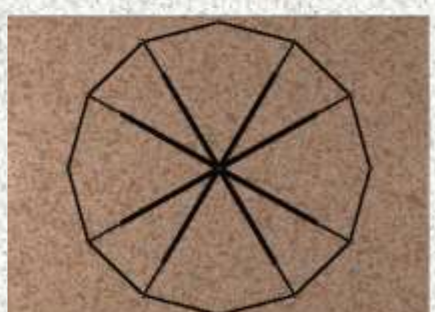
Vertical View

Horizontal View



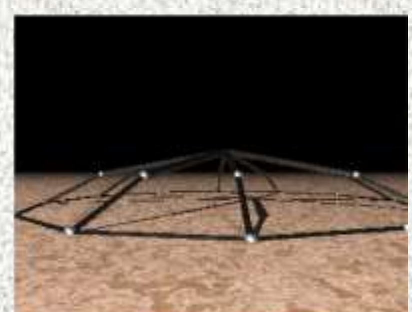
Bird's Eye View

Vertical View



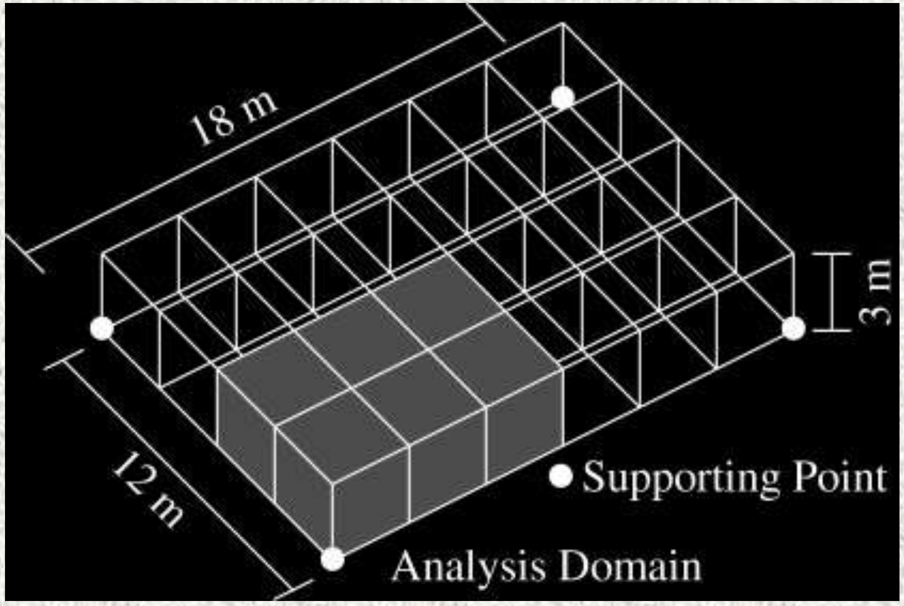
Horizontal View

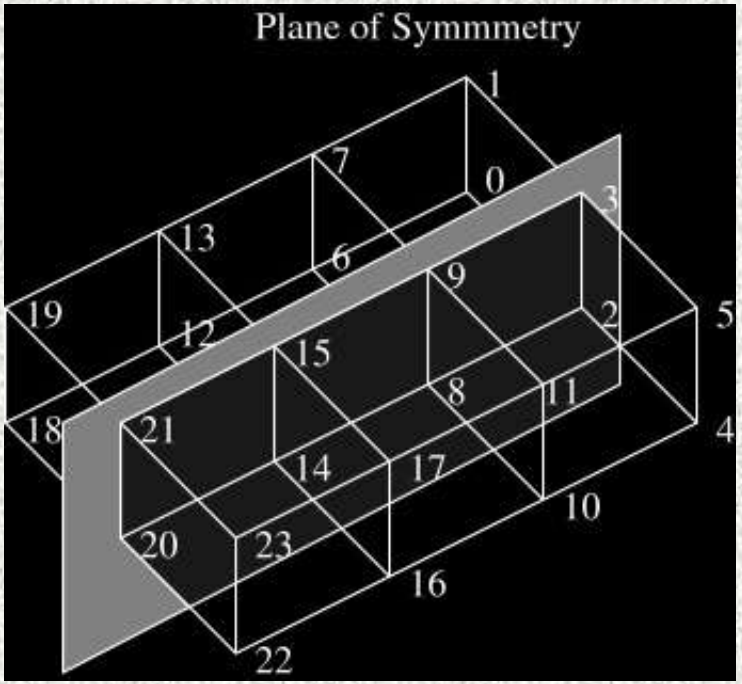
Bird's Eye View



Vertical View

Roof Truss



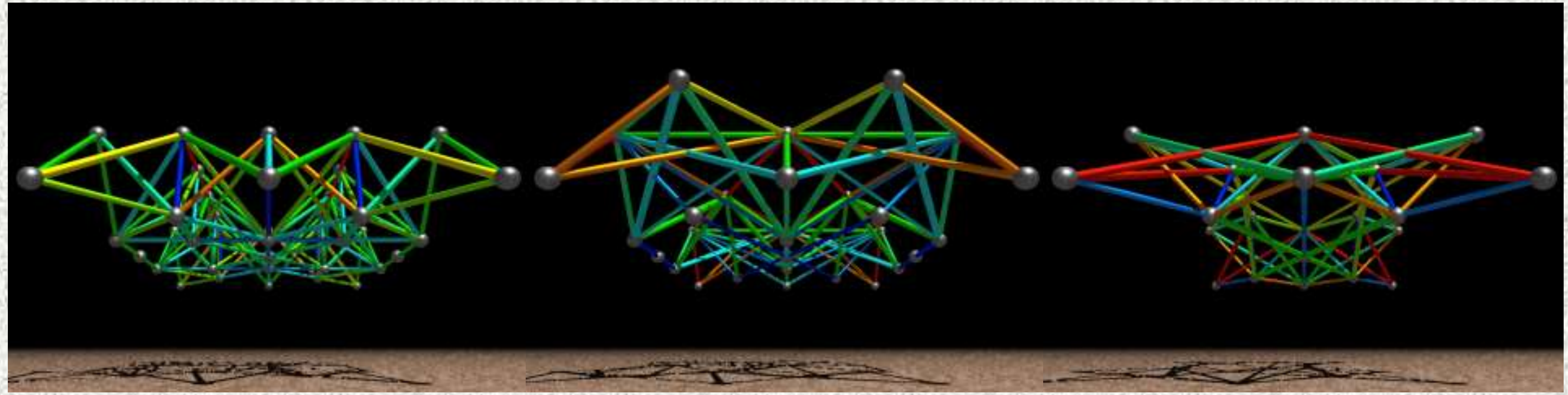


Whole Shape

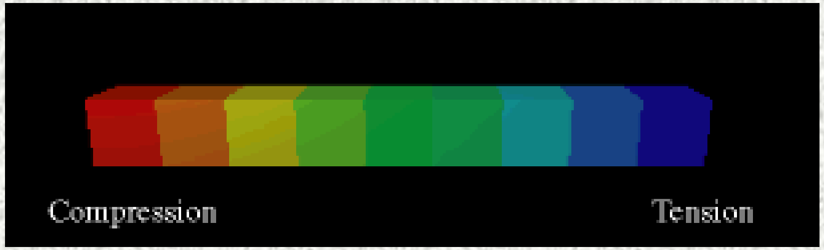
Target Region

500 Pa Vertical Load on the Top Plane

Trusses with Maximum Element Length

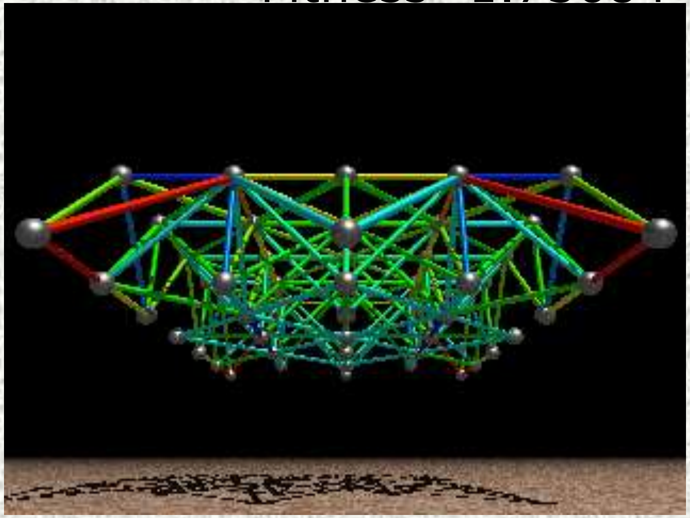


520 cm(Shortest) 750 cm(Middle) 1040 cm(Longest)



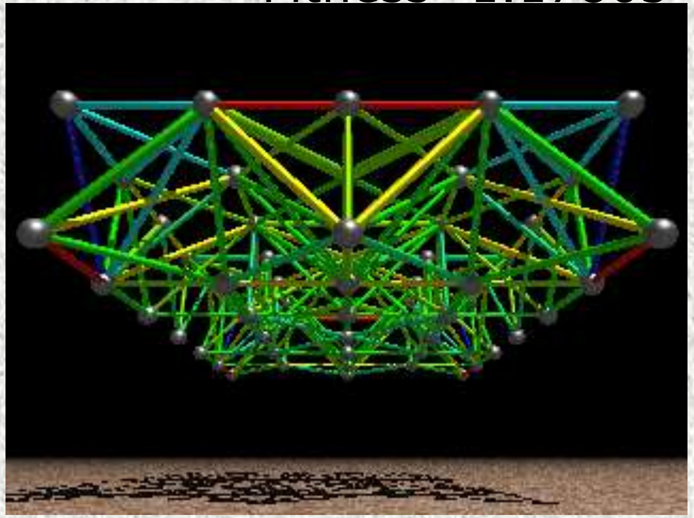
Trusses with Various Kinds of Element

Fitness=1.73684

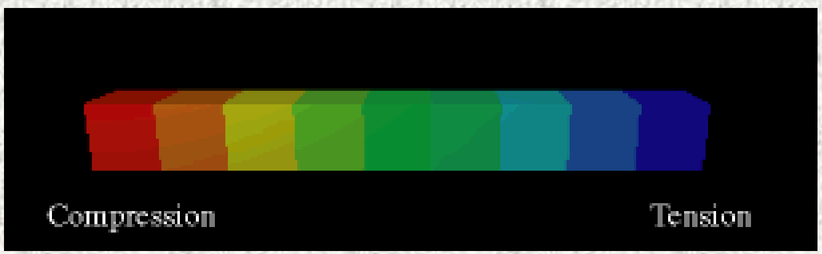


4 Kinds

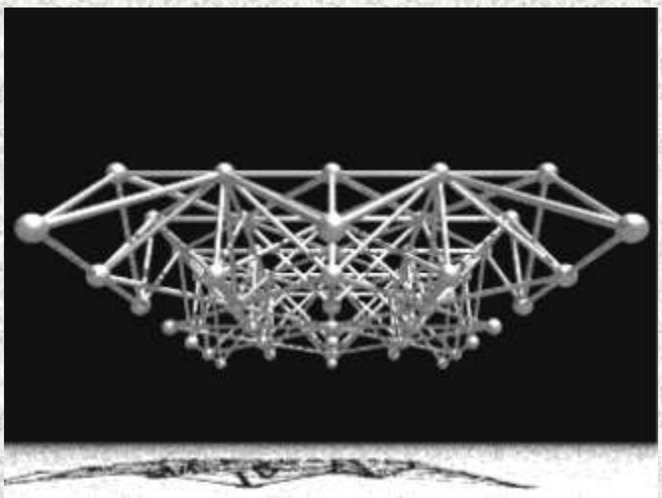
Fitness=1.17865

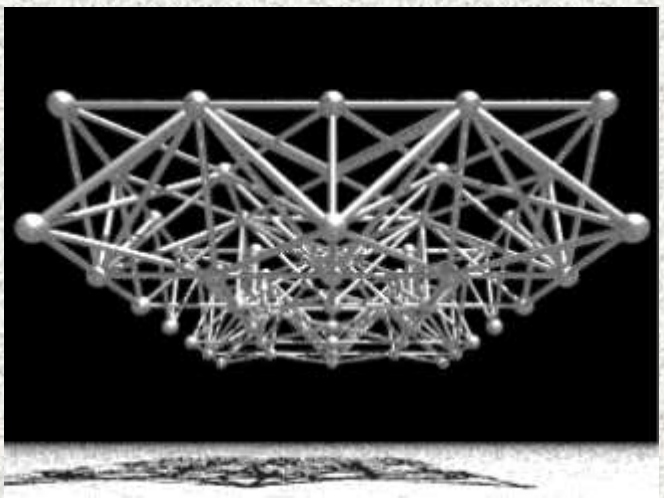


16 Kinds

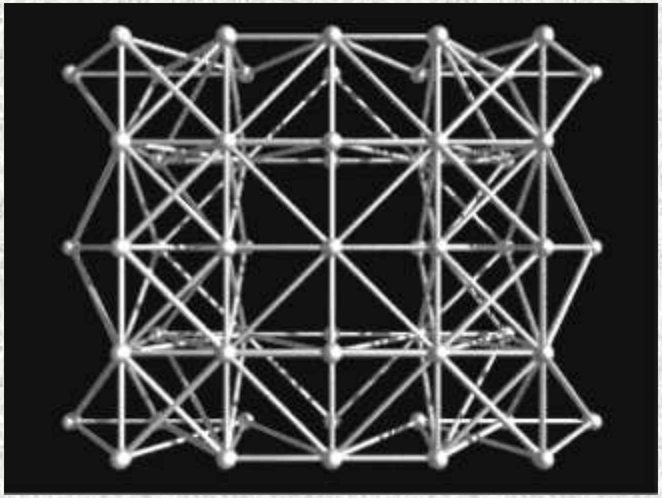


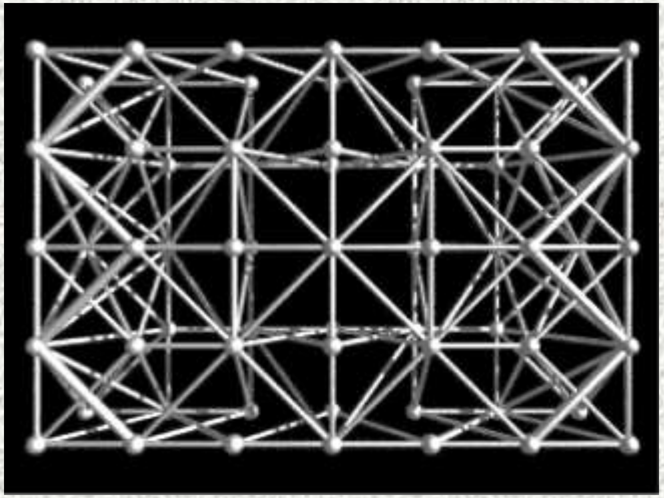
Truss Optimization





Birds View



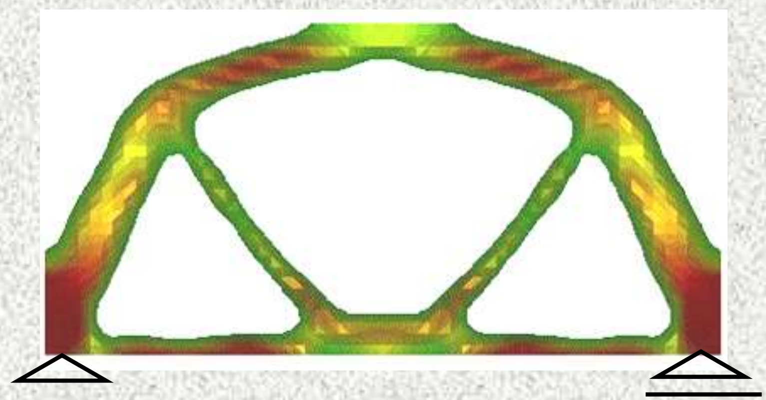


Plan

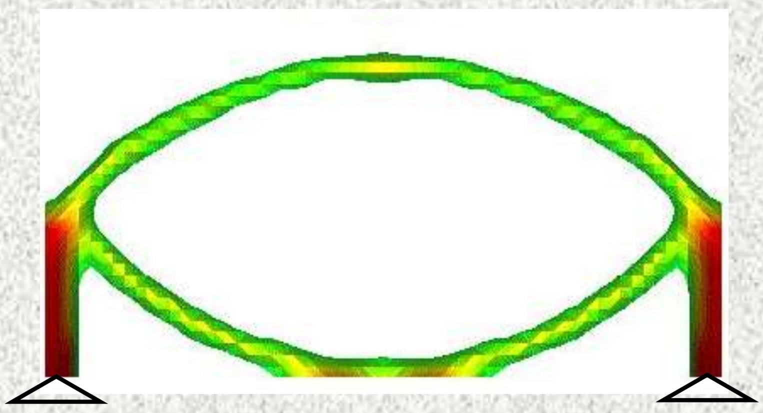
4 Standard Elements

16 Standard Elements

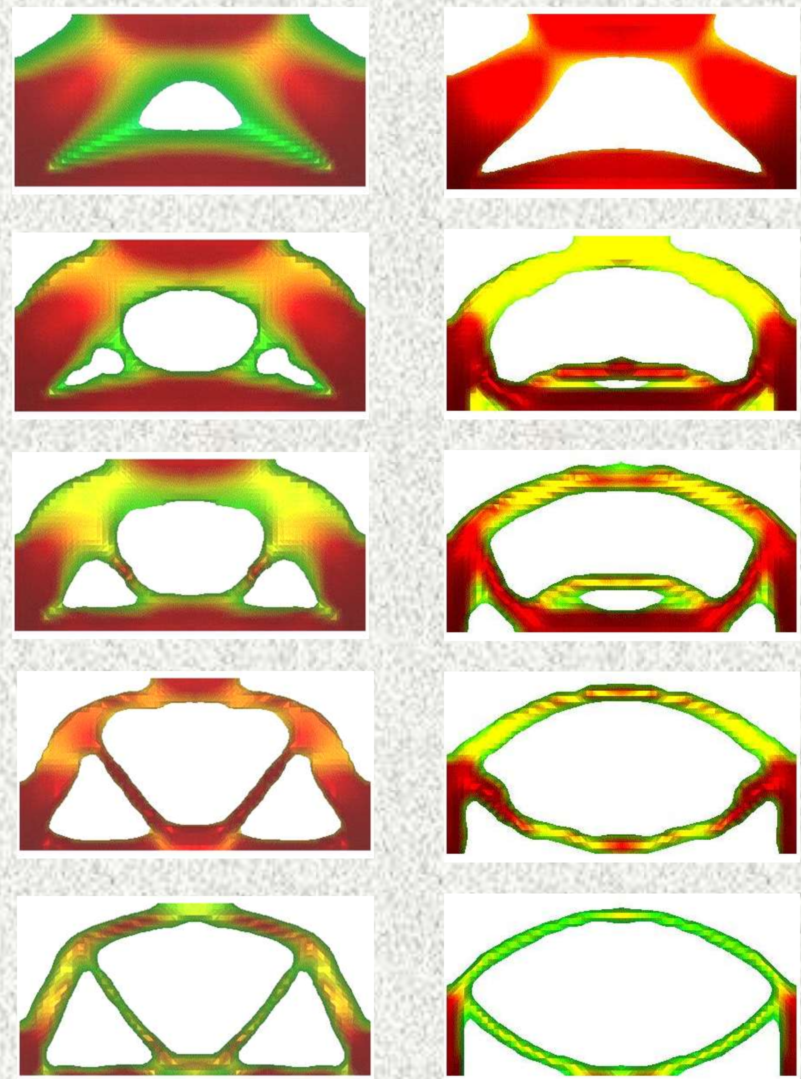
Comparison between ESO & Extended ESO



ESO

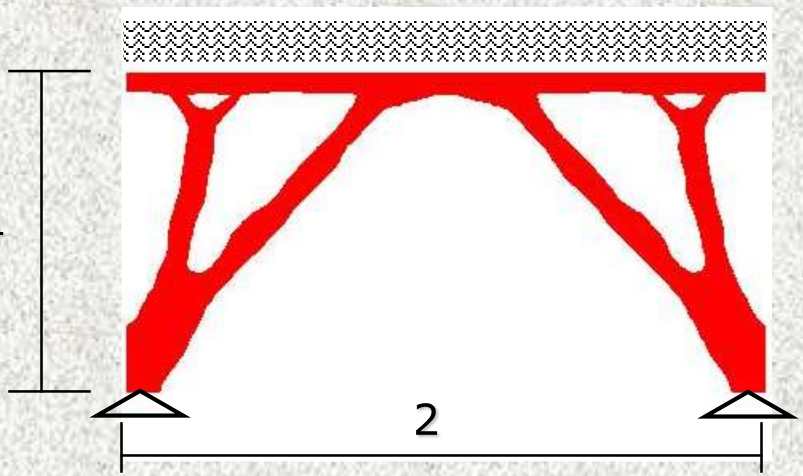


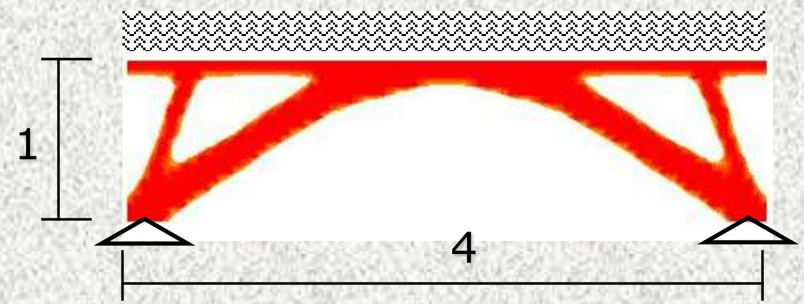
Extended ESO

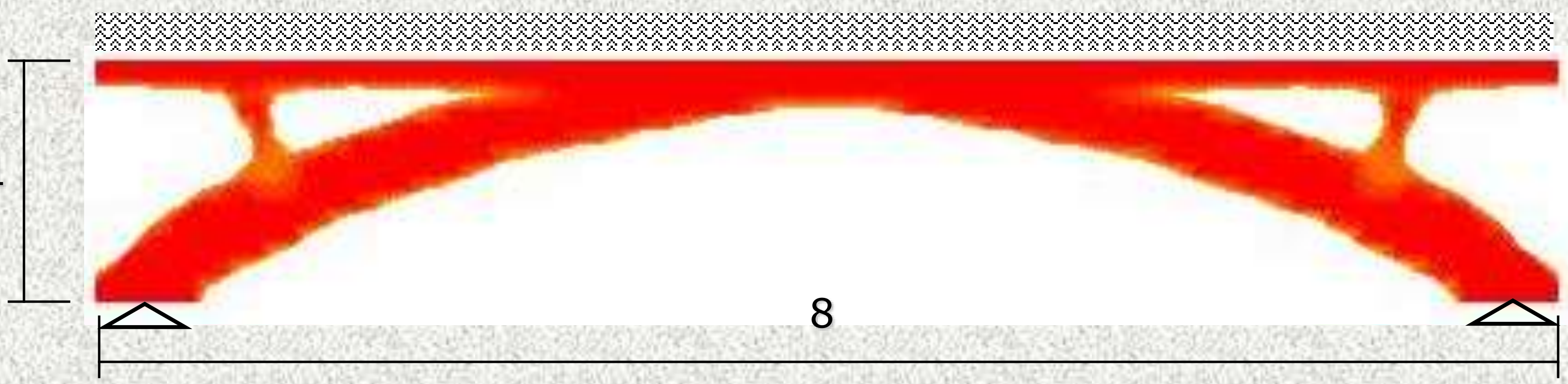


ESO Extended ESO

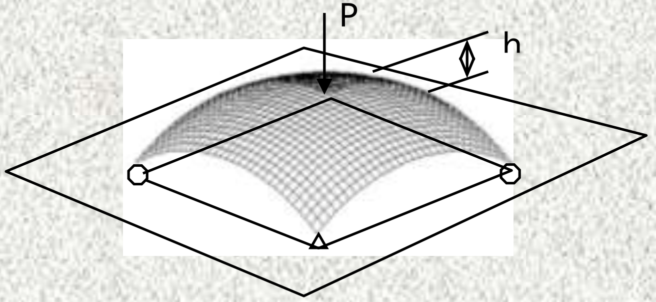
Bridge Structures

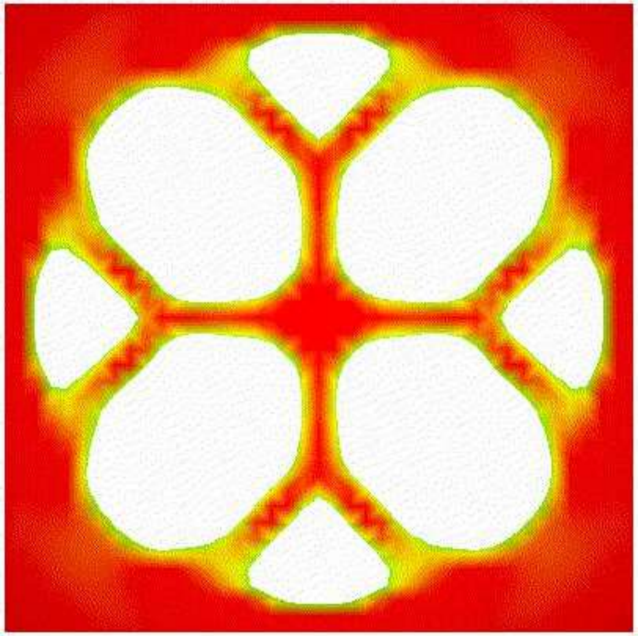




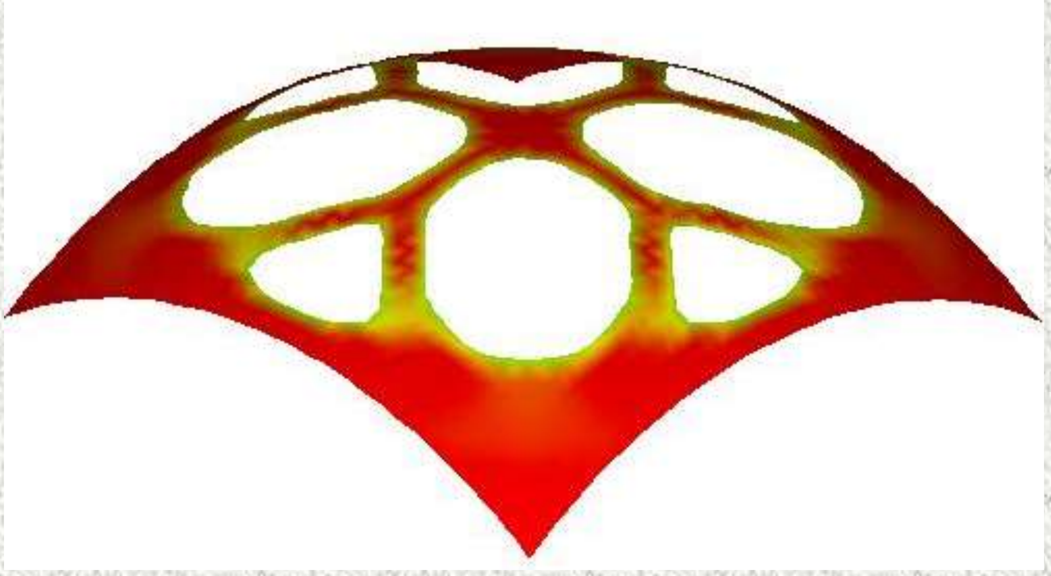


Shell



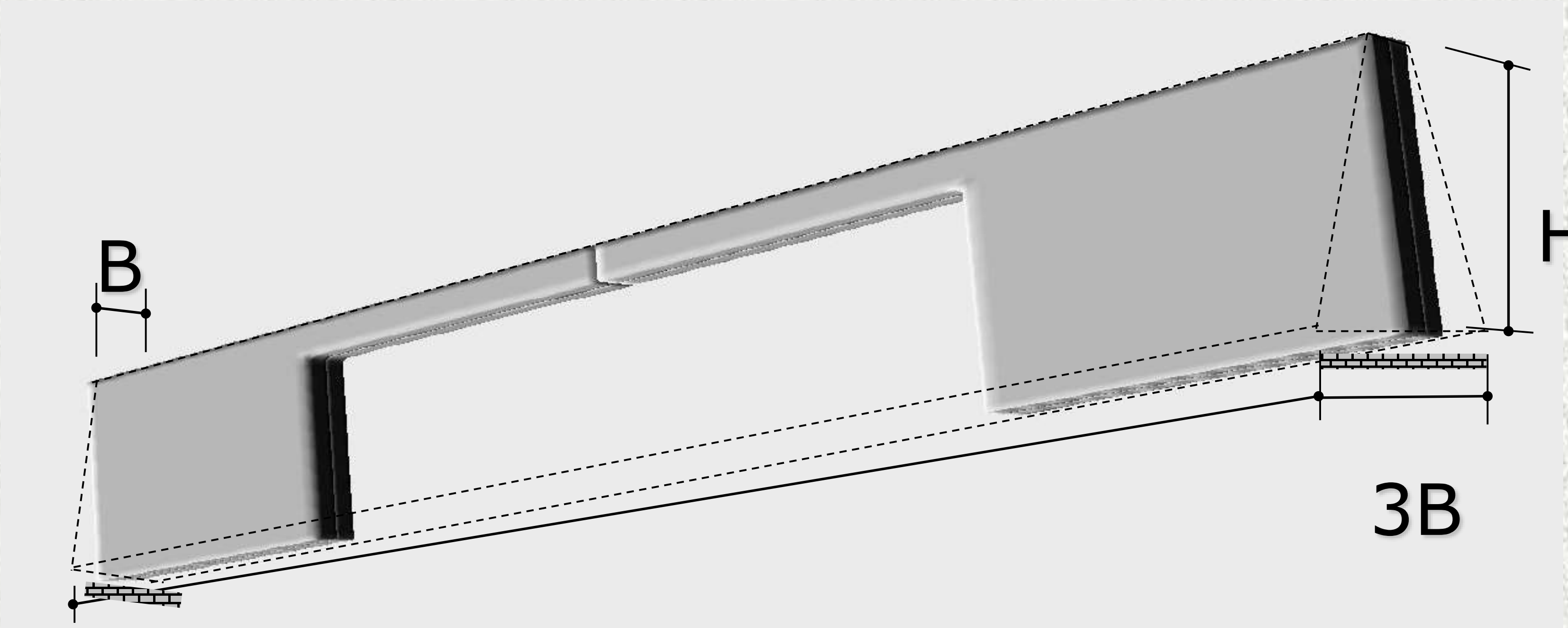


Plan

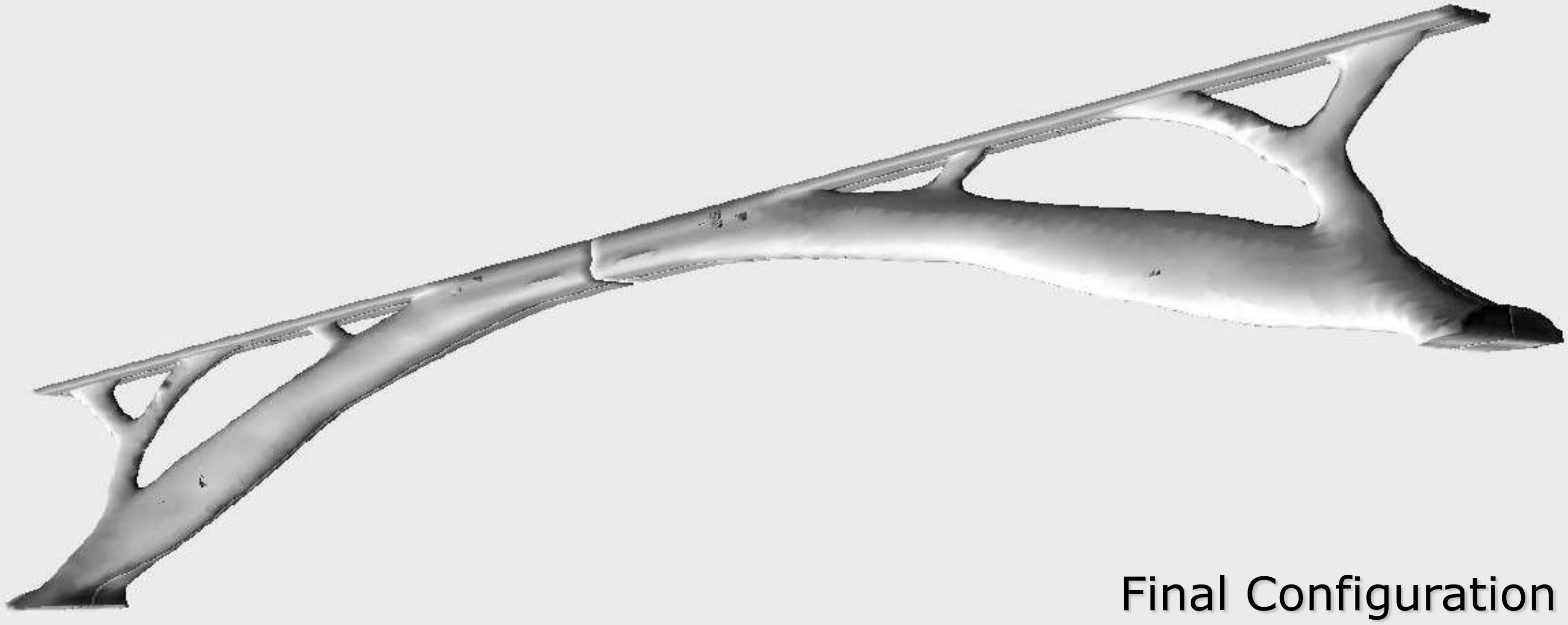


Perspective

3D Bridge Structure

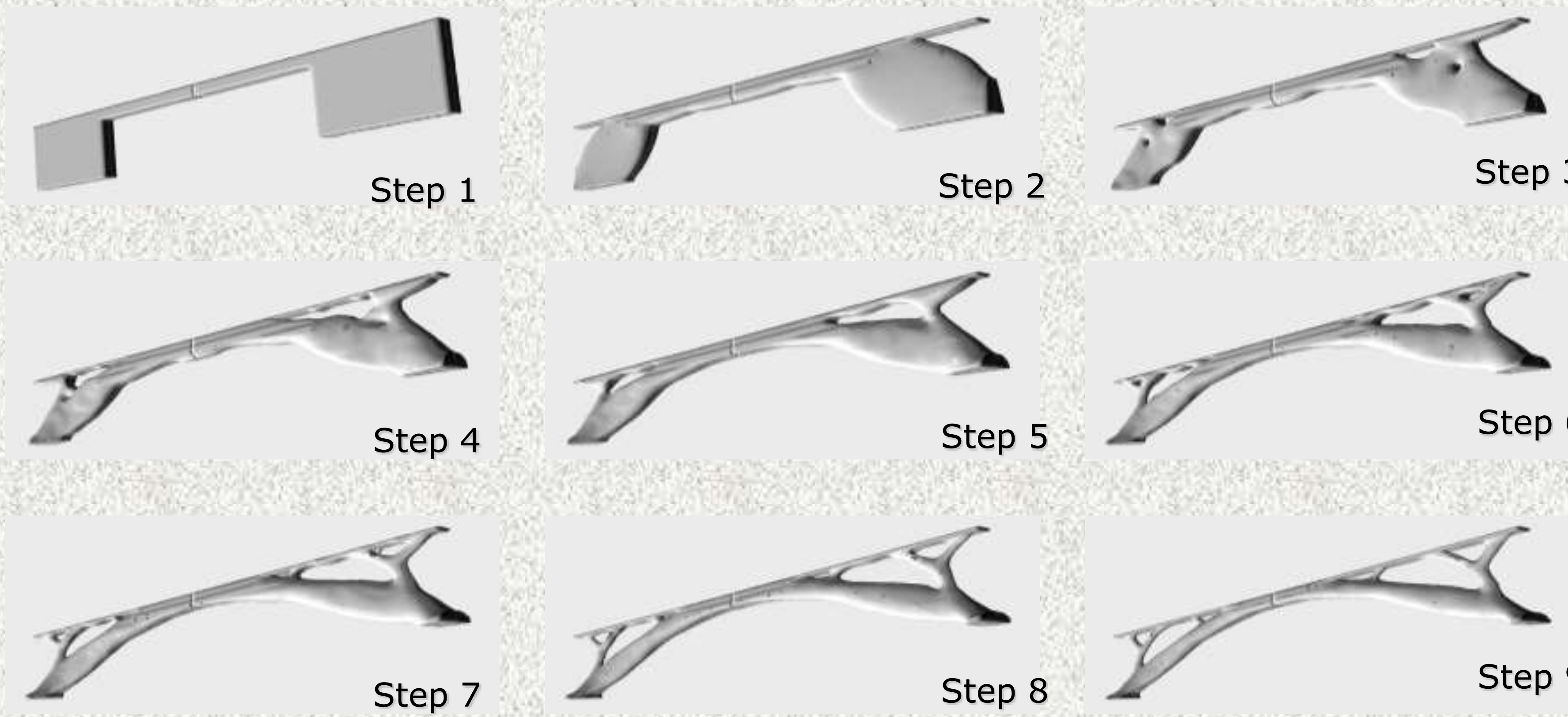


3D Bridge Structure

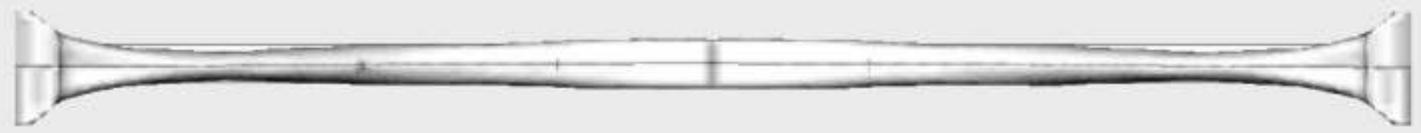


Final Configuration

3D Bridge Structure



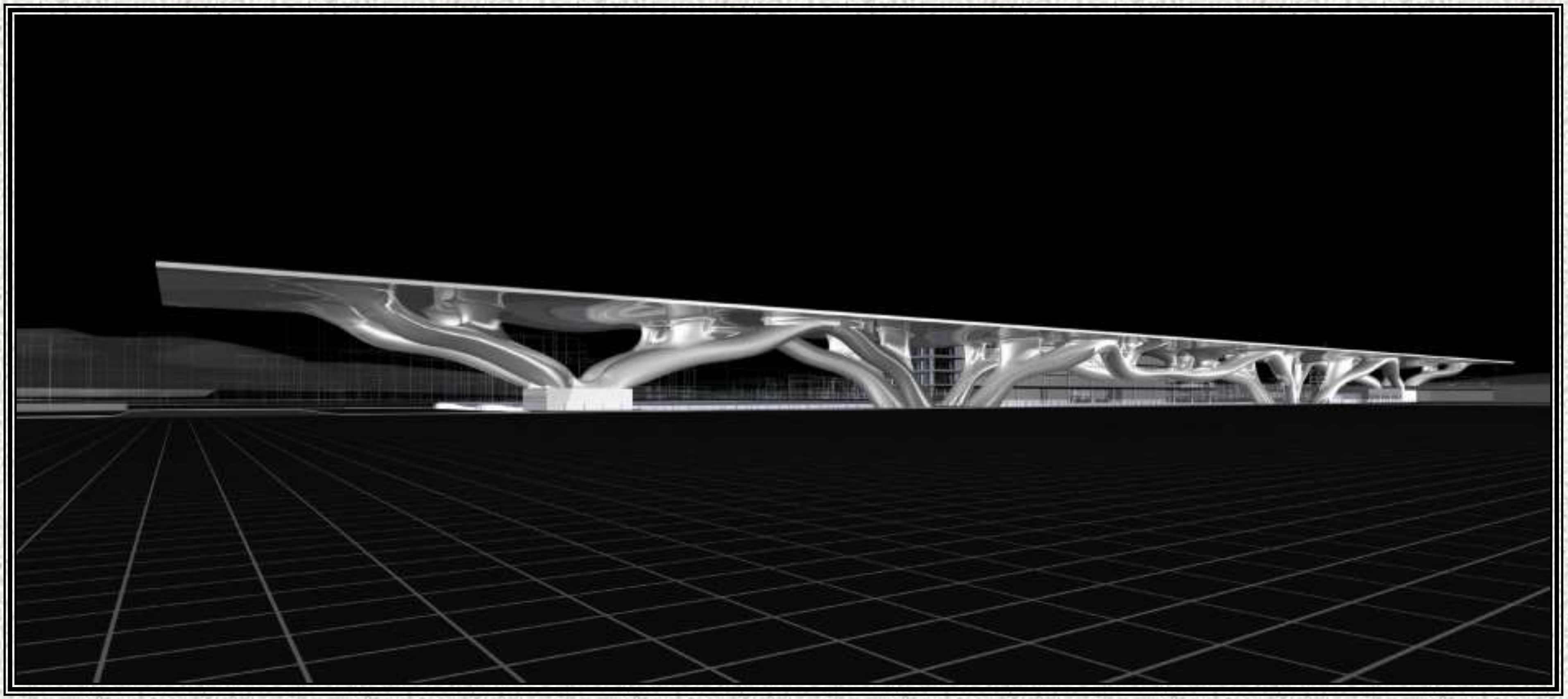
3D Bridge Structure



Plan

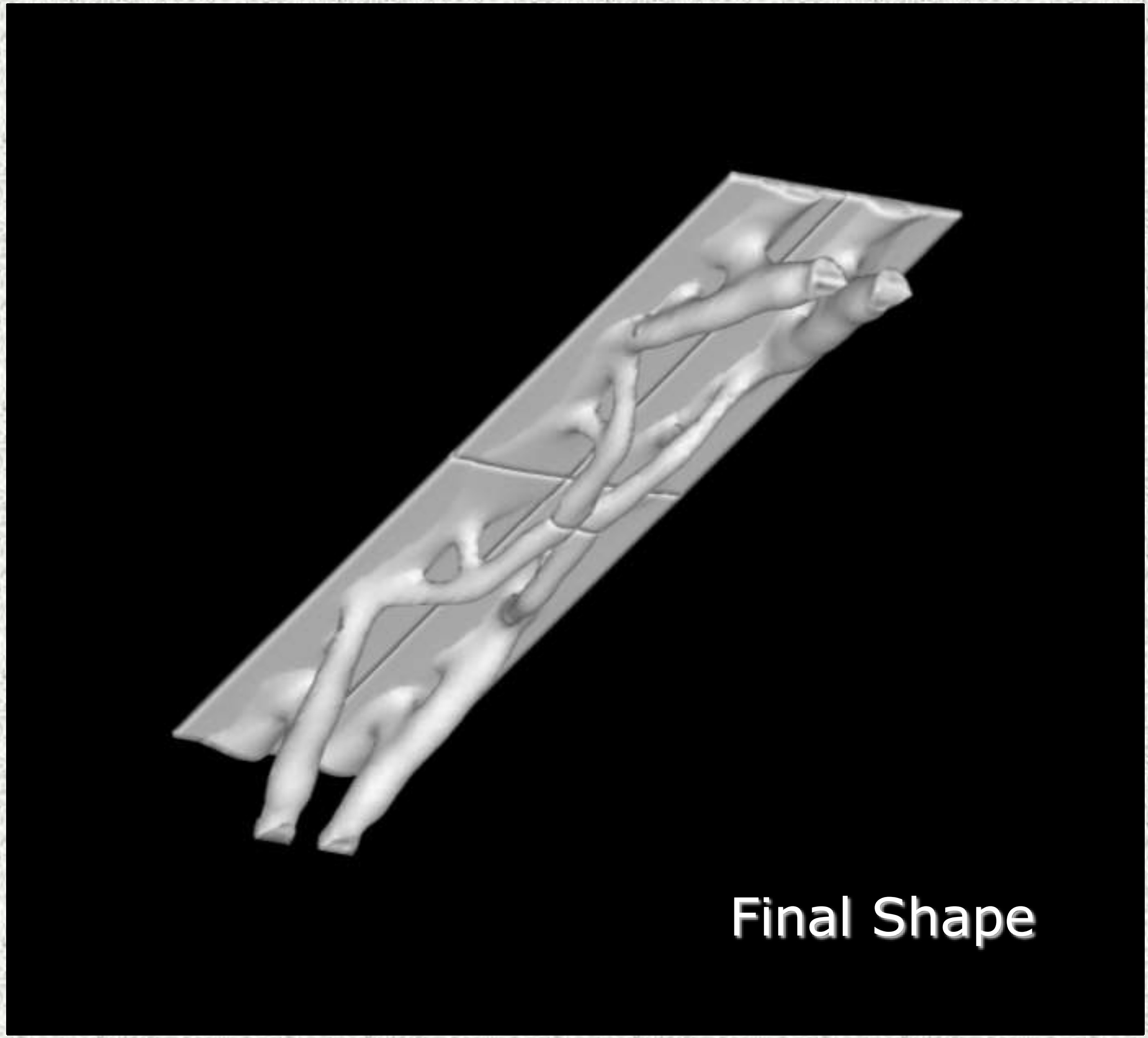
Elevation

Firenze New Station Building Project

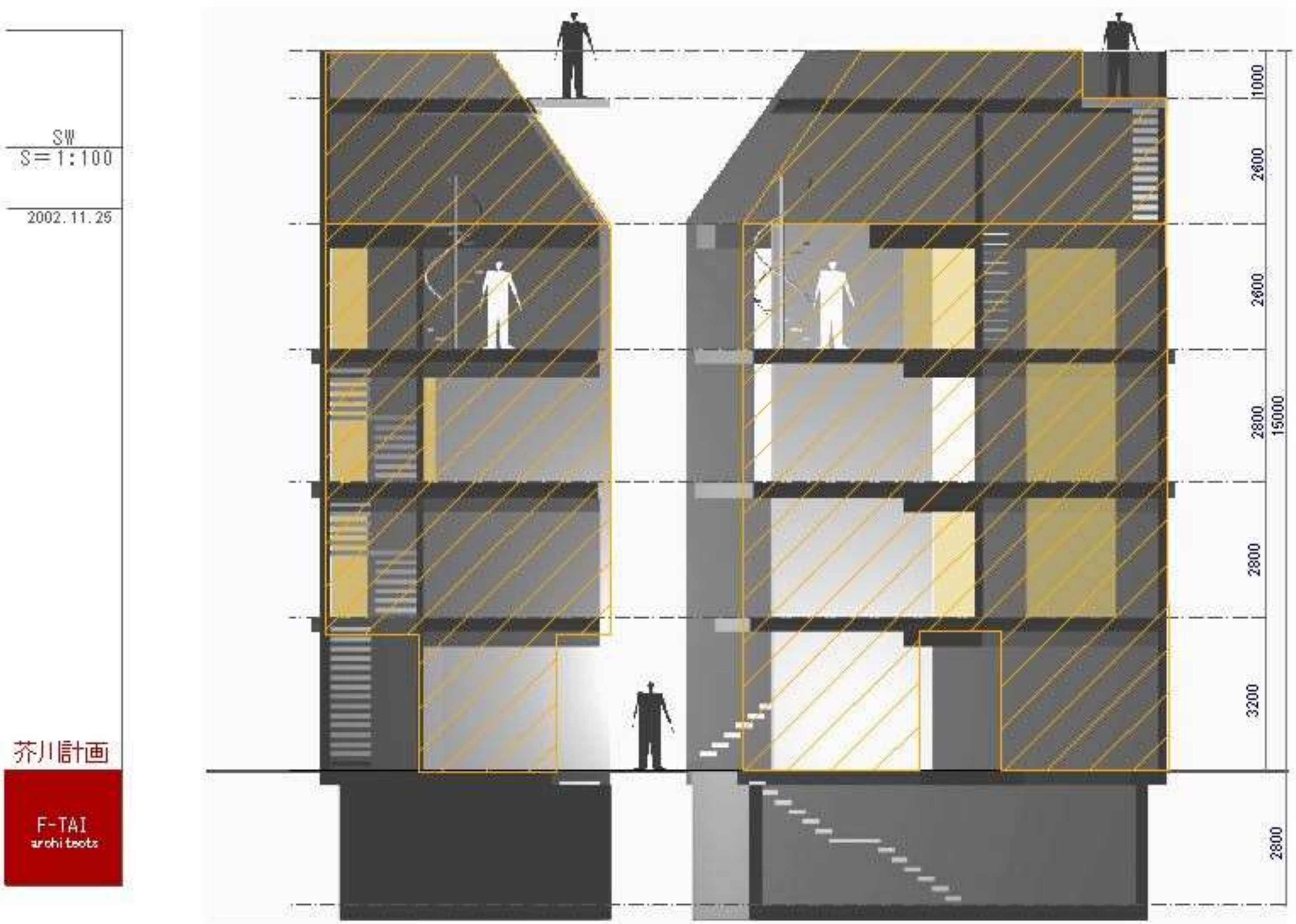


Global Structure Perspective

By Courtesy of Arata Isozaki Atelier + Mutsuro Sasaki Structural Design Office


Final Shape

Application to Office Building Design



West Elevation South Elevation

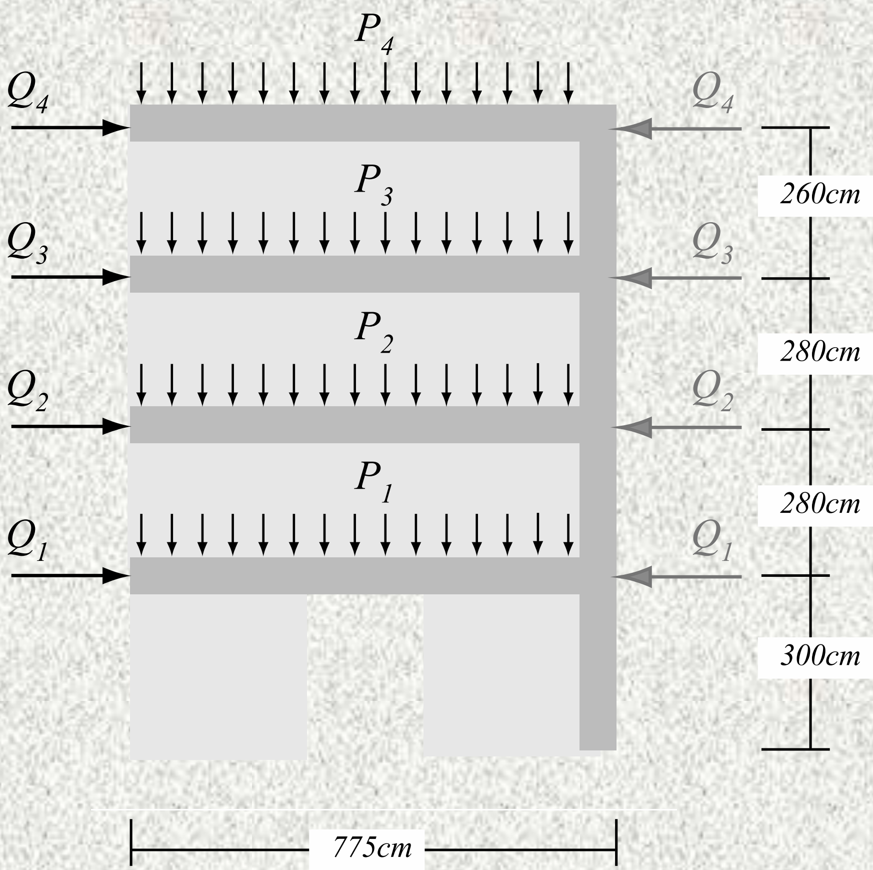
F-tai Architect + Iijima Structural Design Office, Cooperation: Mutoh Laboratory(Meijo Univ.)

Akutagawa Westside Project

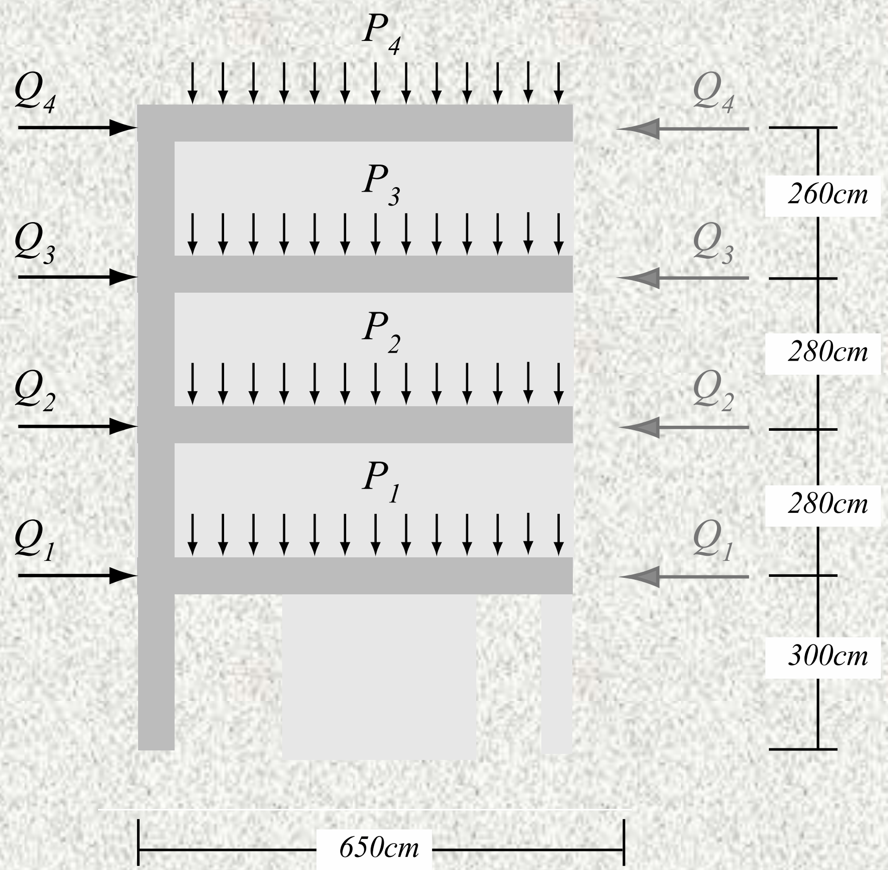
Northwest Elevation

Southwest Elevation

Loading Condition

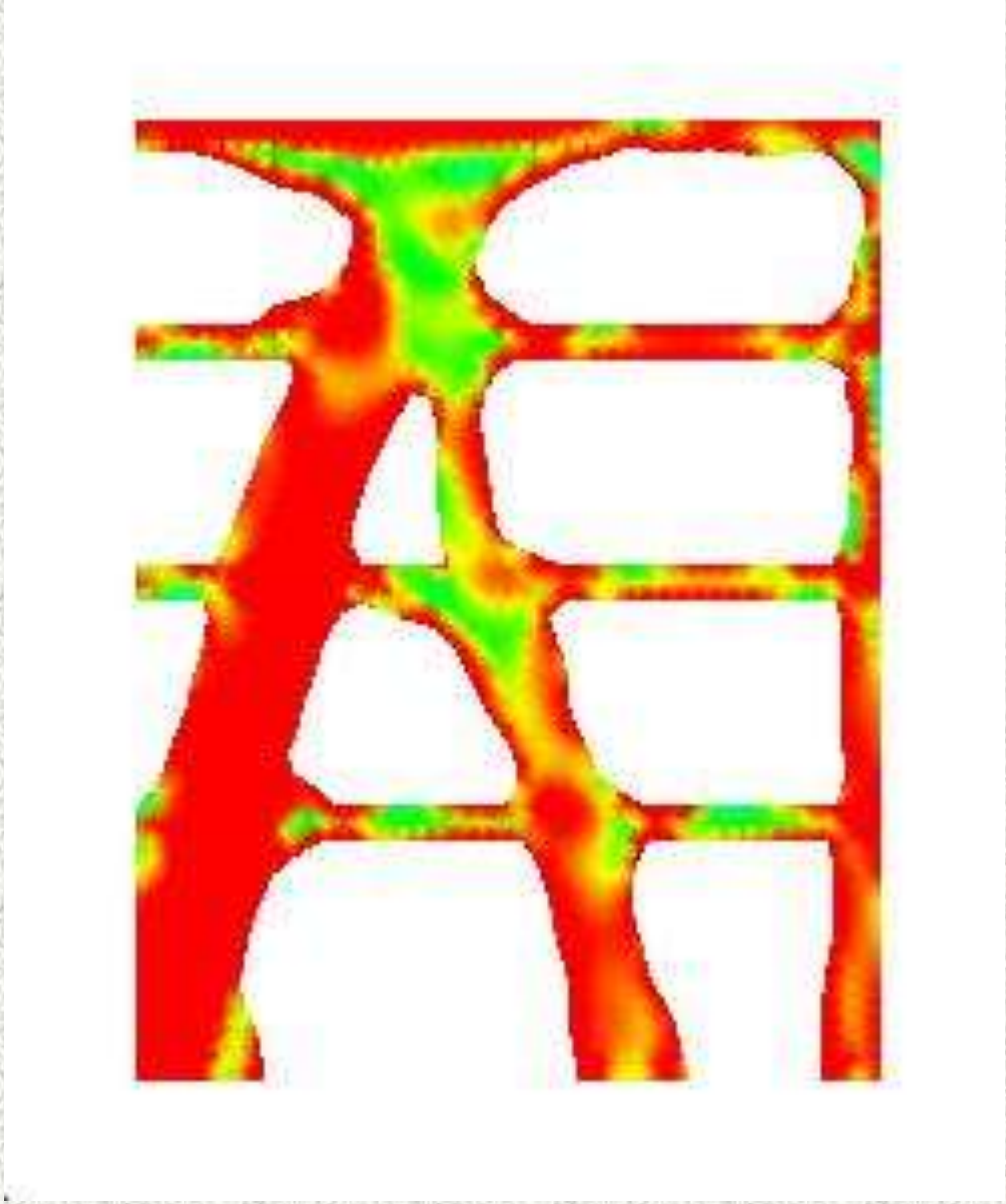


South



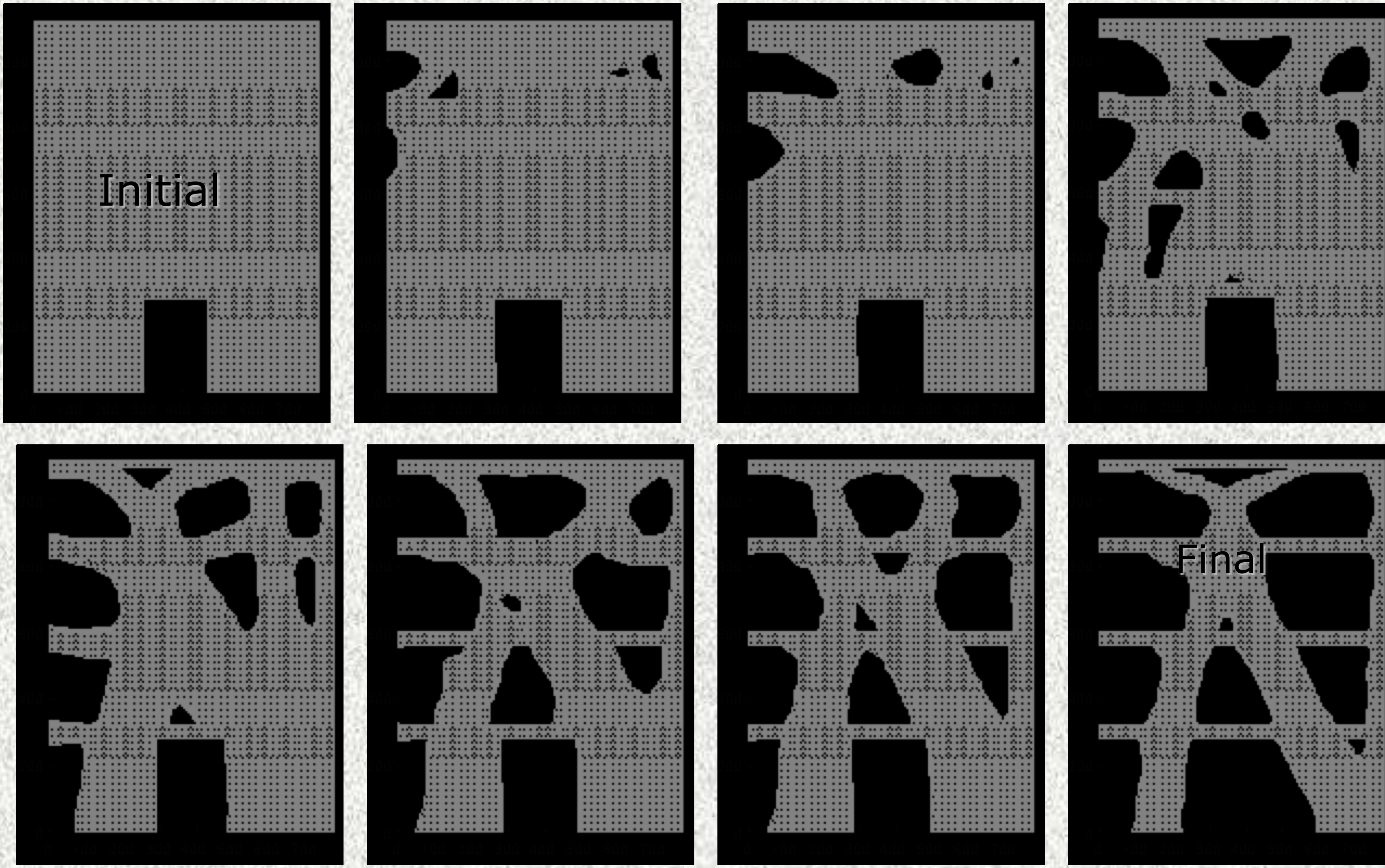
West

South Wall Evolution

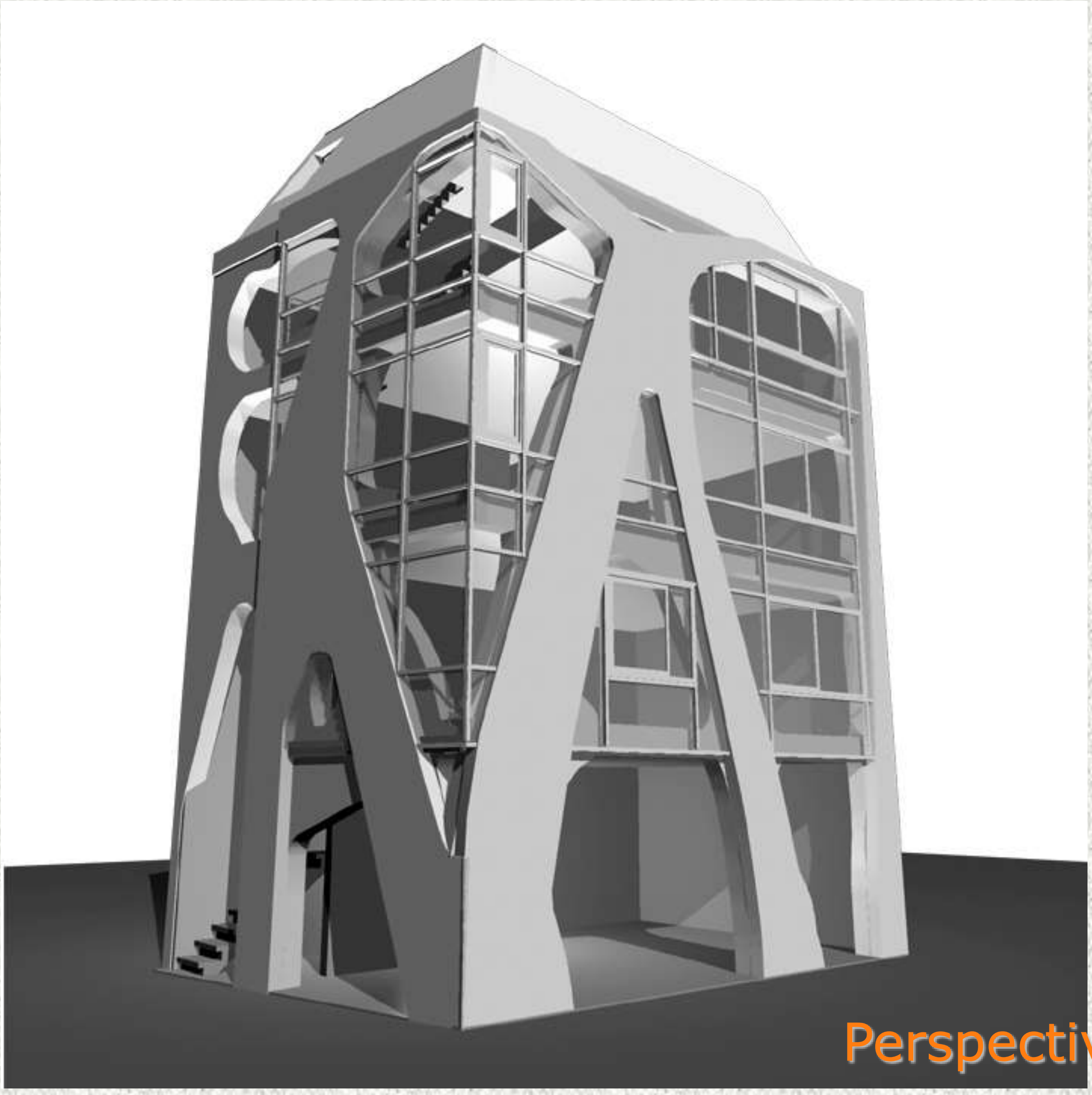


Final

Evolution Process



F-tai Architect + Iijima Structural Design Office, Cooperation + Mutoh Laboratory(Meijo Univ.)

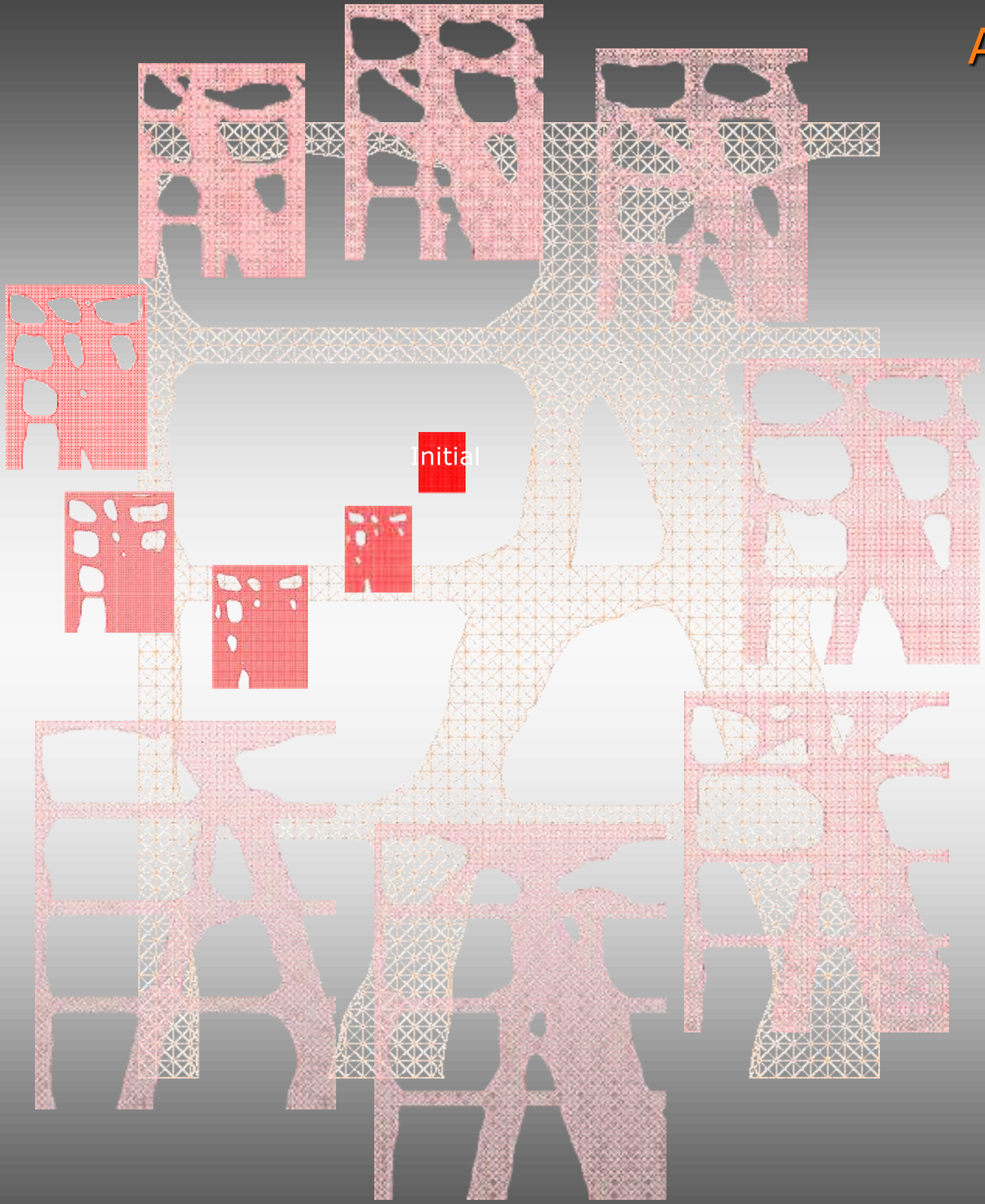


Perspective View


Mold and Reinforcement Construction


From Arcade

Akutagawa Westside Project



Akutagawa Westside Project

Life Cycle Design of Building Structures

- Background

Traditional Design Approach → Sustainable Design Approach

Environmental Problem → Reduction of Environmental Impact

Warming Temperature

Acid Precipitate etc.

- Purpose

Design Approach Considering Life Cycle (LC) → Life Cycle Design (LCD)

Deteriorating Some Determining Factors During Life Cycle

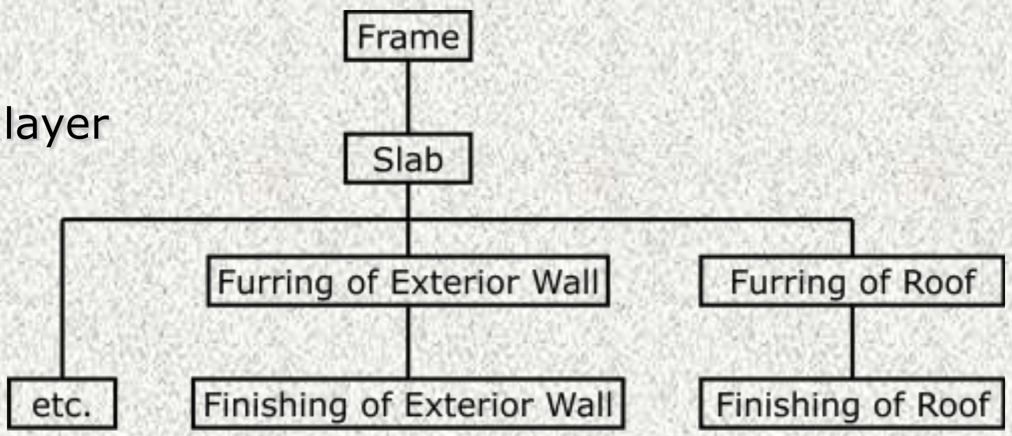
→ Optimization

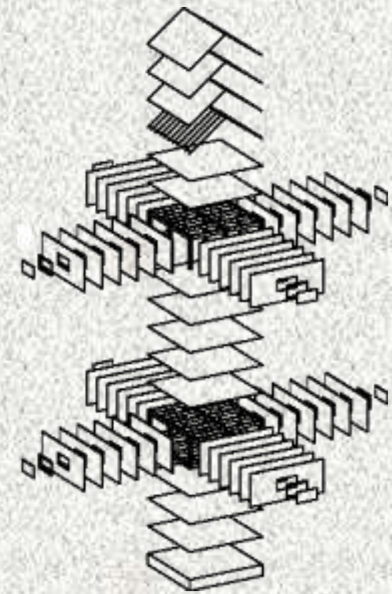
Life Cycle Design → IDEAL WAY of building design

Life Cycle Evaluation Method

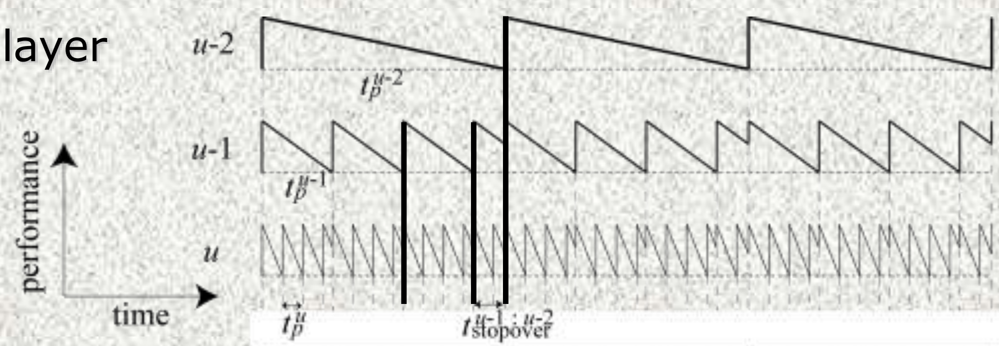
- “Hierarchy” of Building Materials

Upper layer





Upper layer



Life Cycle Evaluation Method

- Evaluation of “Hierarchy”

$$C_{eval} = \sum_i \left\{ \prod_{x=0}^{u-2} n^{x+1:x} \sum_{k=0}^{n_i^{u:u-1}} C_{ik} + \sum_{y=0}^{u-3} \prod_{z=y}^{u-3} n^{z+1:z} \sum_{k=0}^{n_{\mathrm{stopover},i}^{u-1:z+1}} C_{ik} + \sum_{k=0}^{n_{\mathrm{stopover},i}^{u-1:0}} C_{ik} \right\}$$

$$n^{a:b} = \left\lceil \frac{t_p^b}{t_p^a} \right\rceil - 1$$

$$n_{\mathrm{stopover},i}^{a:b} = \left\lceil \frac{1}{t_{p,i}^u} \left\{ t_p^b - \left(\left\lceil \frac{t_p^b}{t_p^a} \right\rceil - 1 \right) \cdot t_p^a \right\} \right\rceil - 1$$

a :Rank of Member i

b :Rank of “Supporting” Member

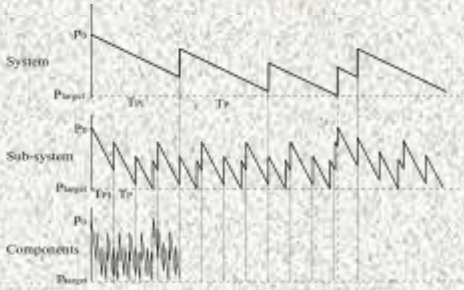
Physical Unit of Product

CO_2 → Life Cycle CO_2 ($LCCO_2$)

Cost → Life Cycle Cost (LCC)

Treatment as an Optimization Problem

■ Problem Setting



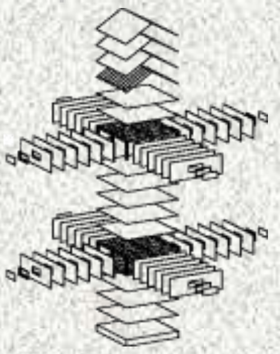
- Design Variable
  - Component Parts
  - Scenario of Building Maintenance

→ Multi-Variable Optimization

- Objective Function
  - Economic : Life Cycle Cost
  - Environmental : Life Cycle CO_2

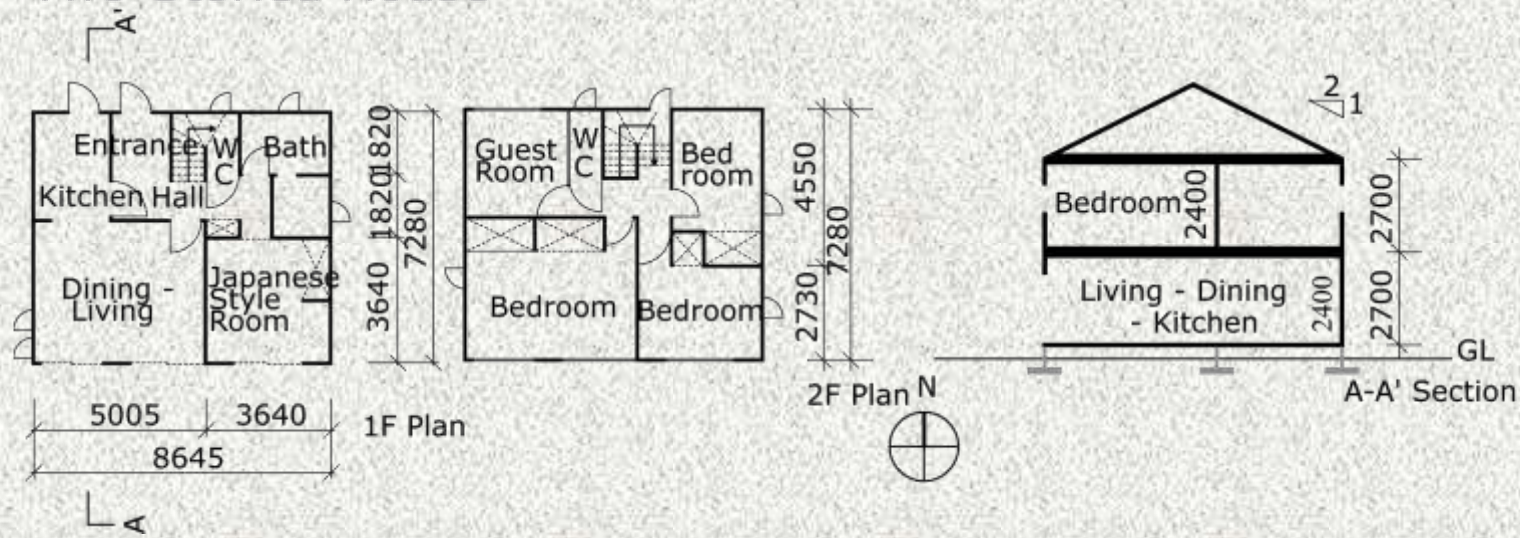
→ Multi-Objective Optimization

- Optimization Method
  - Genetic Algorithm (GA)
- Evaluation Period → 100 Years



Life-Cycle Optimization

- Problem Area
  - Two-Storied House



  - GA Parameters

Single-Objective

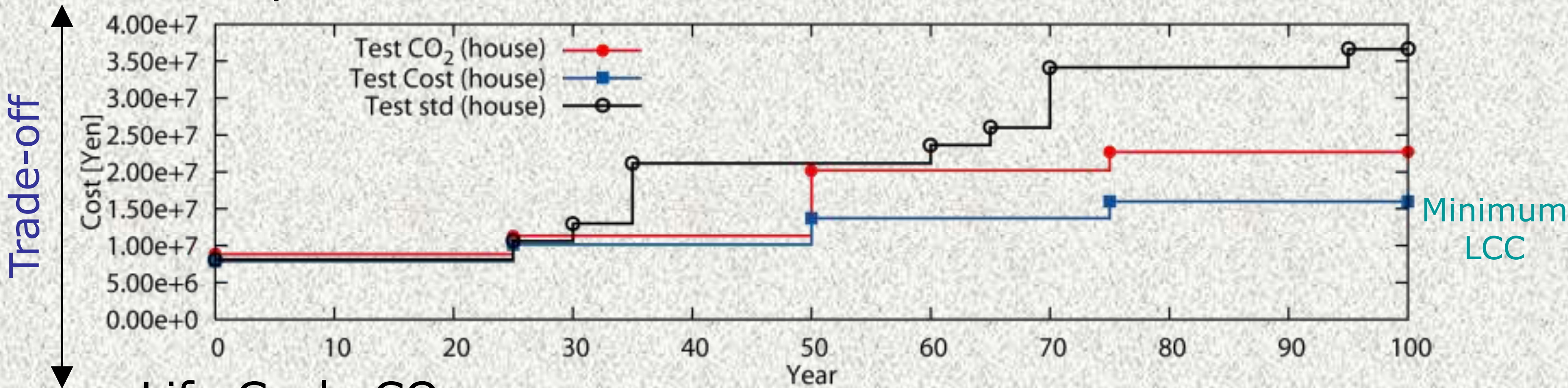
Population	100
Elite	2
Generation	1000
Probability of Crossover	0.01
Probability of Mutation	0.01

Multi-Objective

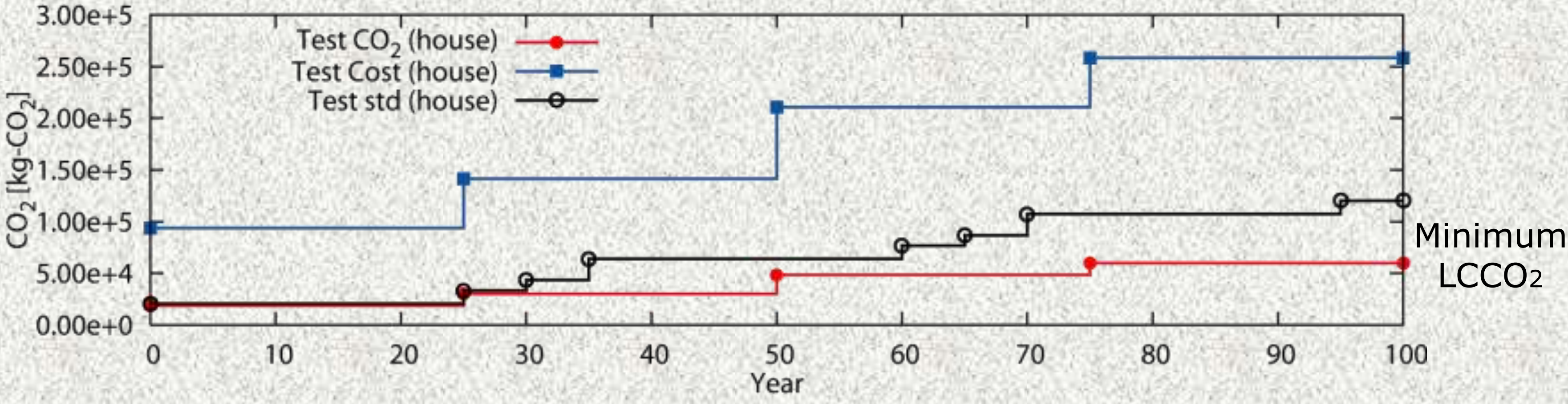
Population	100
Archive	25
Generation	1000
Probability of Crossover	0.01
Probability of Mutation	0.01

Single-Objective Optimization

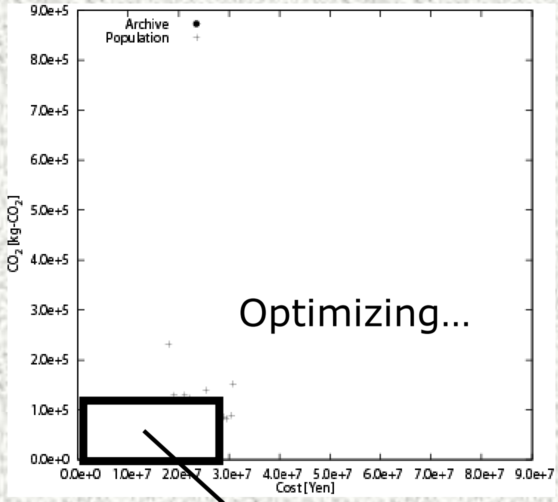
- Life Cycle Cost



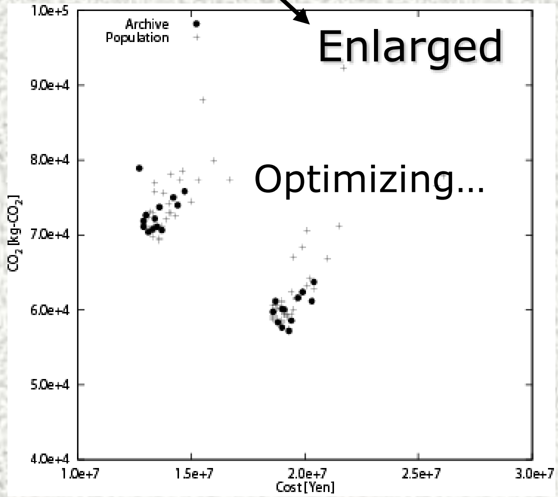
- Life Cycle CO2



Multi-Objective Optimization



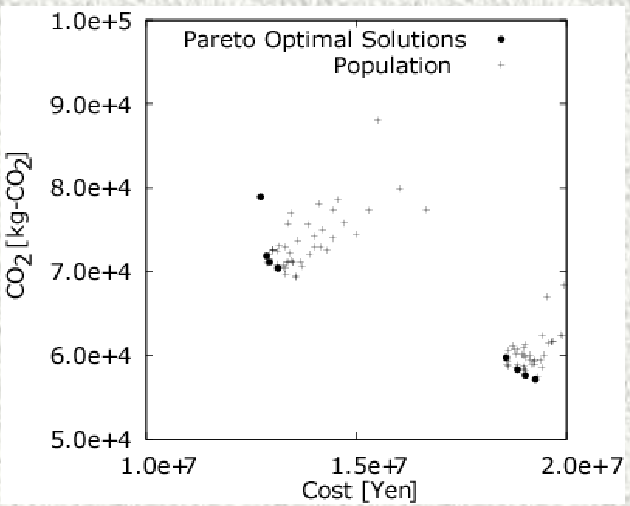
100th Generation



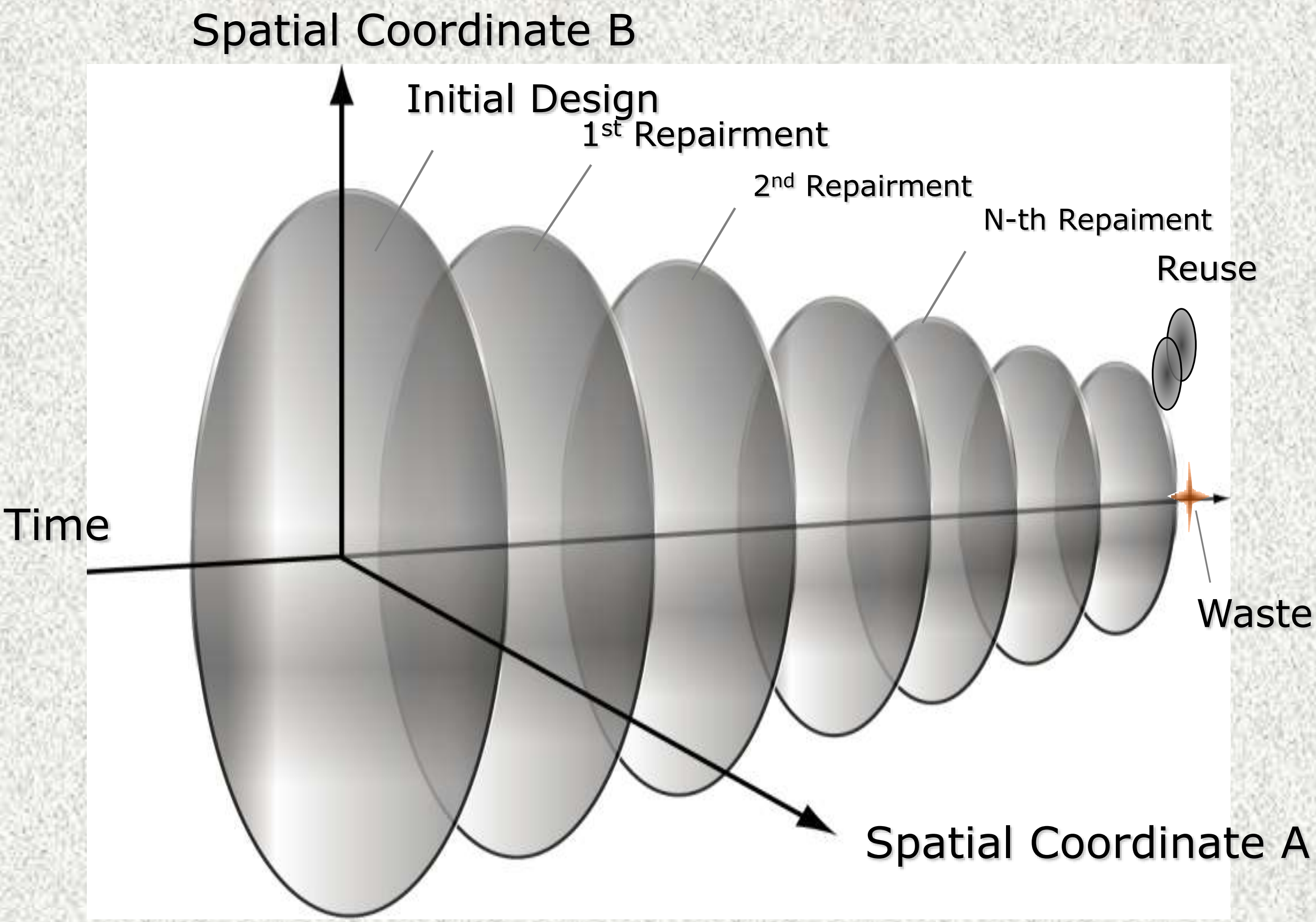
1000th Generation

- Pareto Front
  - Plural Reasonably Optimal Solutions
  - Moderately Dispersed Solutions
  - Structure of Solutions.

Can Support Decision-Maker's Judgement



Optimum Arrangement in Space-Time Continuum



Structural System Proposer as Next Generation of CM

Structural System Proposer

1970's ~ 2000's

Computational Morphogenesis

Structural Analysis(FEM)
1970's ~ 1980's

Structural Optimization
1990's

Structural Mechanics
Mathematical Programming

2000's ~

Life Cycle Design

Strategic System Design
2000's ~

Strategic Scenario Design
2000's ~

Multi-Objective Programming

← Safety・Constructionability →

← Economics →

← Sustainability →

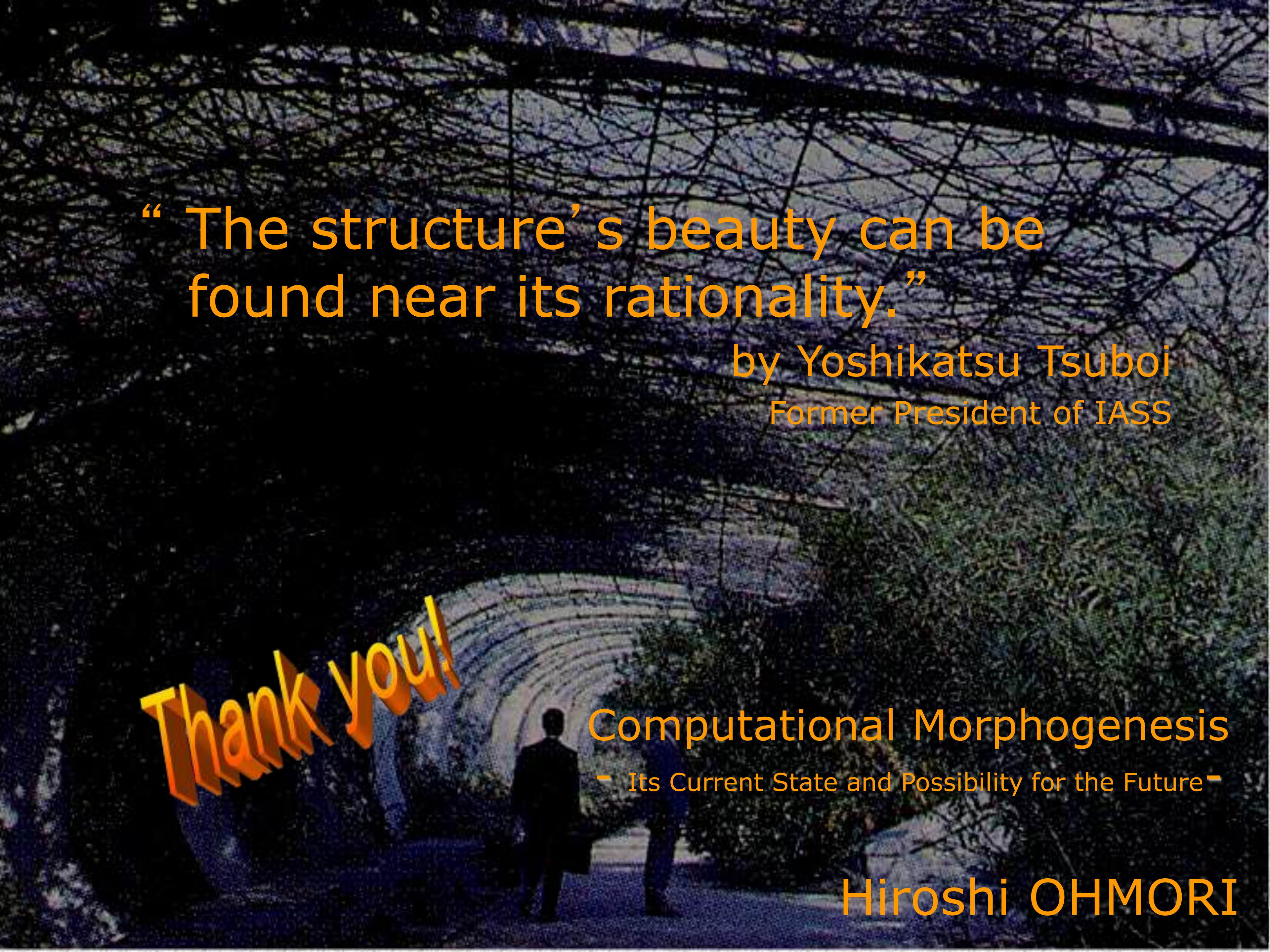
IASS WG/Sub-WG

WG13 – Numerical Methods in Shell and Spatial Structures (A. Samartin, H.Ohmori)

Sub-WG on Computational Morphogenesis (H. Ohmori)

WG15 – Structural Morphology (R. Motro)

WG on Free-Form Design (M. Grohman, A. Borgart)


“ The structure’s beauty can be found near its rationality.”
by Yoshikatsu Tsuboi
Former President of IASS
Thank you!
Computational Morphogenesis
- Its Current State and Possibility for the Future -
Hiroshi OHMORI