

## ***BK4070 – Parametric Design***

*Technisch Ontwerp en Informatica*

*Bige Tuncer*

# Generation/description of form

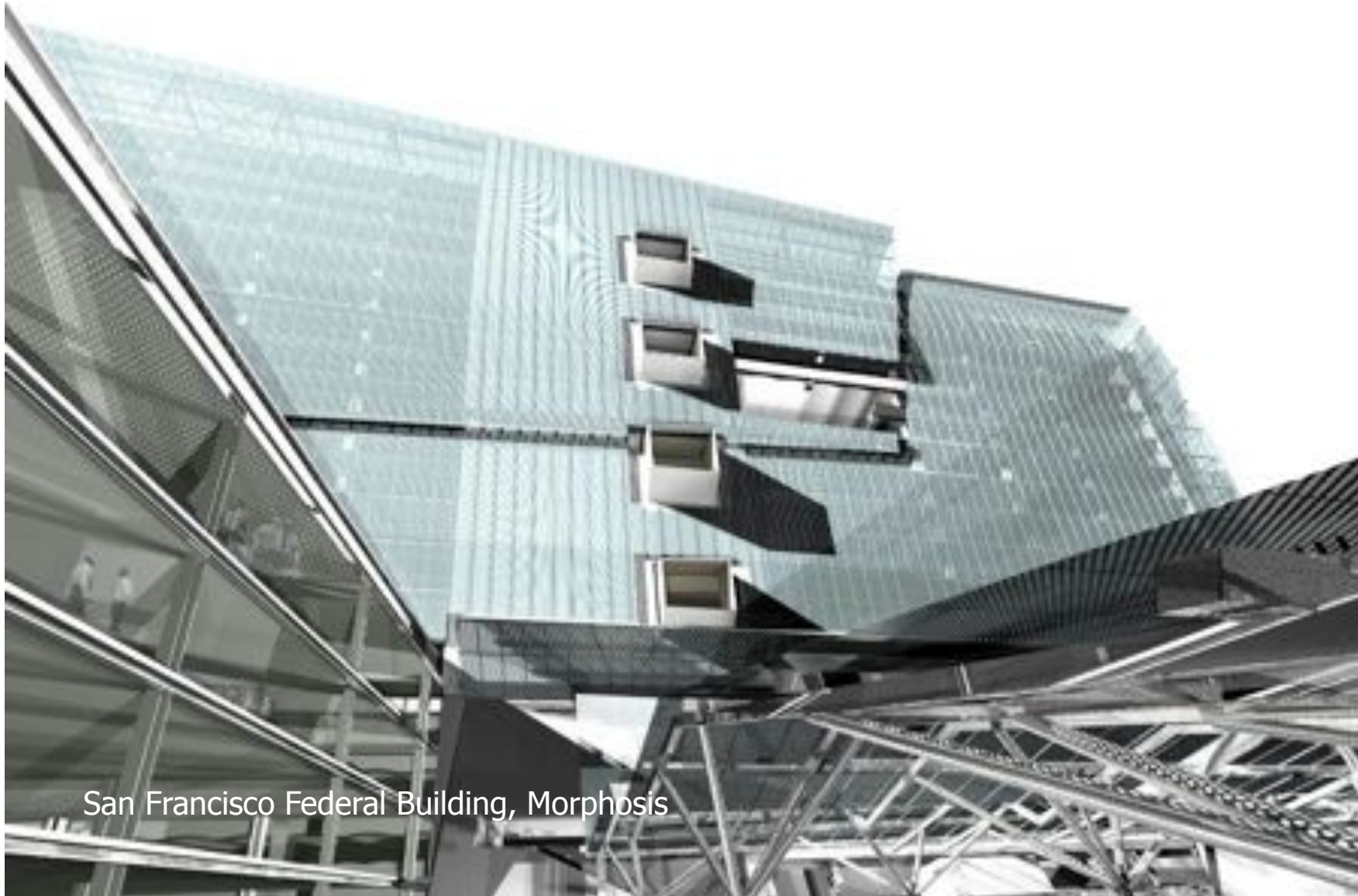
- All starts with a 3D representation of design
  1. Creating 3D geometry through the direct interaction of the designer with the design software
  2. Creating 3D geometry by digitalizing a physical 3D design
  3. Creating 3D geometry through the use of a set of mathematical formulas

+ combinations of these

[ Alan H. Watt, 3D Computer Graphics, 1999 ]

# 1 Creating 3D geometry through direct interaction with design software

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San Francisco Federal Building, Morphosis

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# 2 Creation of 3D geometry by digitalizing a physical model

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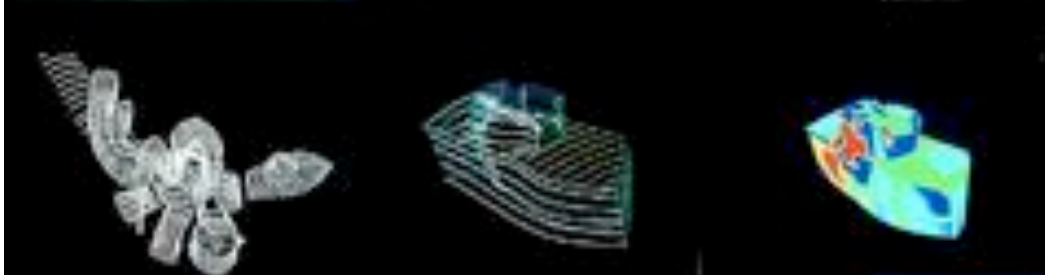
Paul de Ruiter

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# Creation of 3D geometry by digitalizing a physical model

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# 3 Creating 3D geometry through the use of a set of mathematical formulas

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The Great Court  
British Museum  
Foster & Partners and Buro Happold

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# Parametric design

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- Parametric design
- Associative design
- Parameters
  
- It's a way of thinking rather than using a software

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# Parametric design

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- Everyone can draw by hand
- Everyone can draw using a modeling software
- How about giving the pen or mouse pointer some more intelligence?

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# Parametric modeling

- Geometric entities
- Their properties
- For example, a room has a height, width and depth
  - $h = 3$
  - $w = 6$
  - $d = 4$
- The room has 4 walls, a, b, c, and d
- The door of the room is in wall c
- The window of the room is in wall a
- The door and the window also have dimensions
- ...

# Parametric modeling

- The properties of objects are defined as parameters (variables) that can be adjusted
- Objects are related to each other with explicit relationships
- For example, the height of the tower can never be taller than 200m. The area of the circulation core of the tower cannot be bigger than  $\frac{1}{3}$  of the floor plan area at any given floor.  
or
- The façade needs to be subdivided to fit a number of panels. These panels will be manufactured and it's a lot cheaper to have them the same size. But the façade is somehow irregular.

# Parametric modeling

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- Definition of concepts
- System is a collection of concepts

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# Parametric modeling

## Object-oriented

*Also called features, components, assemblies, parts, etc.*

Everything is an object and everything is modeled as an object

*e.g. A line, a wall, a building are all objects.*

An object can have properties, relationships and behavior

e.g. A line has a length, a wall can be connected to the roof, a building can be opened by opening the door

# Parametric modeling

## Parametric

In essence means that the object has properties which the user can edit.

*Many systems in essence has parameters and could be considered parametric*

*Parameters are not only numbers, but can be points, point sets, curves, functions, etc.*

# Parametric modeling

## Associative

In essence means that the object has relationships which the user can define and edit.

Together with the parameters it is possible to define a (design) logic which the system can “understand”

# Parametric modeling

A parametric and associative system therefore is in essence a system where the user can define and edit the properties of and the relationships between the objects

Excel in essence is a parametric associative system, only Excel only works with numbers, not with every possible object

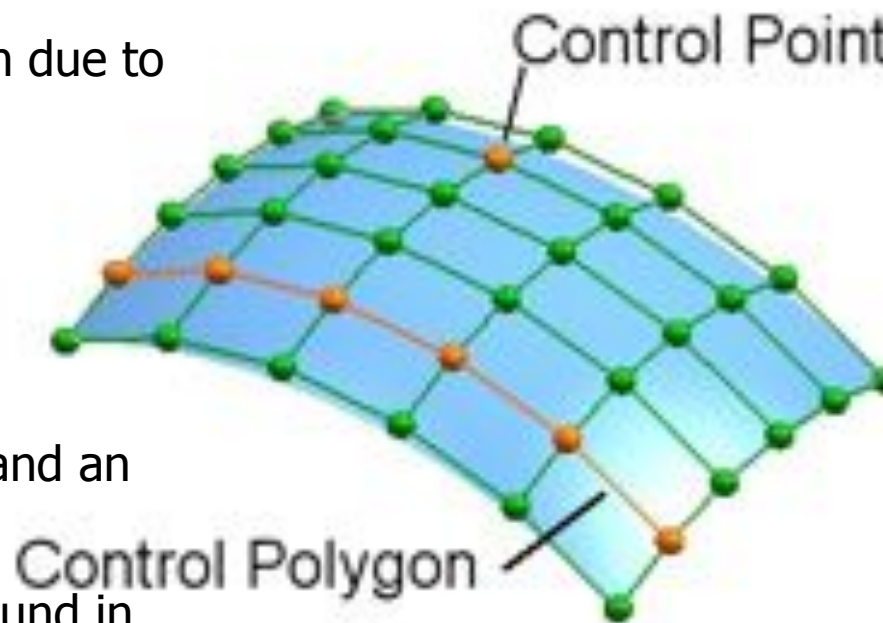
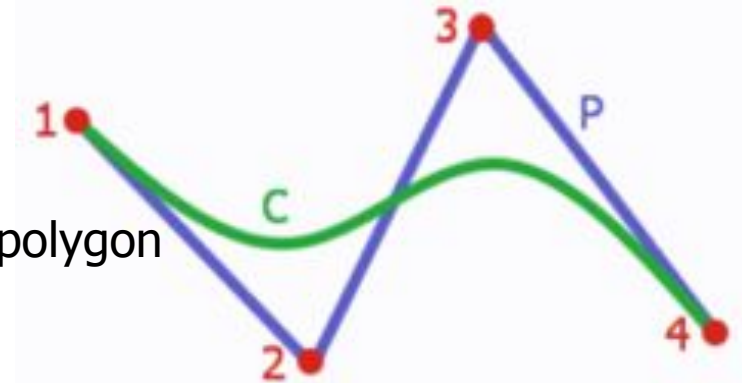
# Parametric modeling

- Generate a lot of design alternatives within a self-defined range of possibilities
- Design exploration
  - Looking at various formal possibilities
- Working out specific design issues



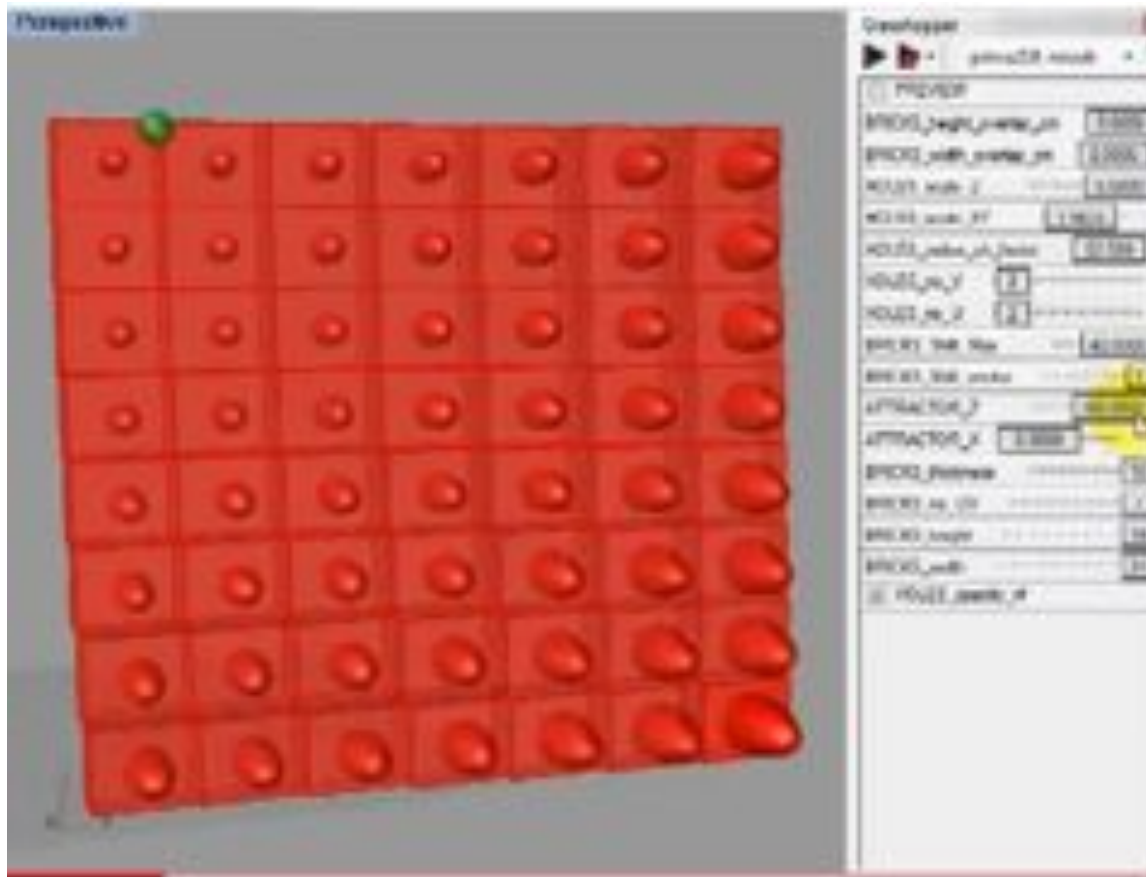
# NURBS

- Non-Uniform Rational B-Splines
- Resulting from from an initial control-polygon to a curve
- Bézier curves
- Useful for computational design due to
  - Easy controllability
  - General applicability
  - Smoothness
  - Continuity possibilities
- Degree, control points, knots, and an evaluation rule
- Description knowledge to be found in mathematics / geometry books and TOI-pedia



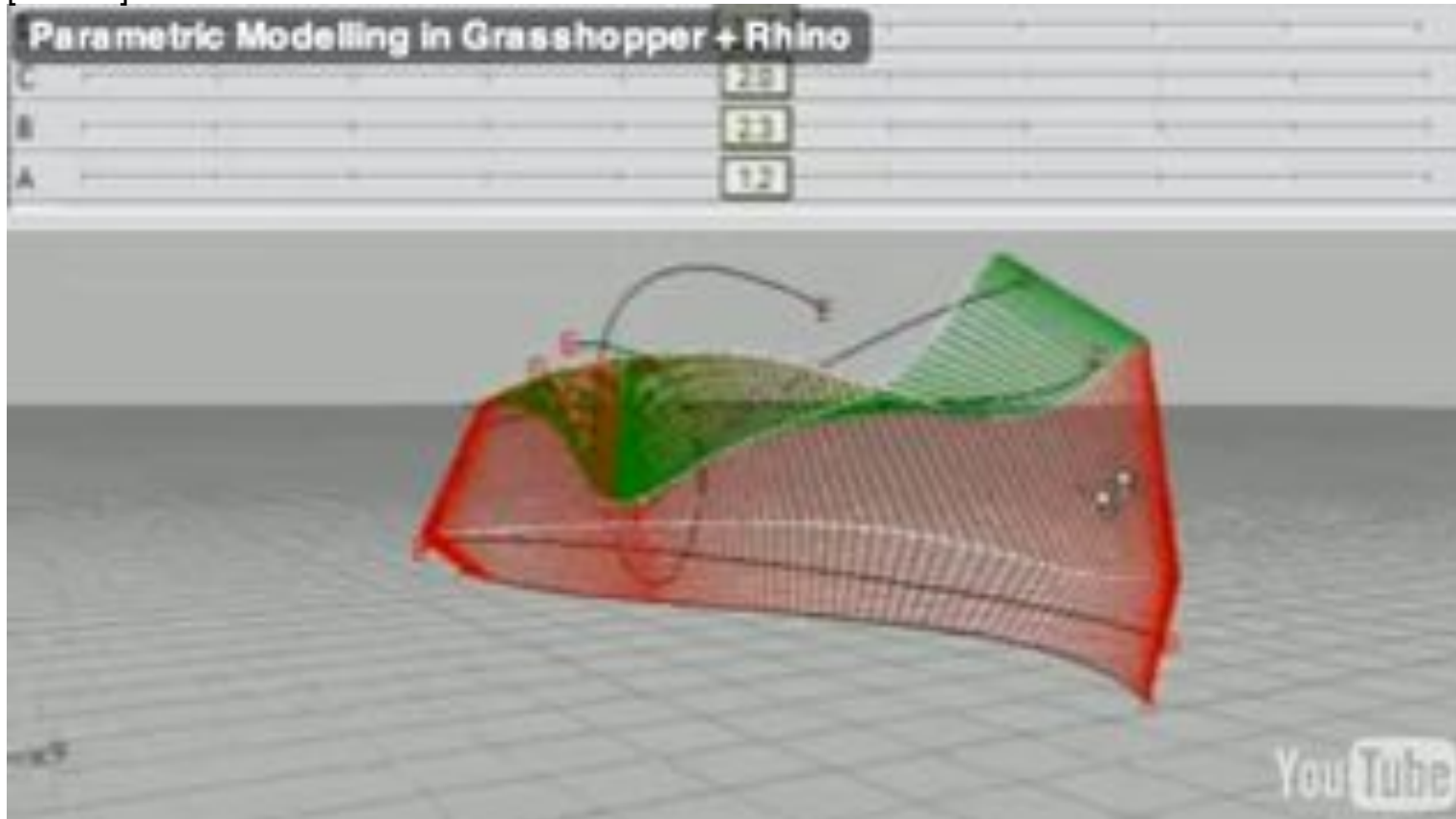
# Parametric modeling example

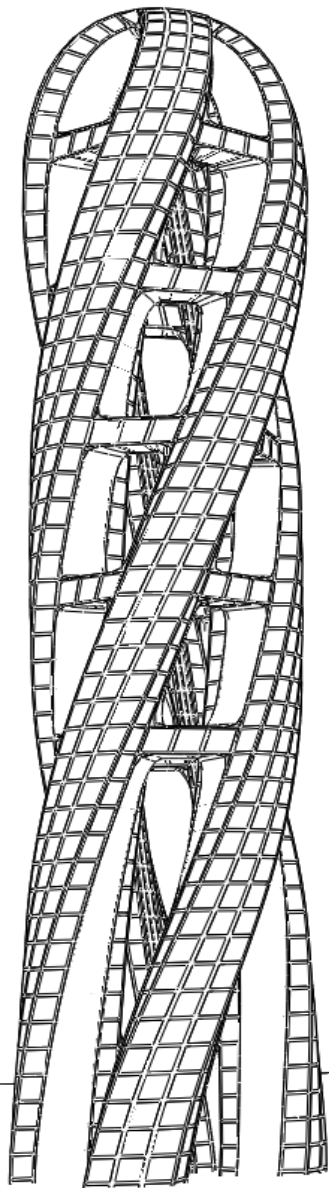
[ movie ]



# Parametric modeling example

[ movie ]

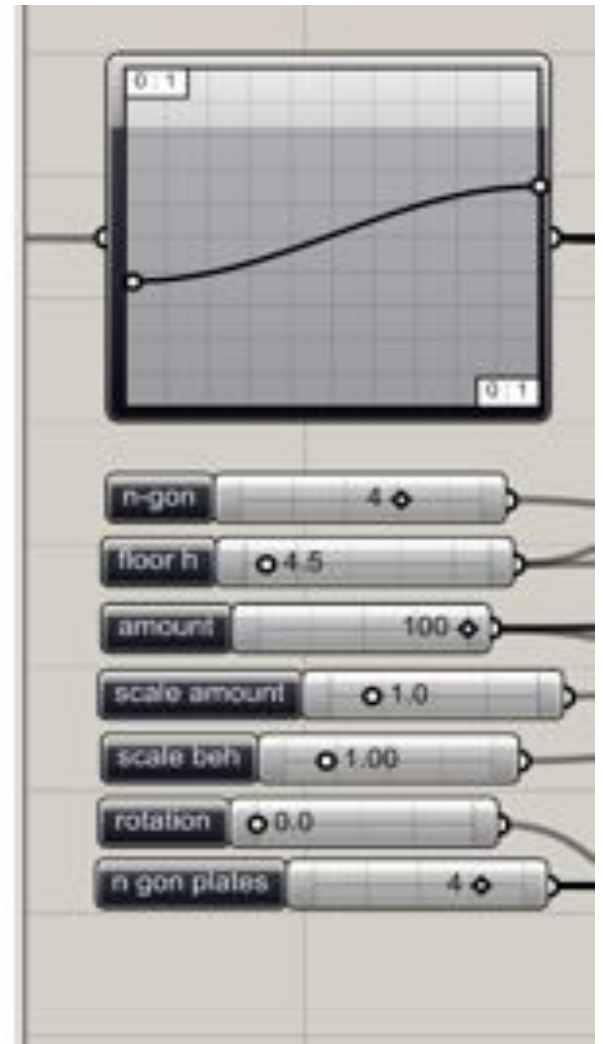
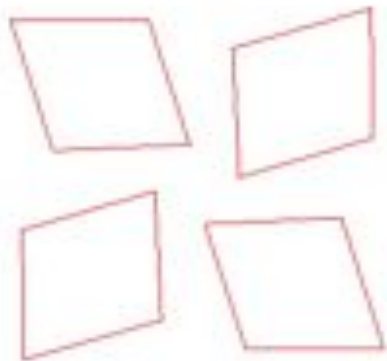




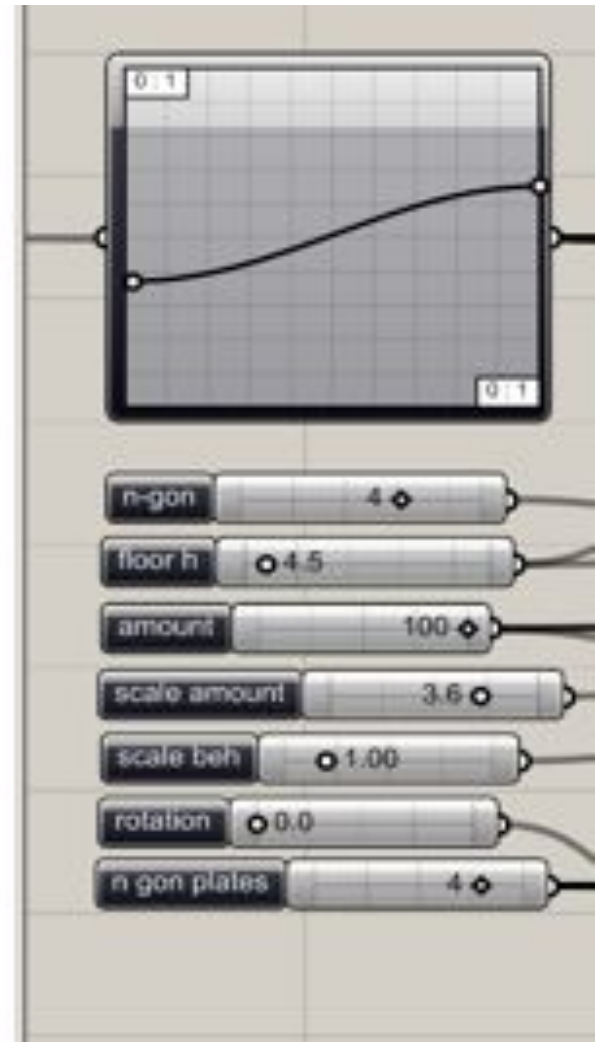
By Florian Heinzelmann

**Spiral Tower – Form & Structure**

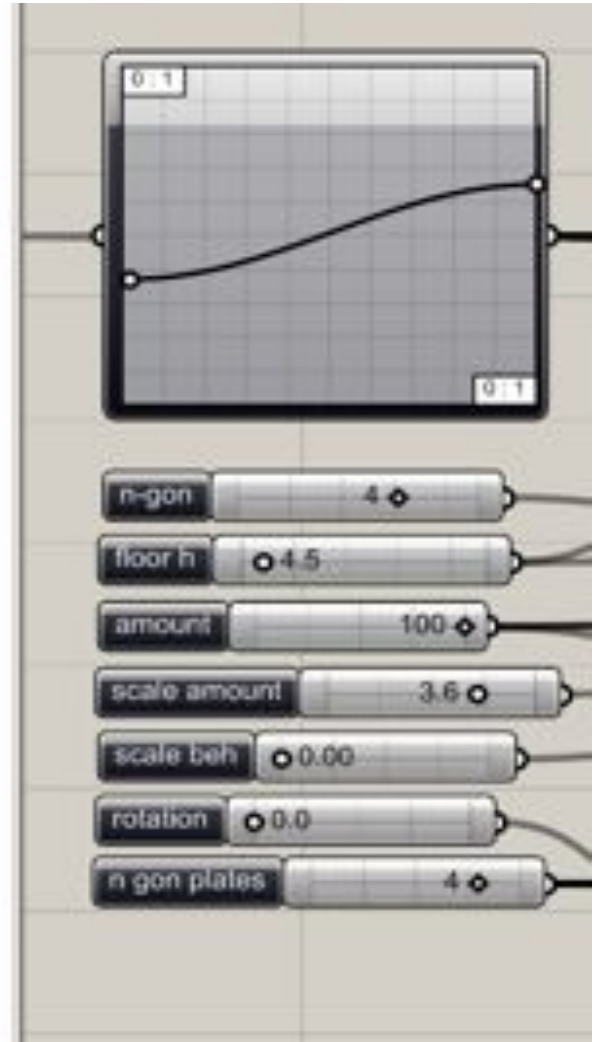
# Parametric settings in grasshopper



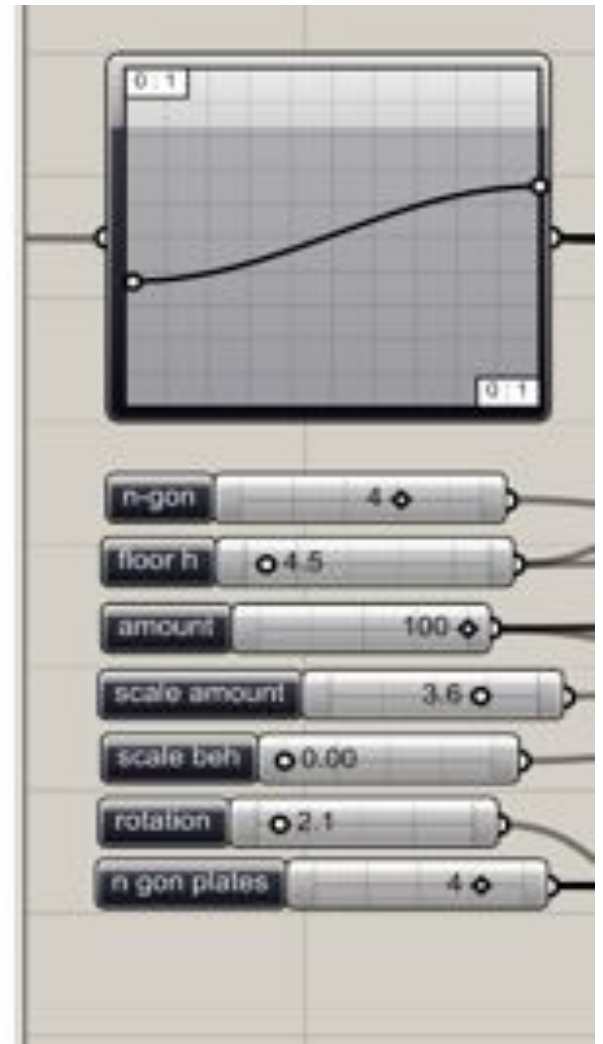
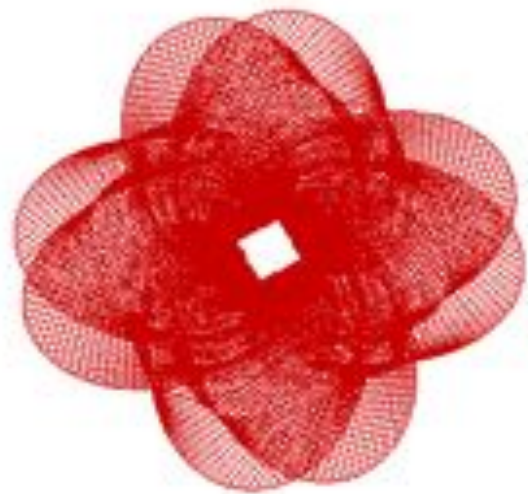
# Parametric settings in grasshopper



# Parametric settings in grasshopper

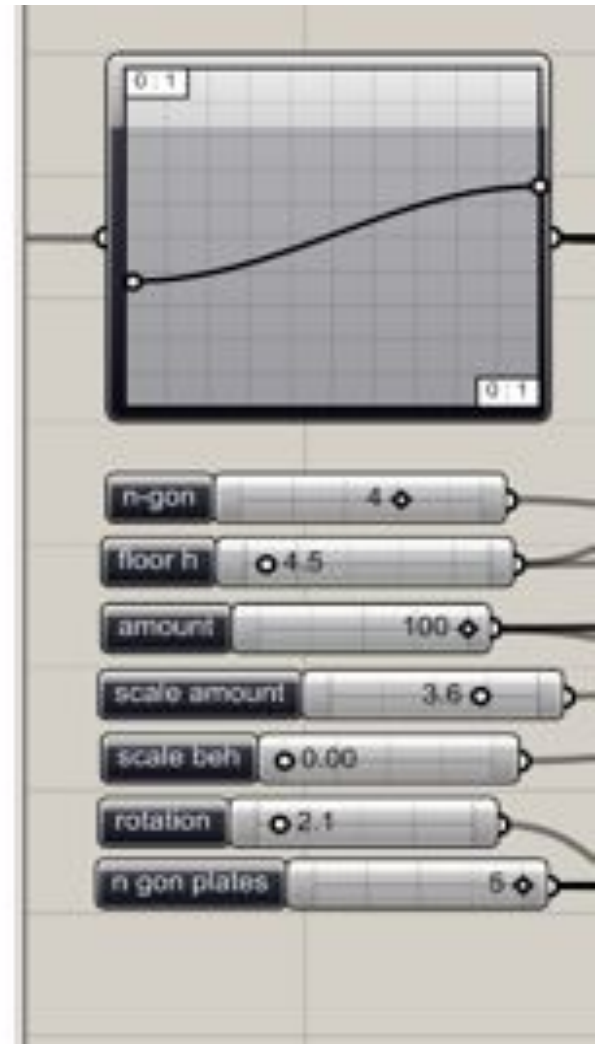
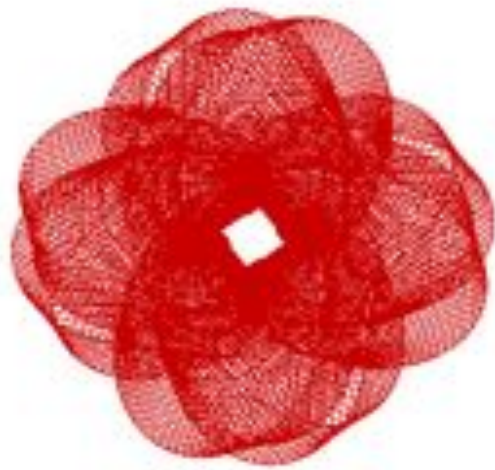


# Parametric settings in grasshopper

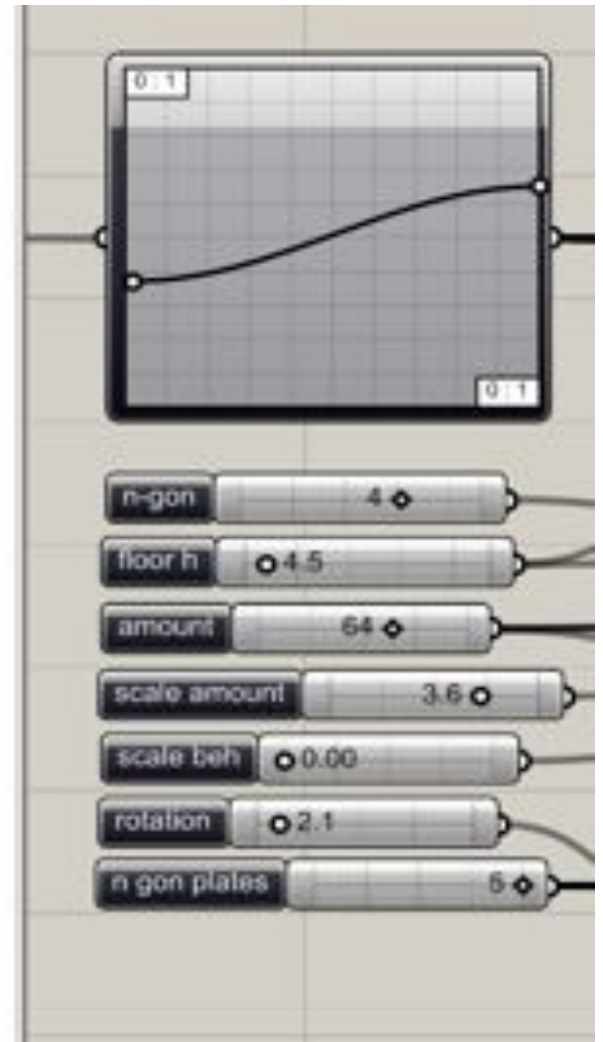
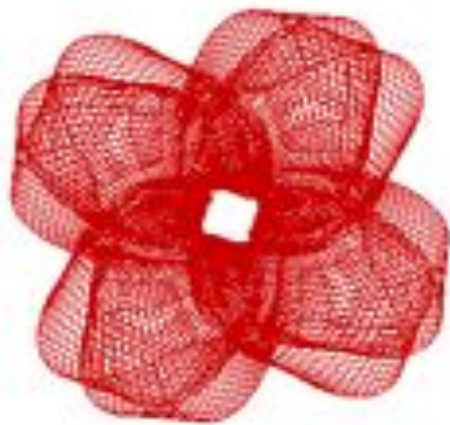




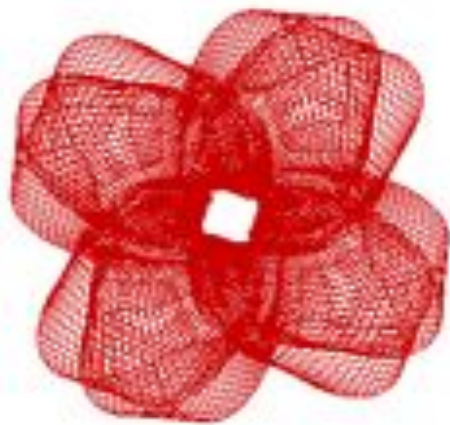
# Parametric settings in grasshopper



# Parametric settings in grasshopper

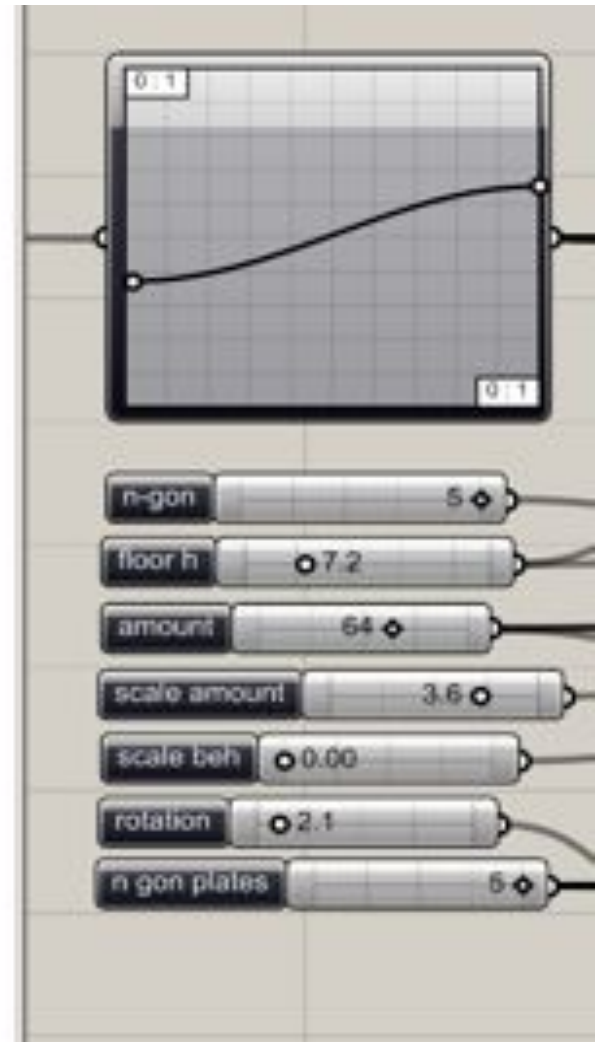


# Parametric settings in grasshopper

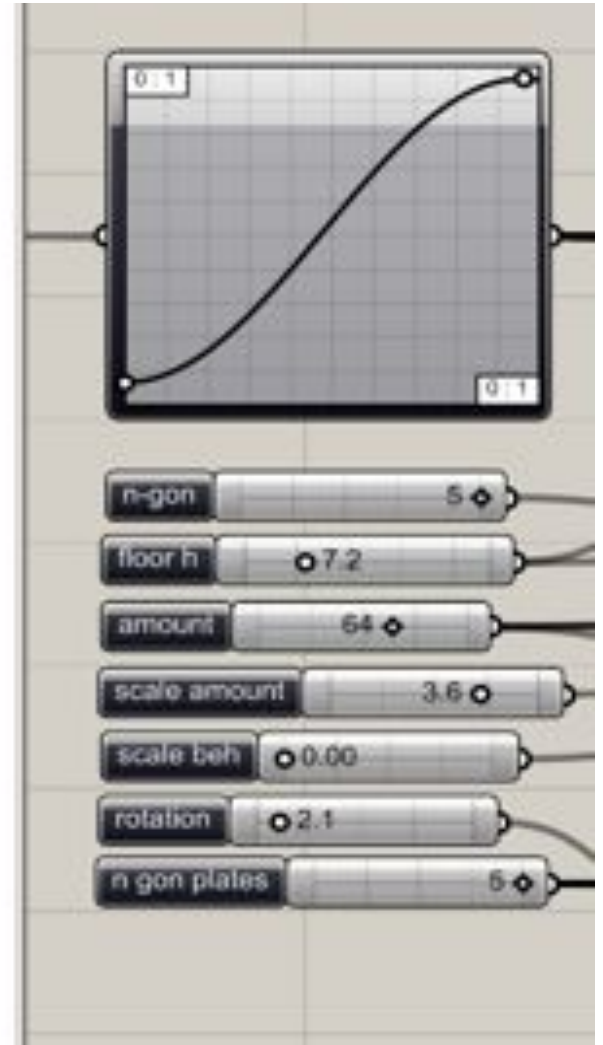
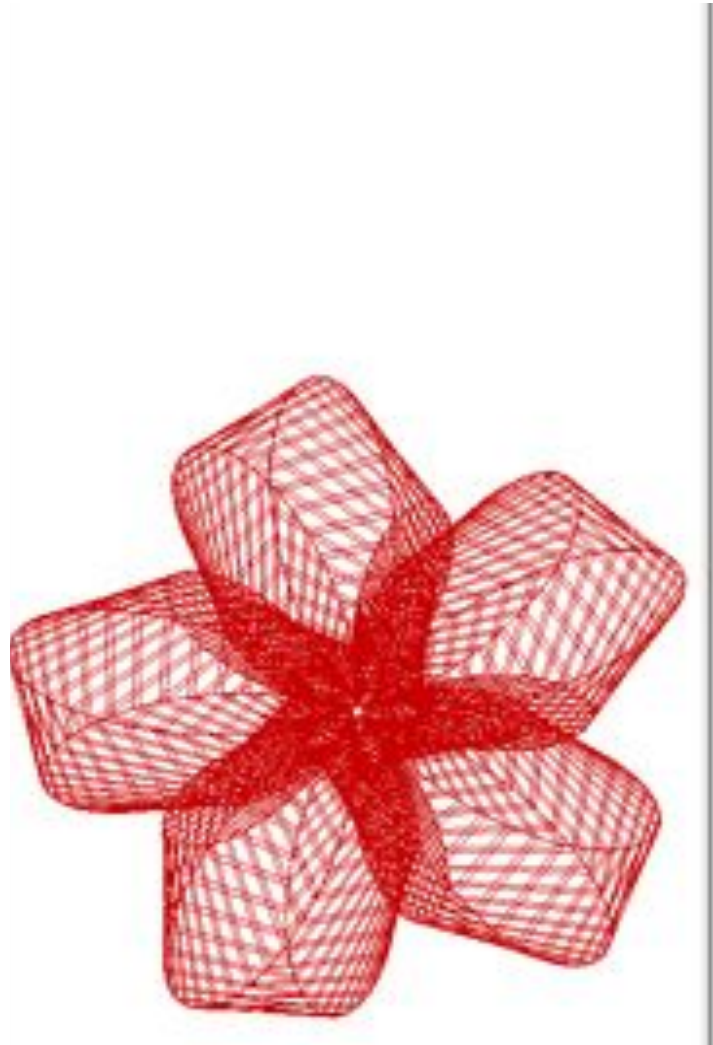
A screenshot of the Grasshopper parametric settings panel. It features a graph at the top and several sliders below. The graph shows a curve starting at (0,0) and ending at (1,1). The sliders are labeled with their names and current values.

Parameter	Value
n-gon	4
floor h	7.2
amount	64
scale amount	3.6
scale beh	0.00
rotation	2.1
n gon plates	6

# Parametric settings in grasshopper



# Parametric settings in grasshopper

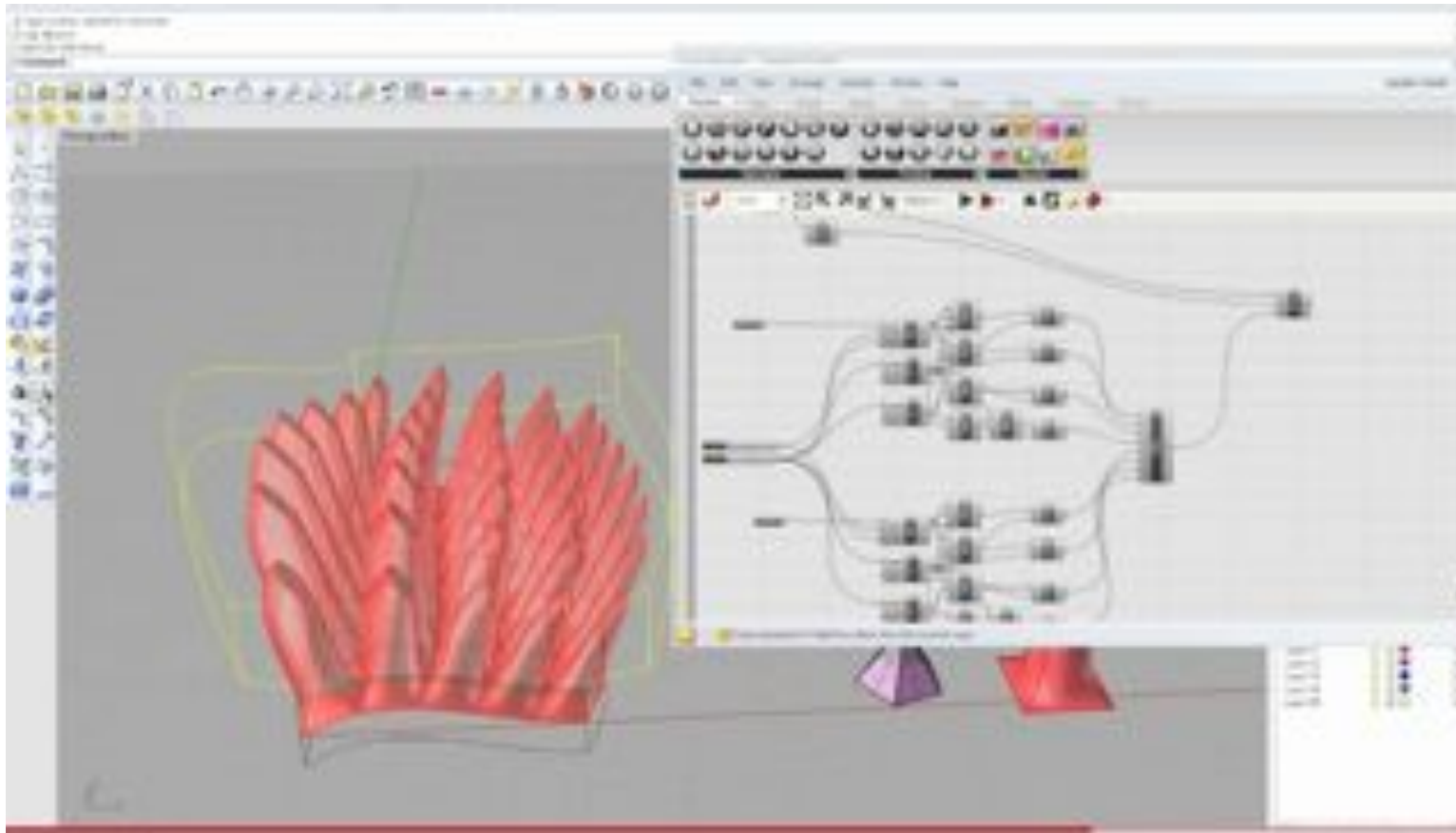


# Repetition

- Make one object use it as a reference in a repetitive way according to some composition

# Populating a surface

[ movie ]



# Parametric design

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- A design passes through a lot of phases
- And a lot of changes and revisions
- Therefore needs to be modeled many times
  
- A simple project (or geometry) can be redrawn and remodeled easily
- A complex (geometry) building is a killer to be remodeled many times

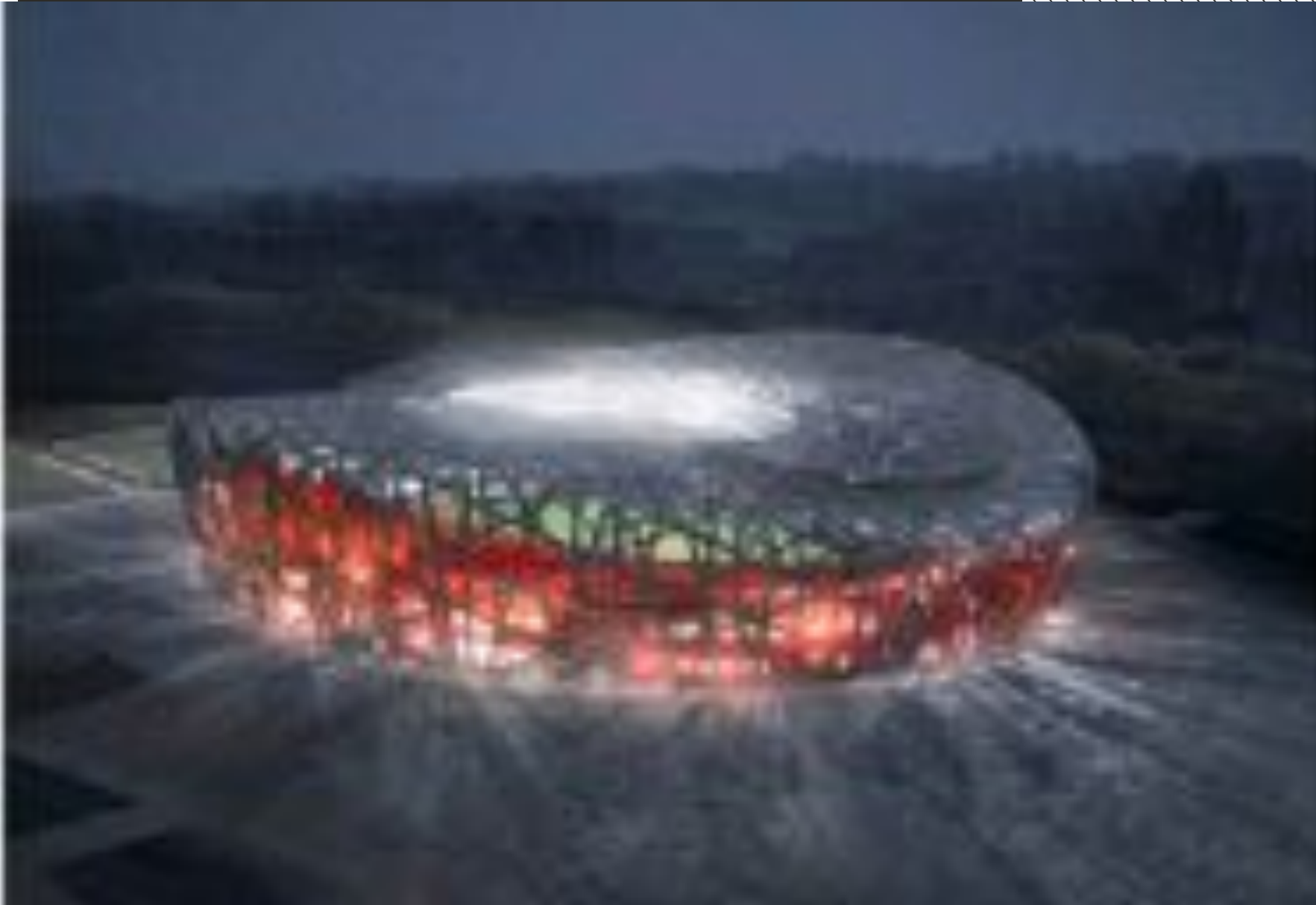
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# National Stadium, Beijing, China

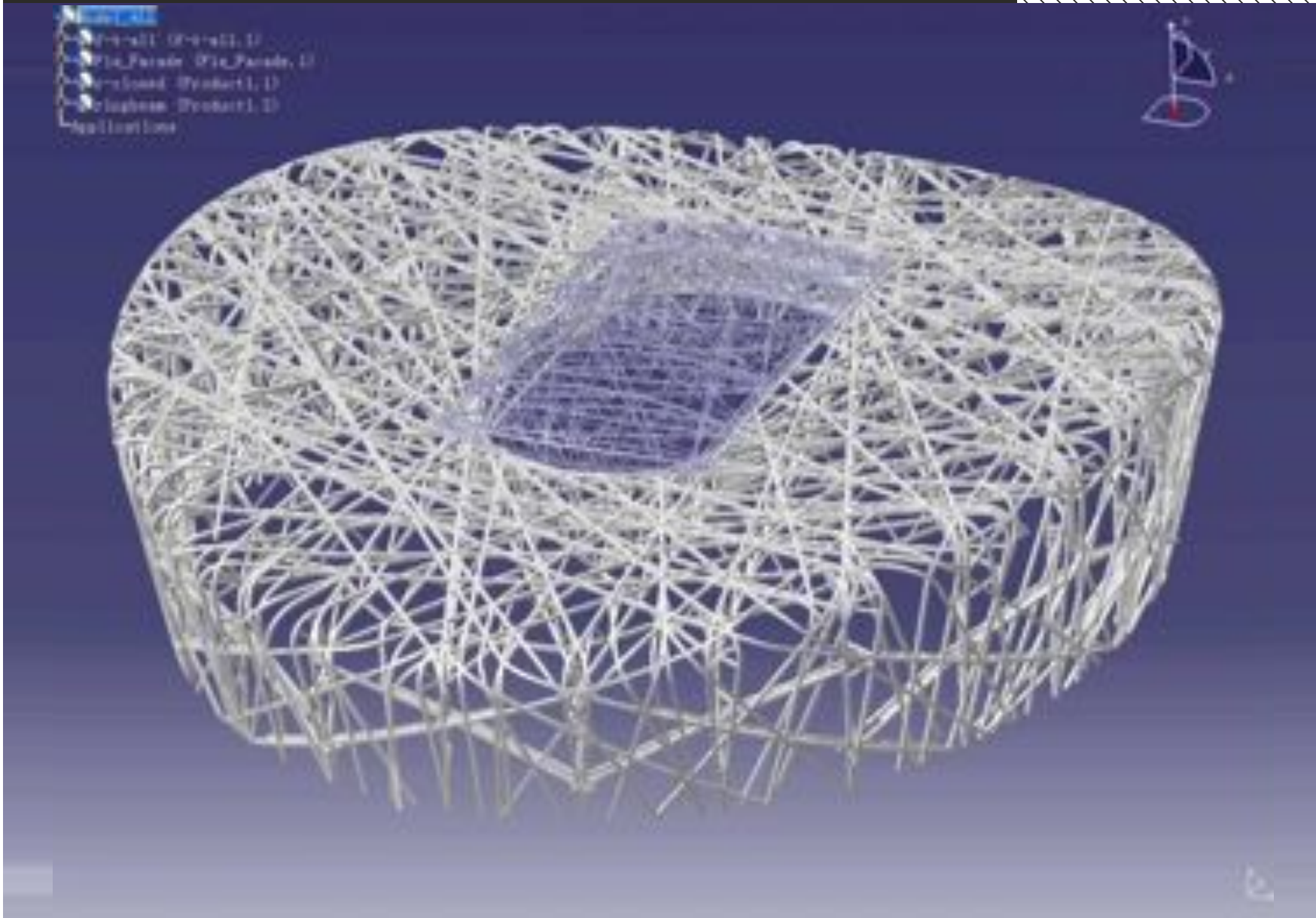
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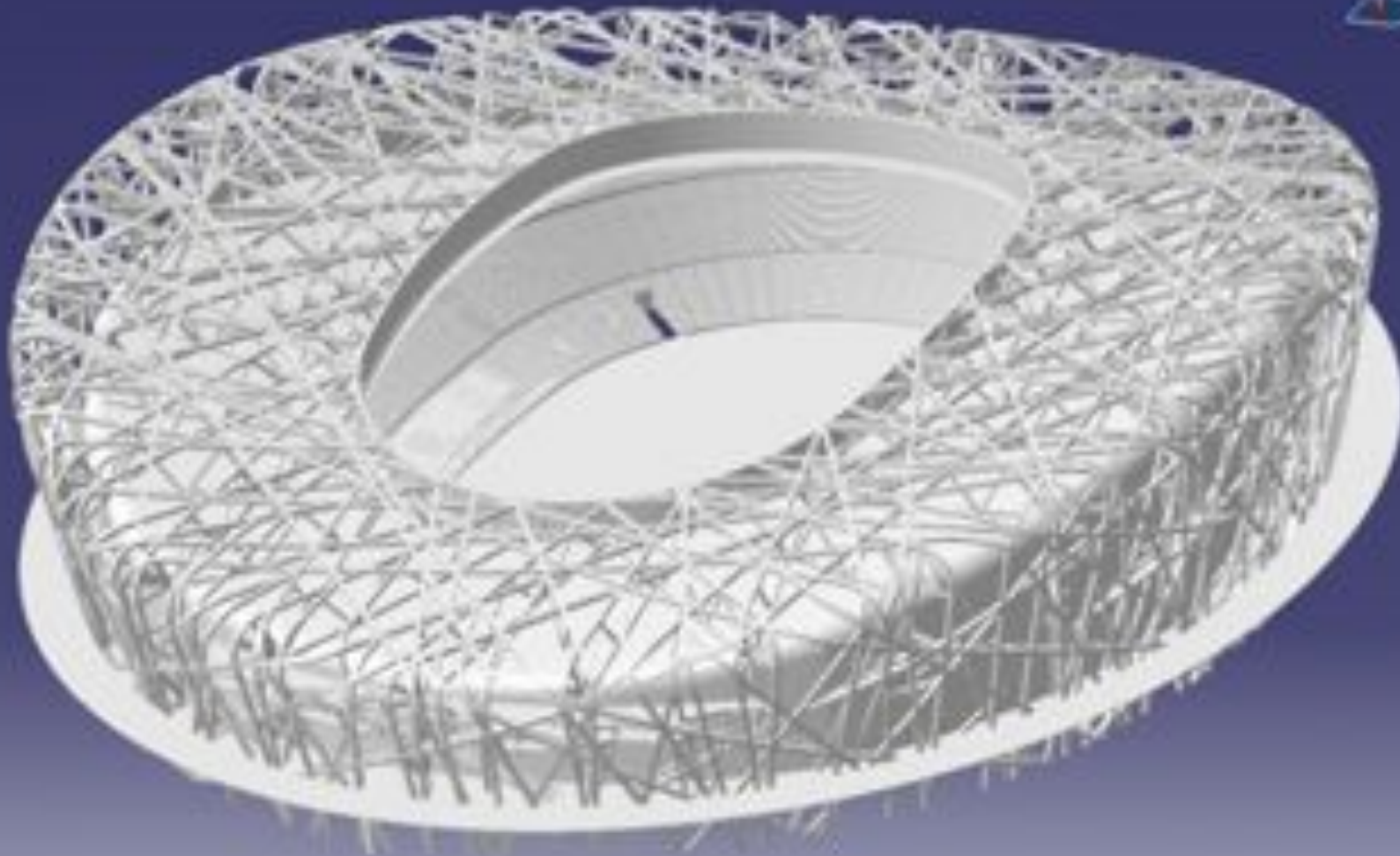


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# Manpower

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# Parametric design: Performative design

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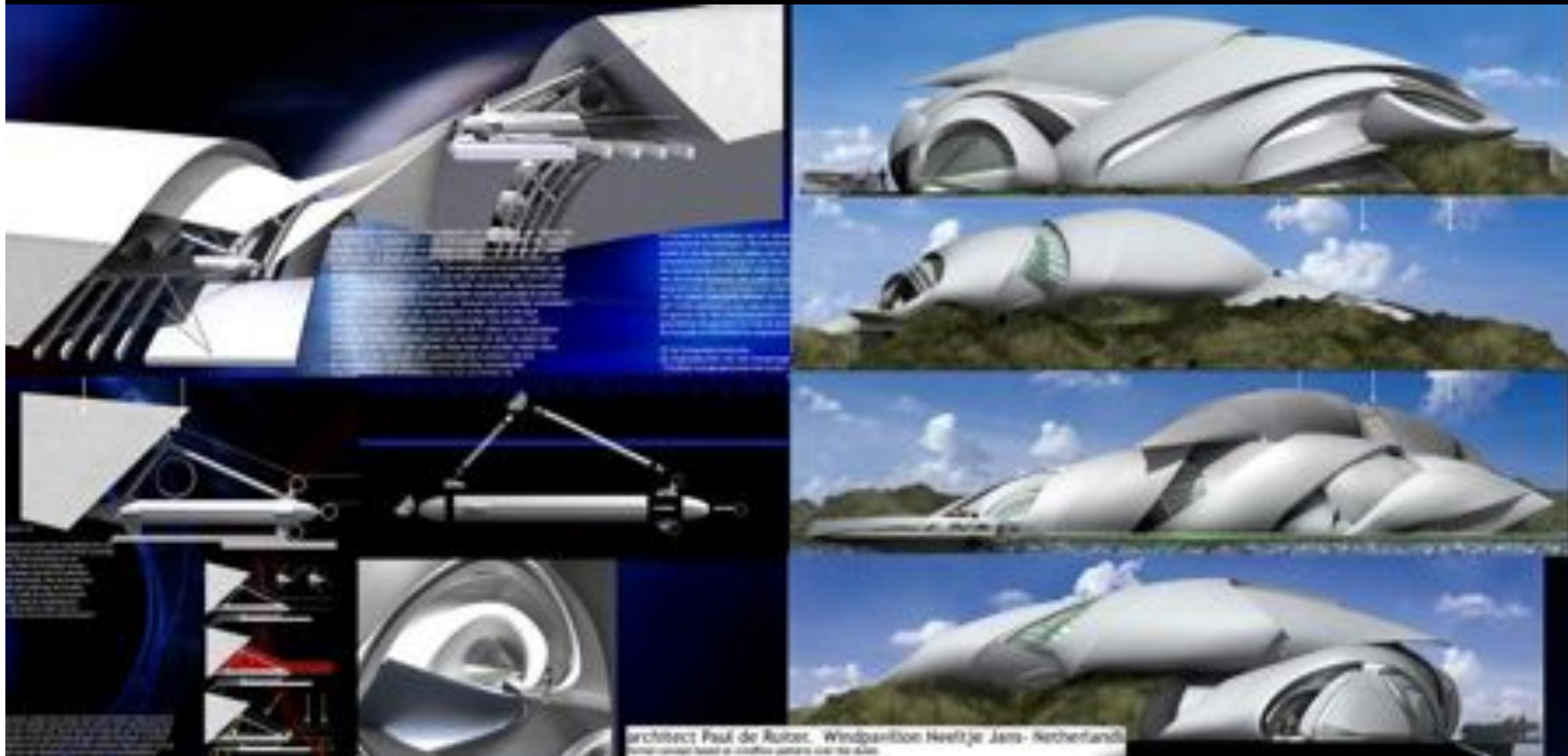
- Performative architecture
- Performance

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# Performance analysis

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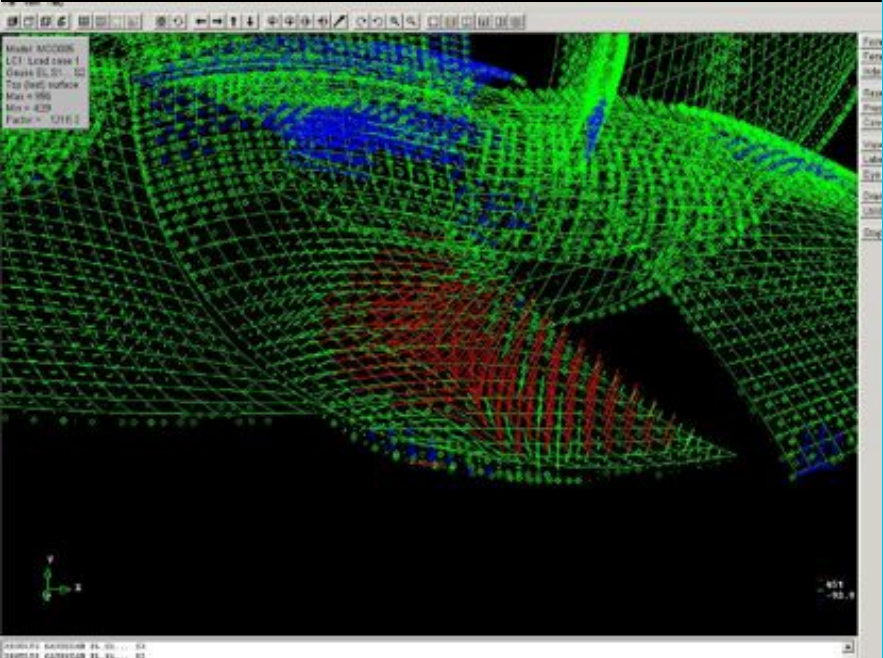
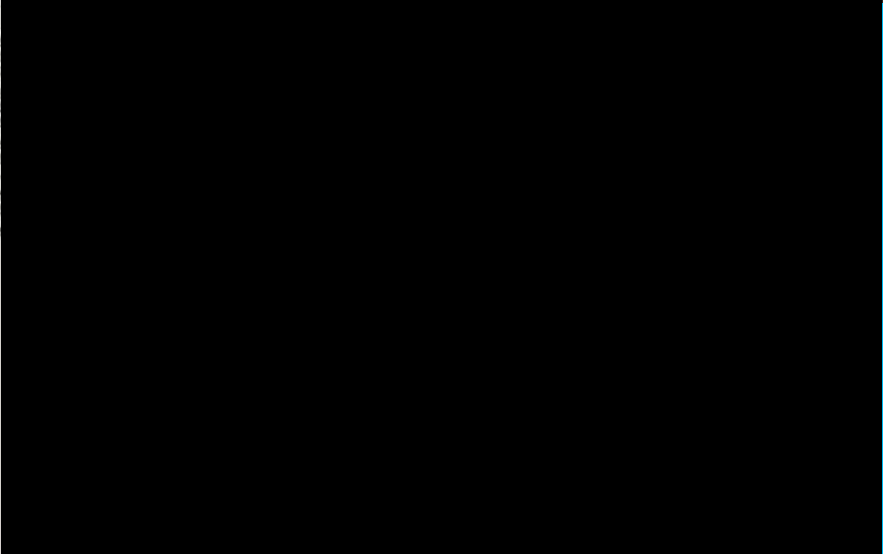
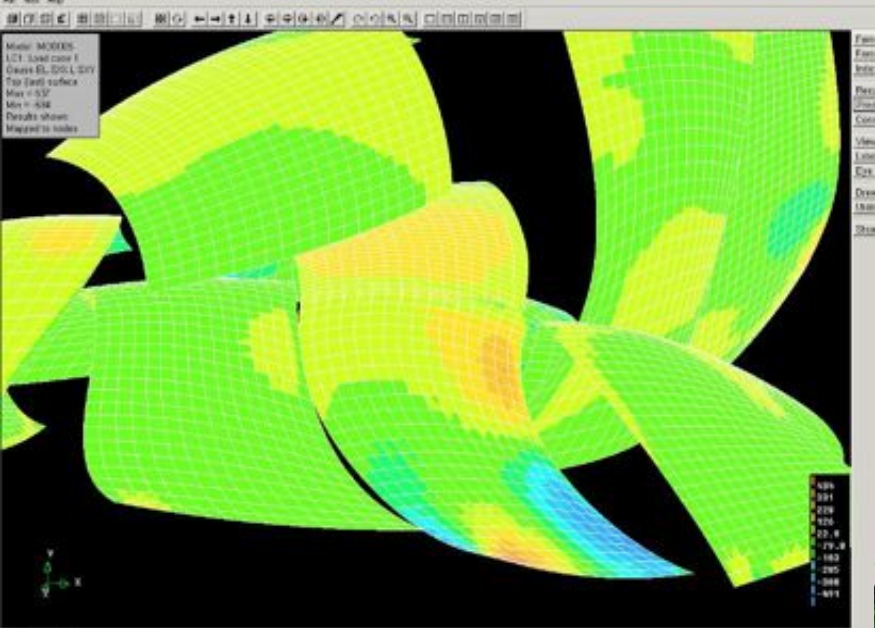
Light, acoustics, thermal, wind, structural, ...

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# Performance analysis

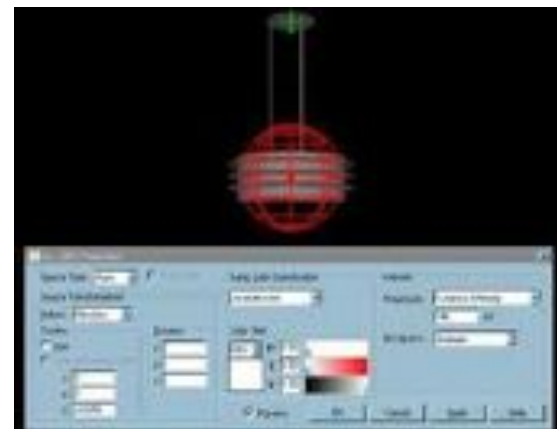


structural

# Performance analysis

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## Light



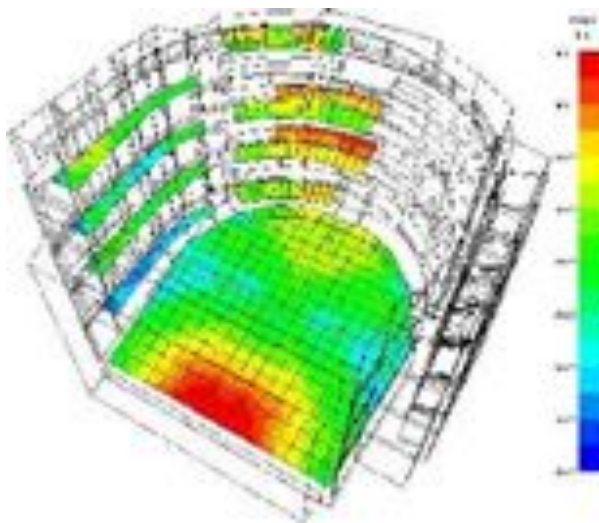
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# Performance analysis

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## Acoustics

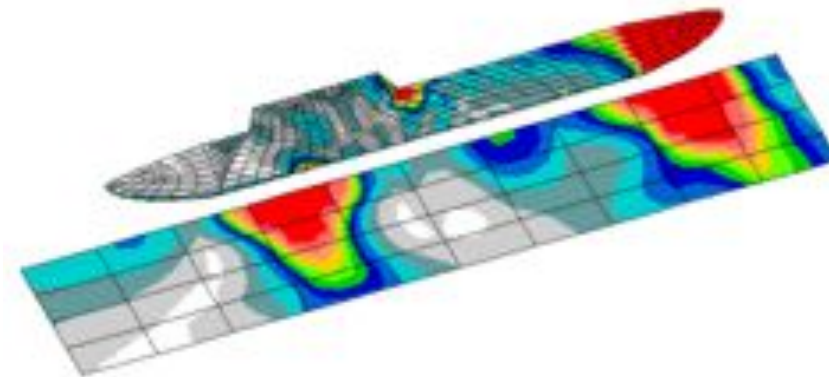
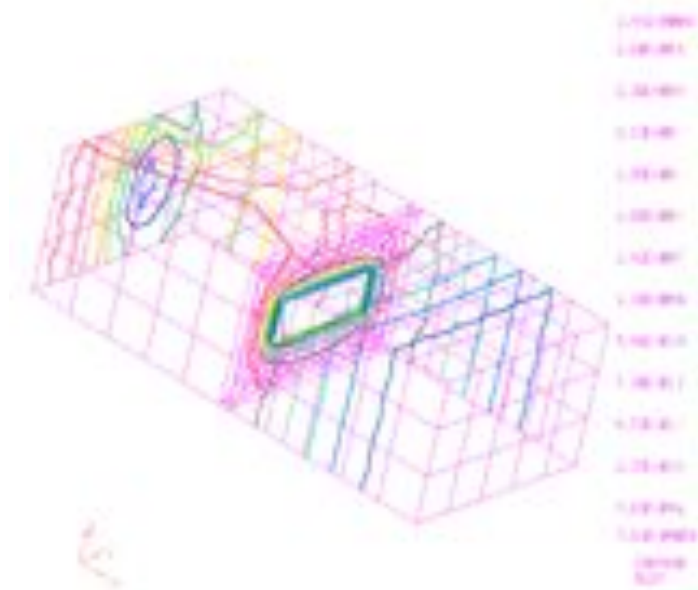


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# Performance analysis

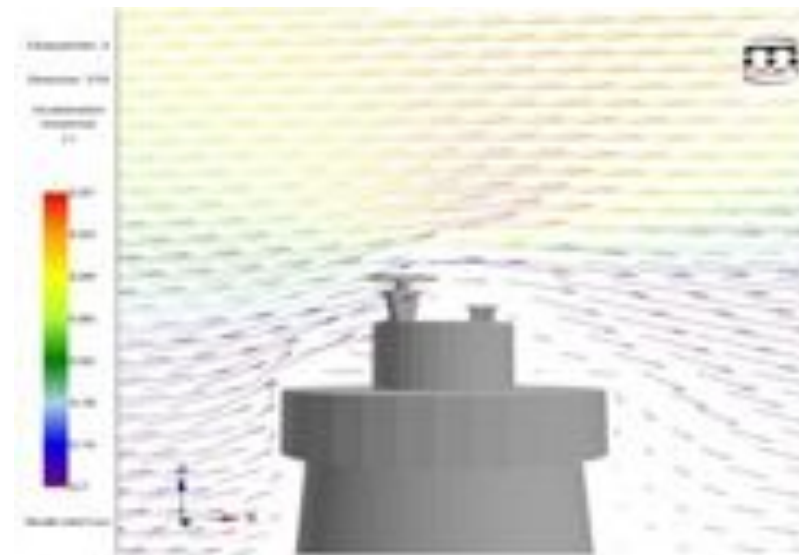
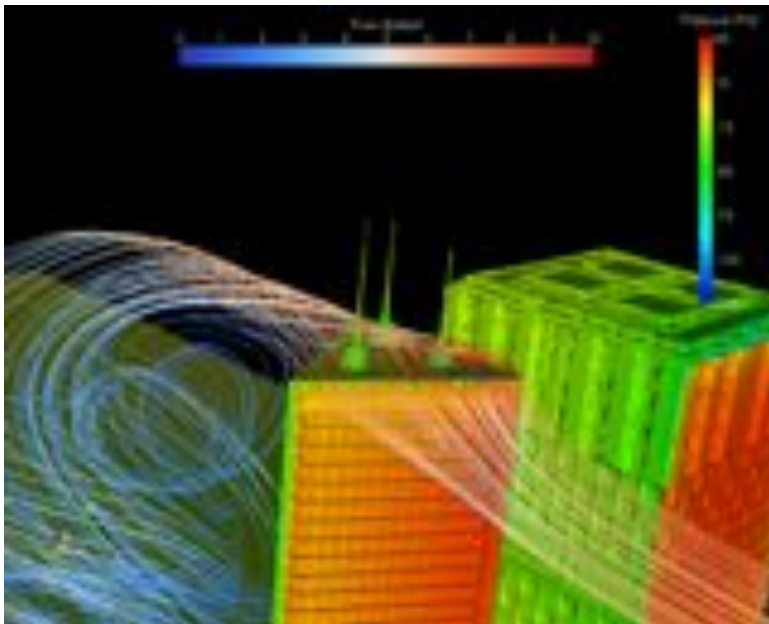
## Heat transfer



# Performance analysis

## Wind

- CFD

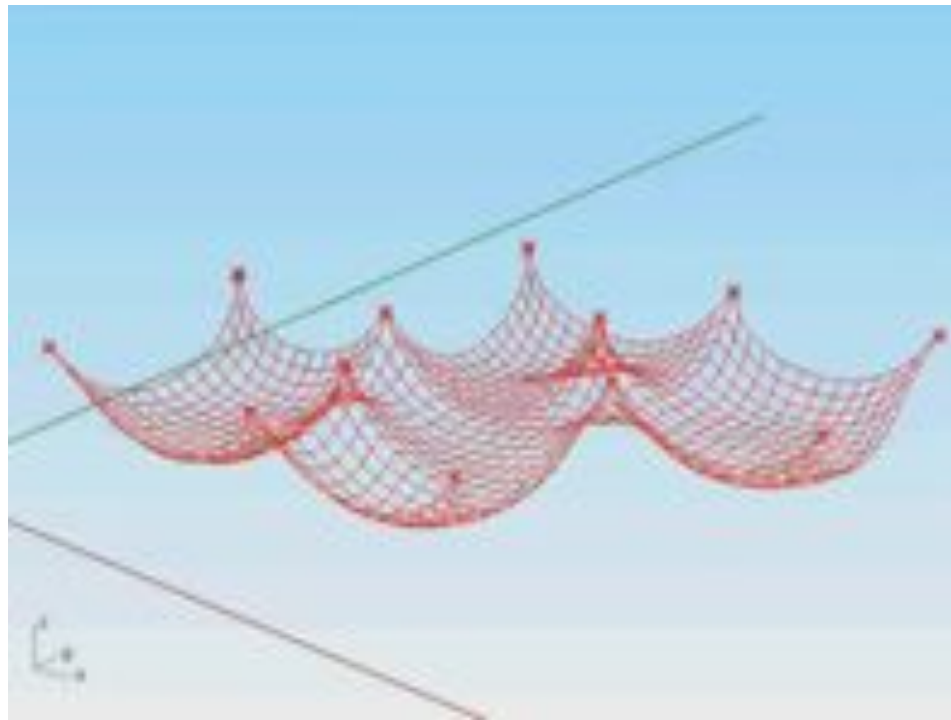


# Kangaroo in Rhino / Grasshopper

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- Live 3D physics

[ movie ]



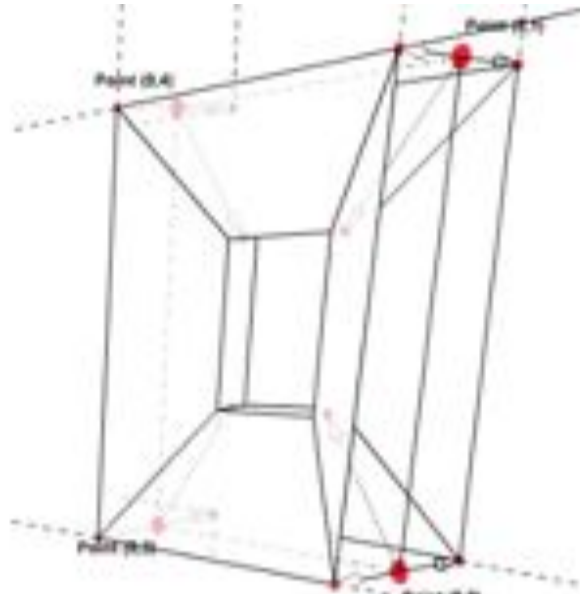
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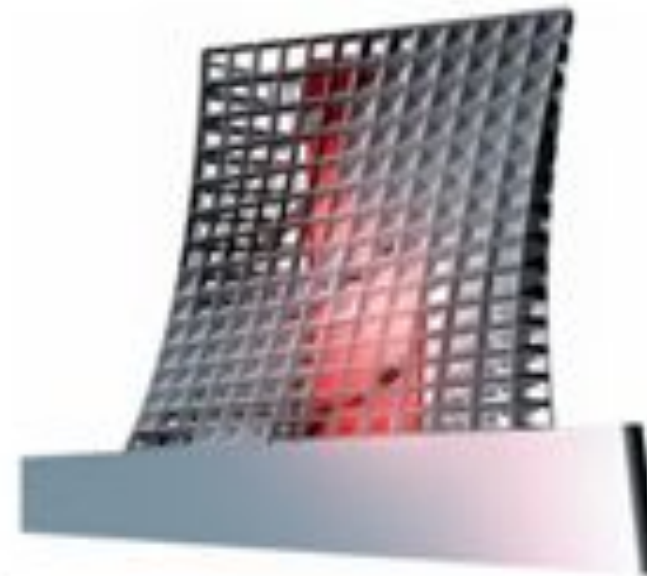
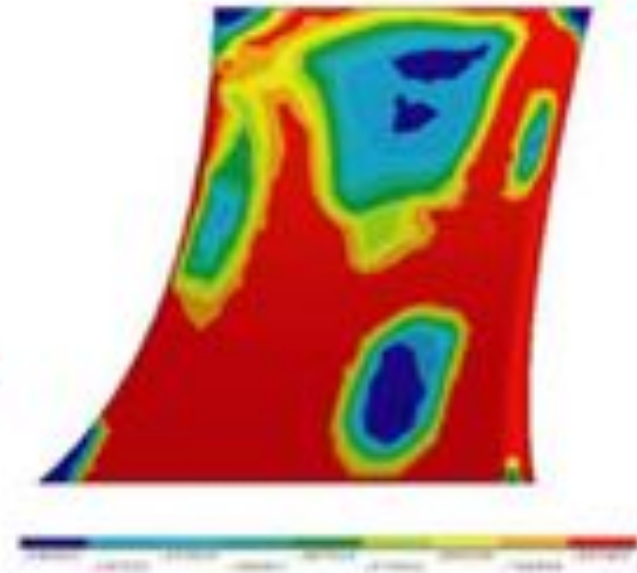
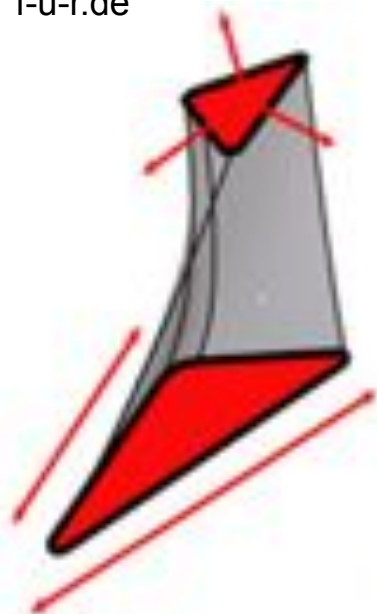
# Performance analysis

surface strategies –  
in combination with  
structural optimization

embrassere space frame



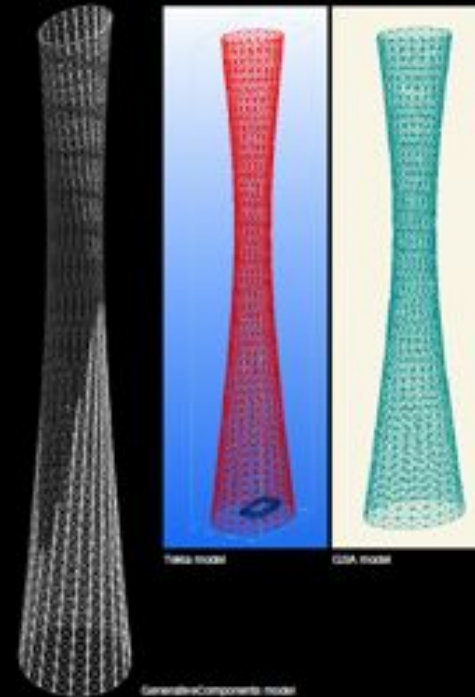
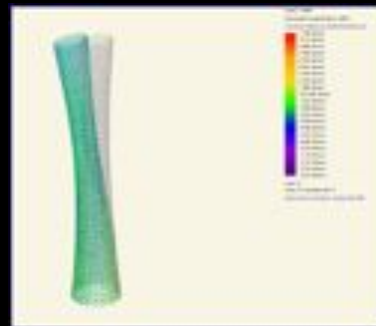
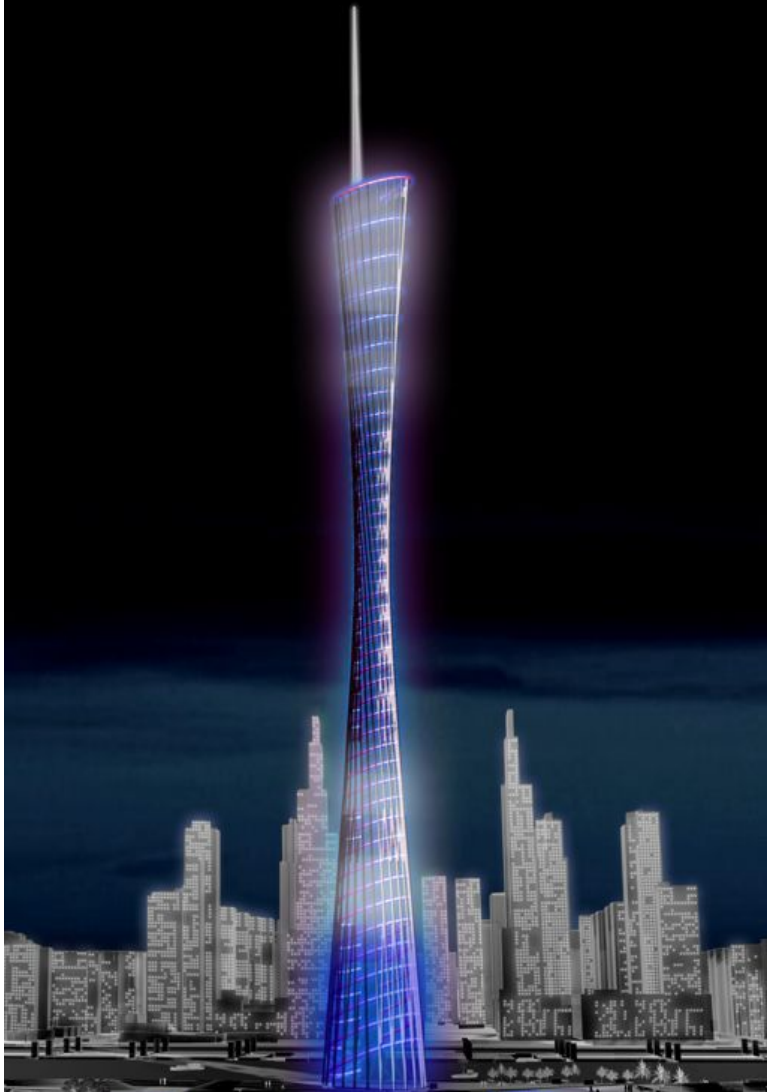
f-u-r.de



# Arup Amsterdam / Guangzhou TV & Sightseeing Tower

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Direct (live) interfacing between parametric and analysis software

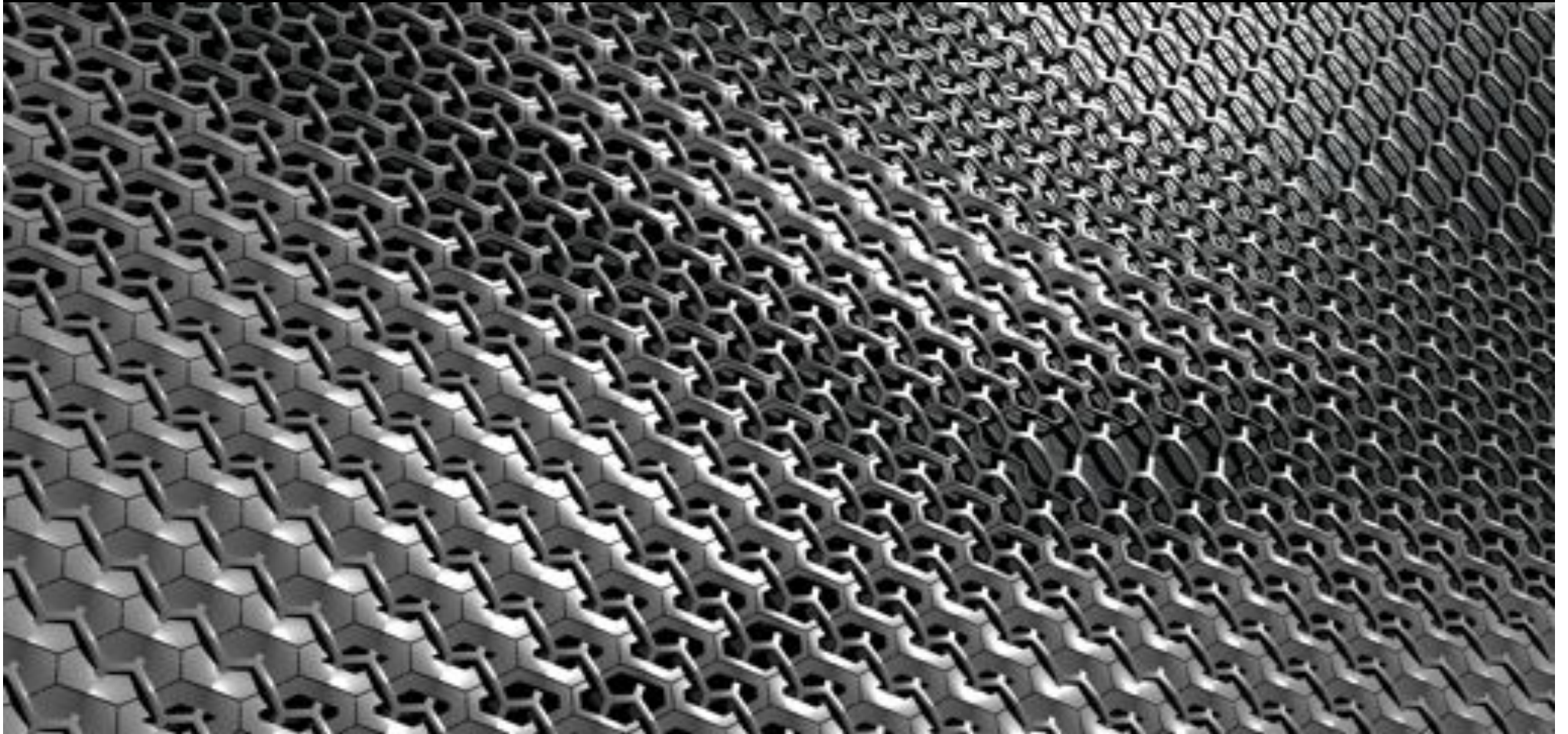


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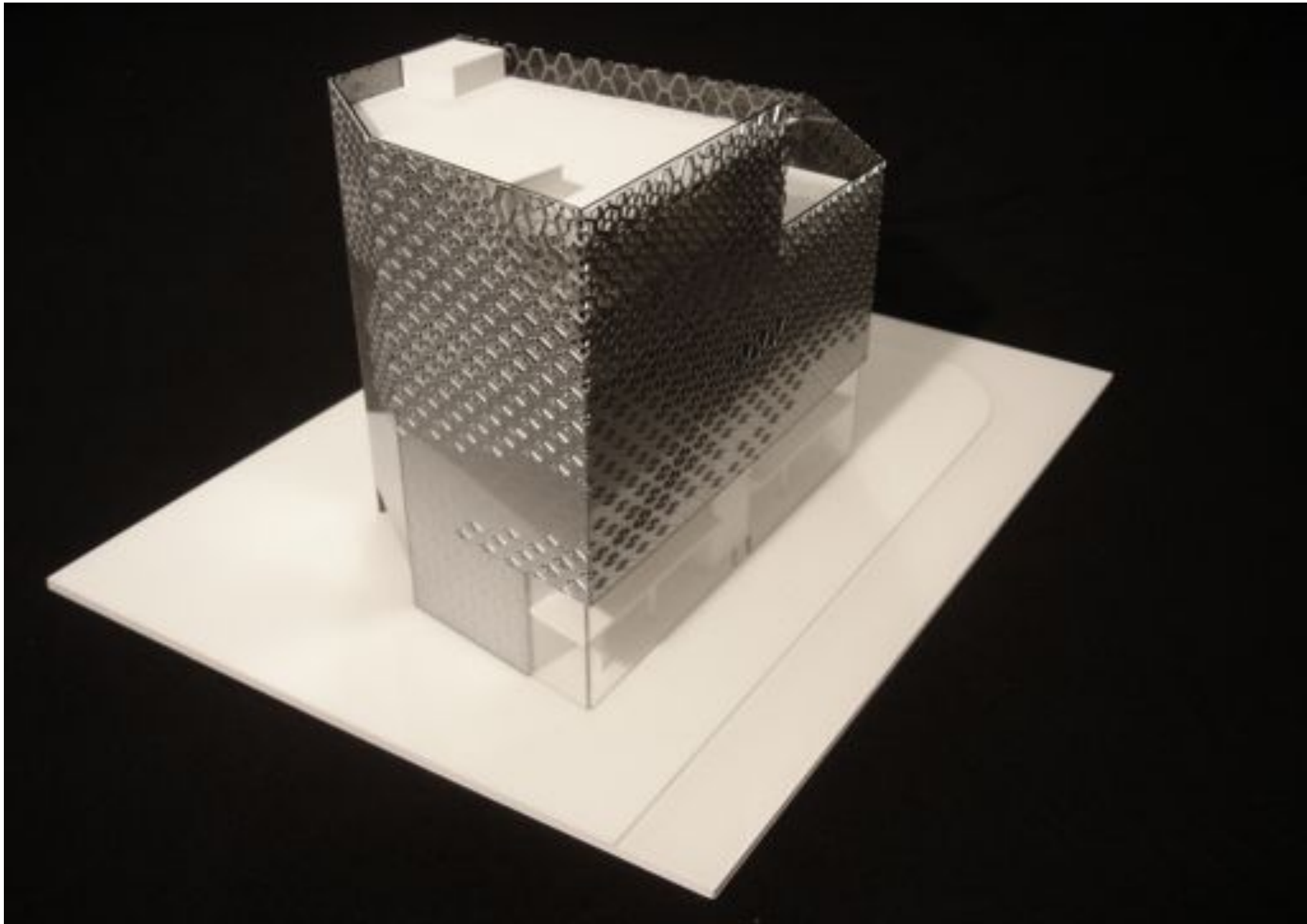


**UNStudio** by Florian Heinzlmann

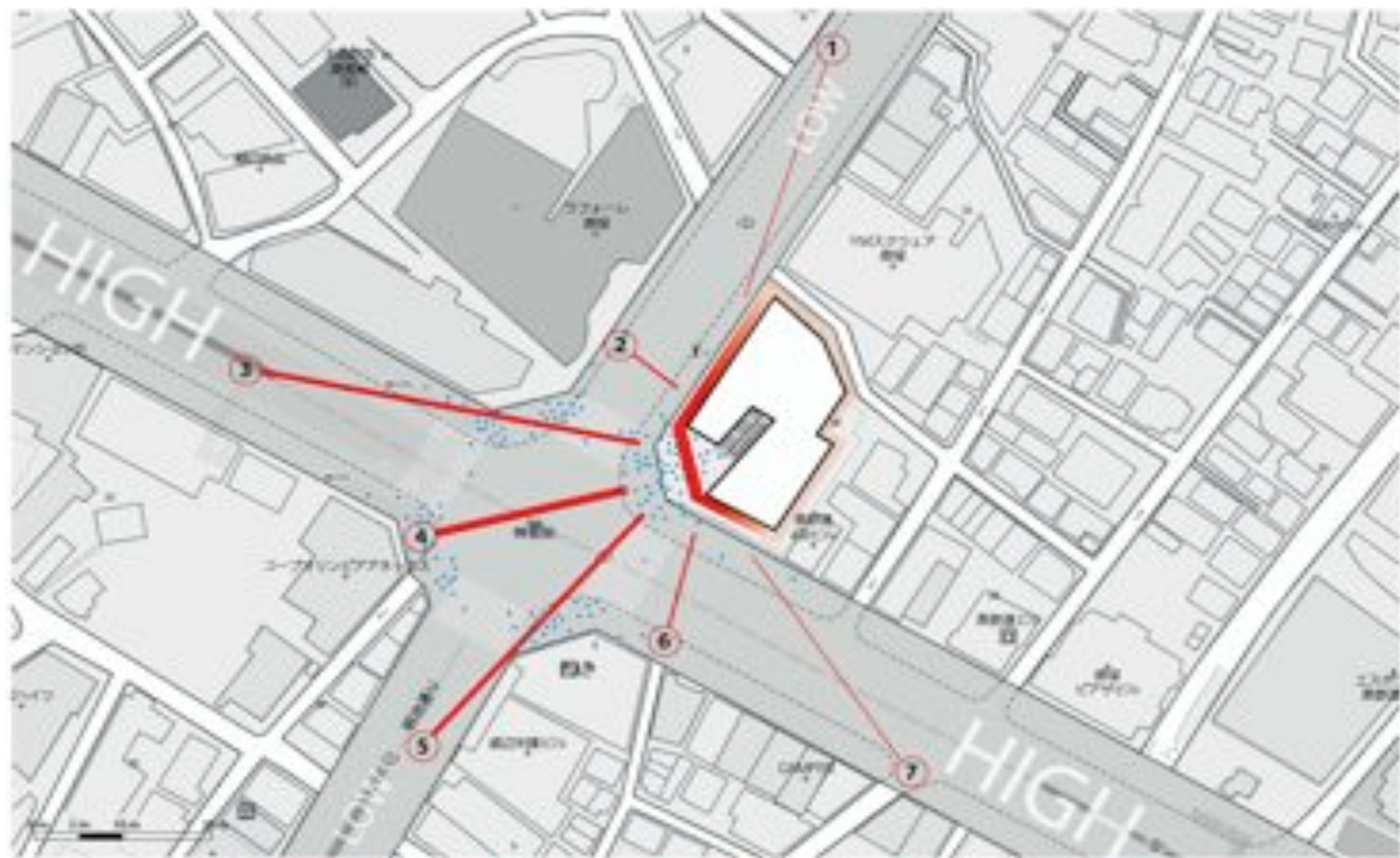


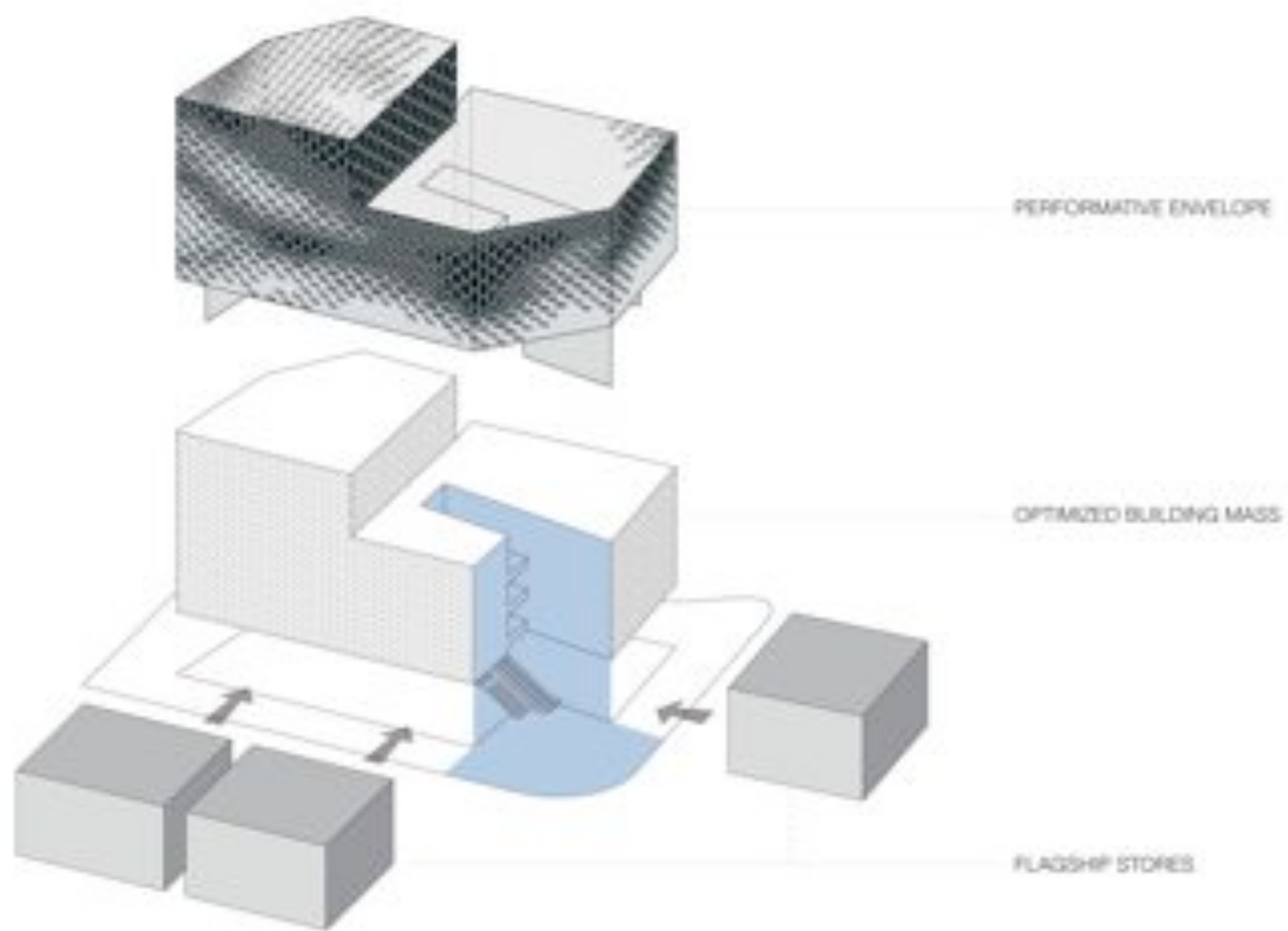
**Omotesando**

Façade and Structure





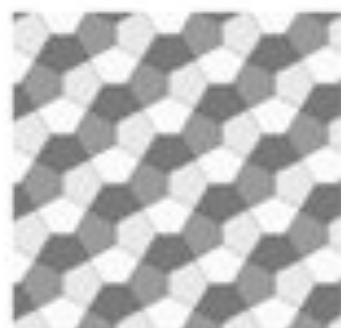




WRAPPING THE ENVELOPE



BELL FLOWER



TESSELLATION



INTERWEAVING



PENTAGON

x 4 =

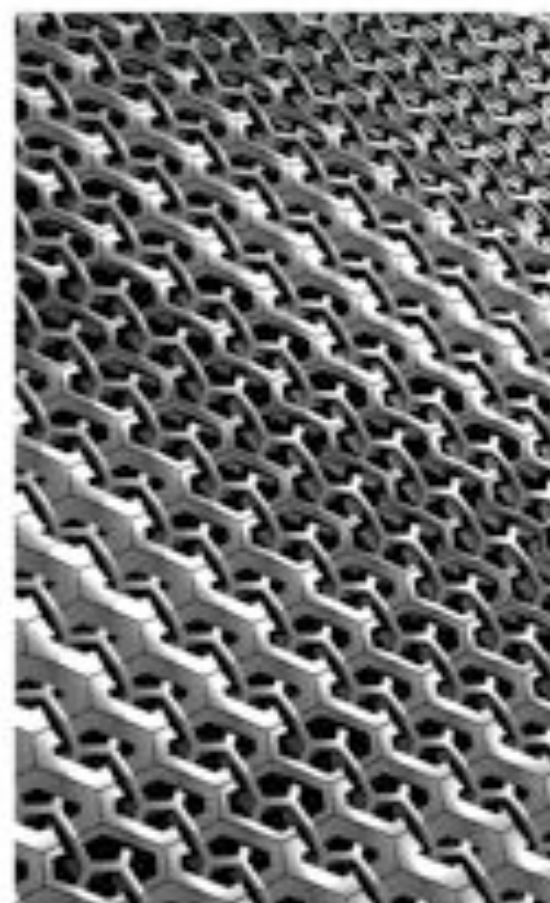


HEXAGON

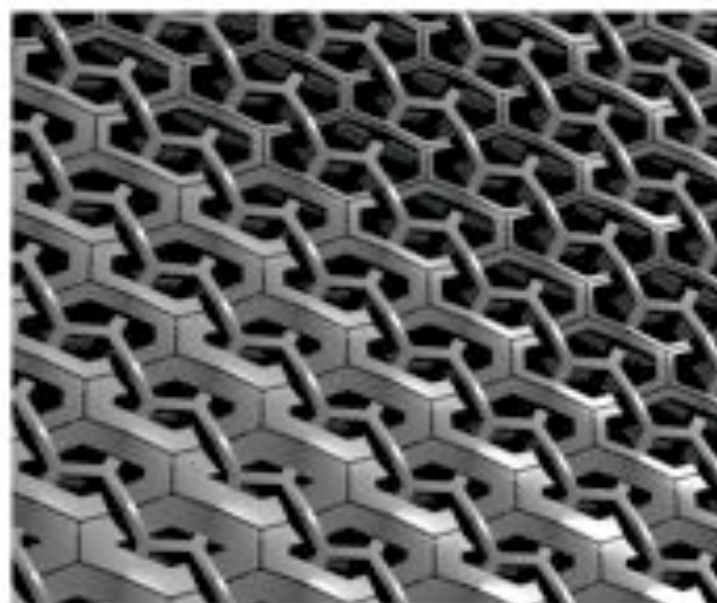
x 4 =



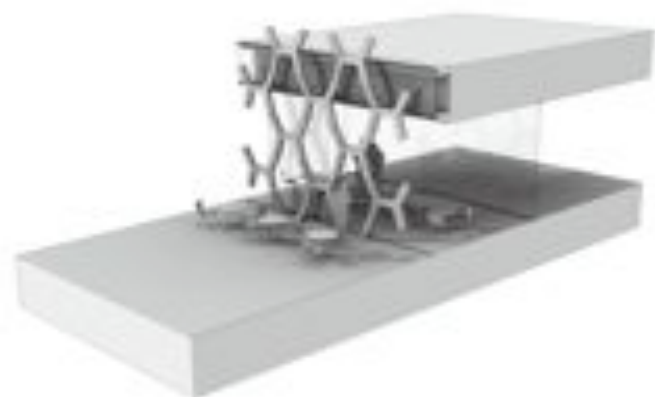
HEXAGON  
IN HEXAGON



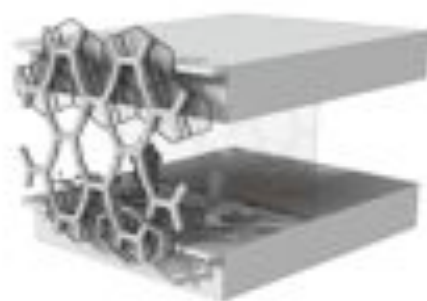
PATTERN TESSELLATION



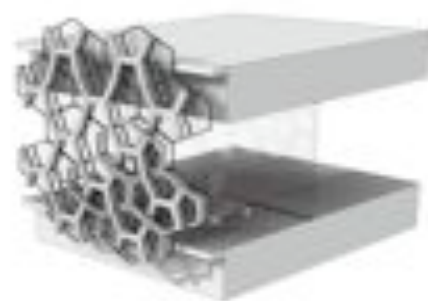
THE SEVEN TILES



RESTAURANT TERRACE  
• SLIDING DOORS



BALCONY  
• OPEN TOWARDS OUTSIDE



RESTAURANT 6<sup>TH</sup> & 7<sup>TH</sup> FLOOR  
• GLAZING WITH MAXIMUM VIEW



SHOP OPEN  
• SHADOWPLAY & DAYLIGHT INSIDE

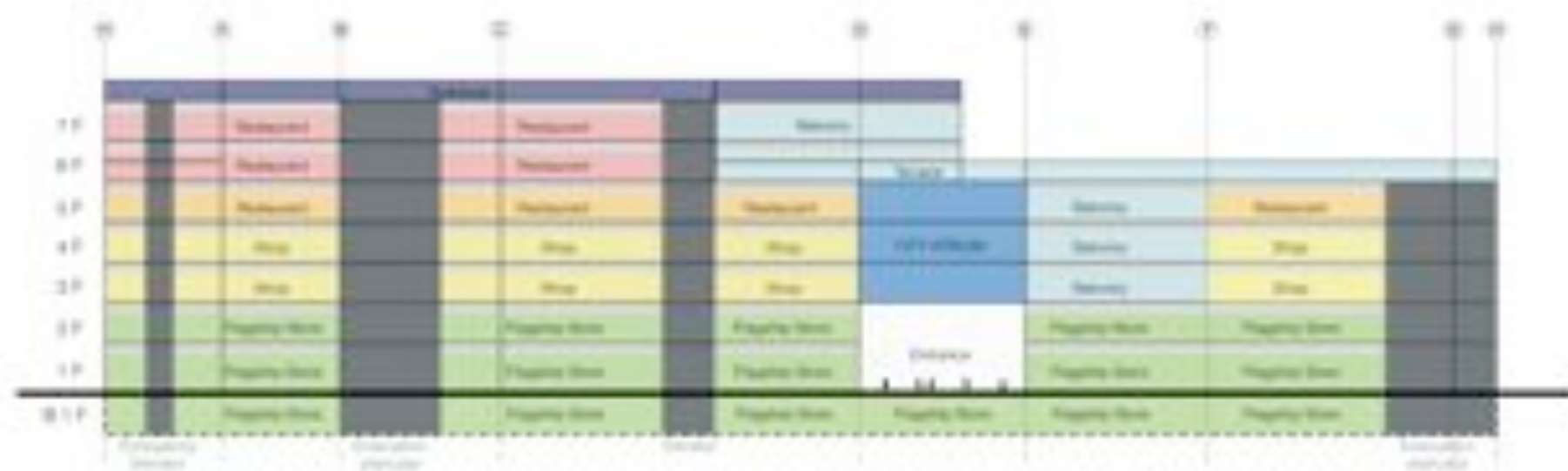


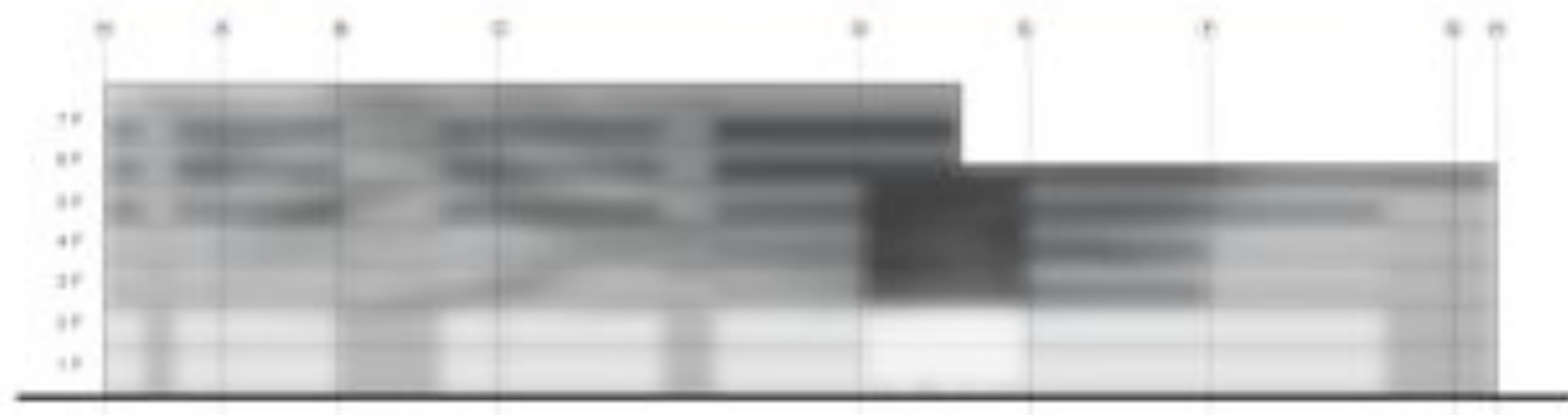
SHOP MEDIUM OPEN  
• ATMOSPHERIC INTERIOR

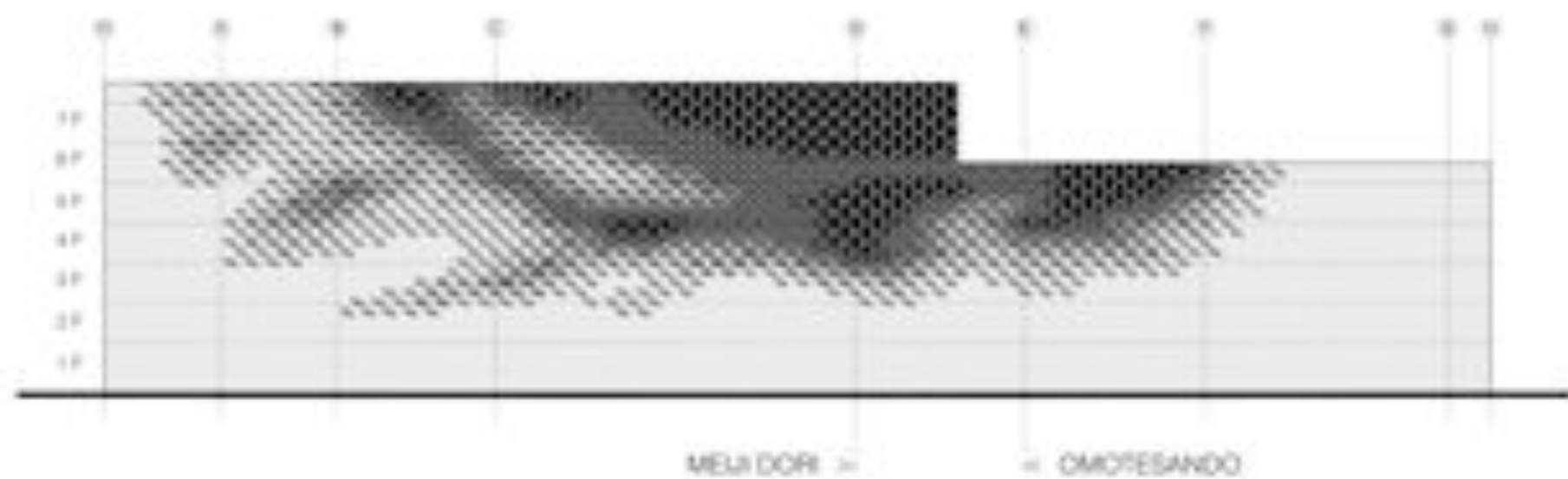


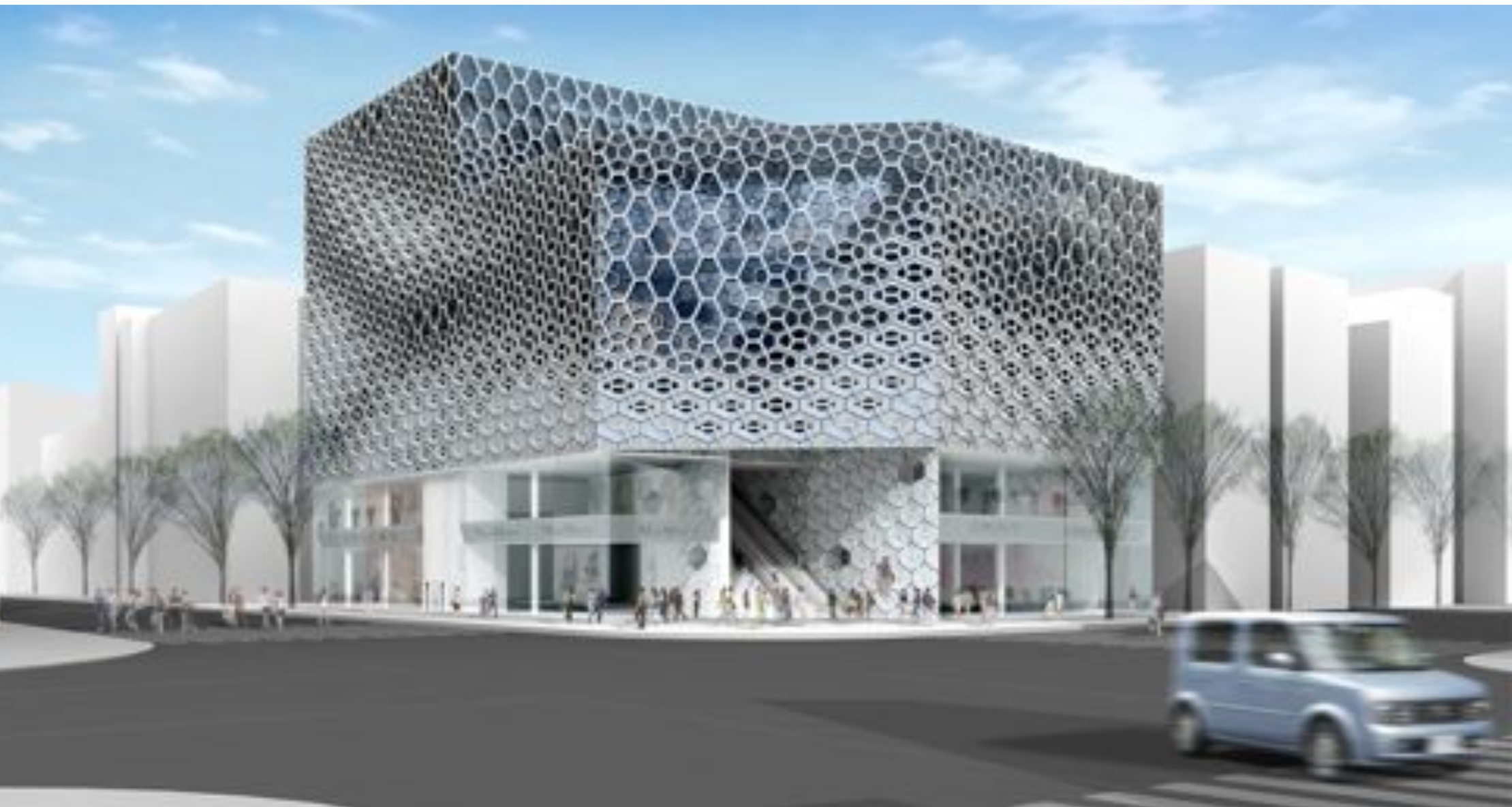
SHOP CLOSED  
• SHELVES PLACED AGAINST OUTER WALLS

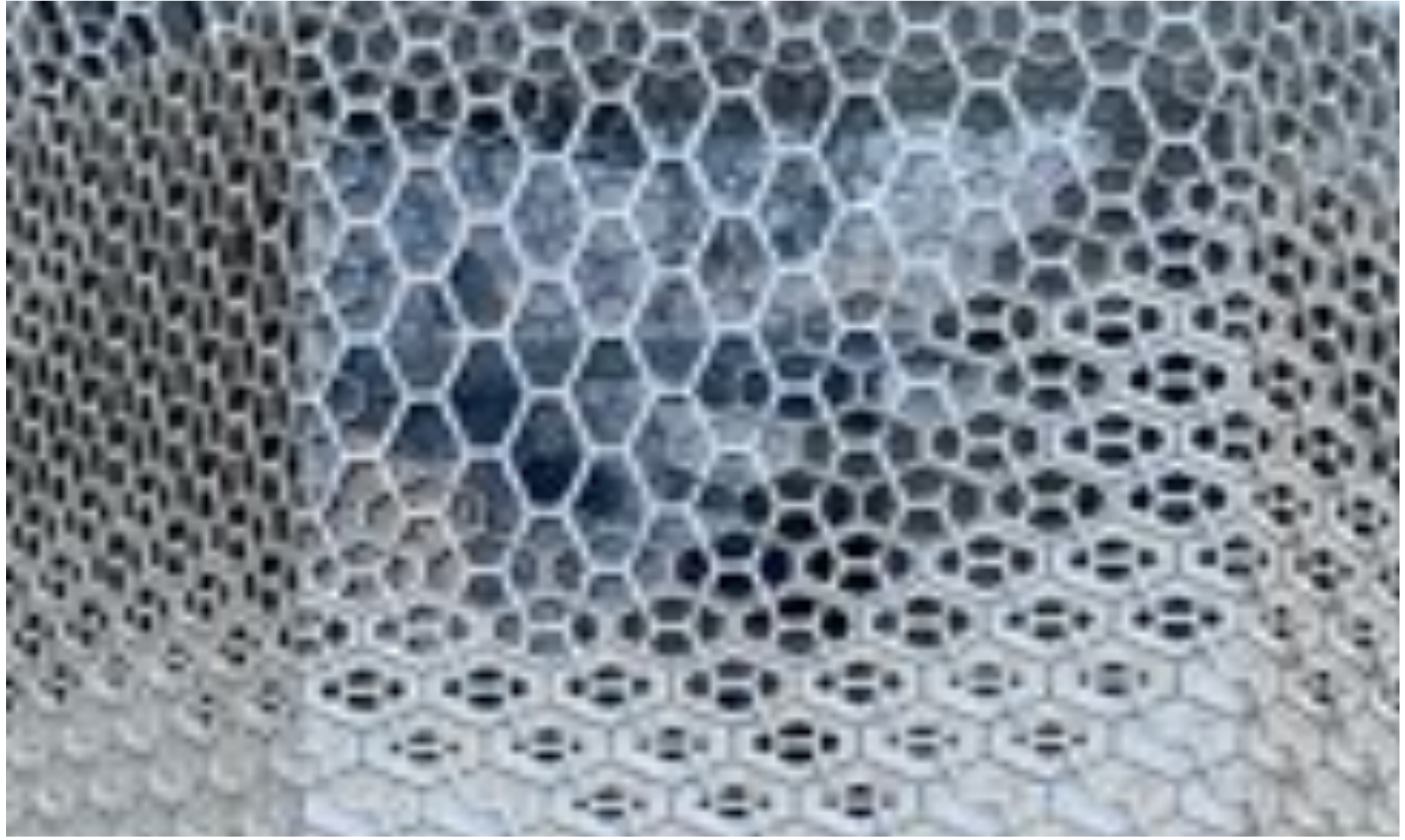


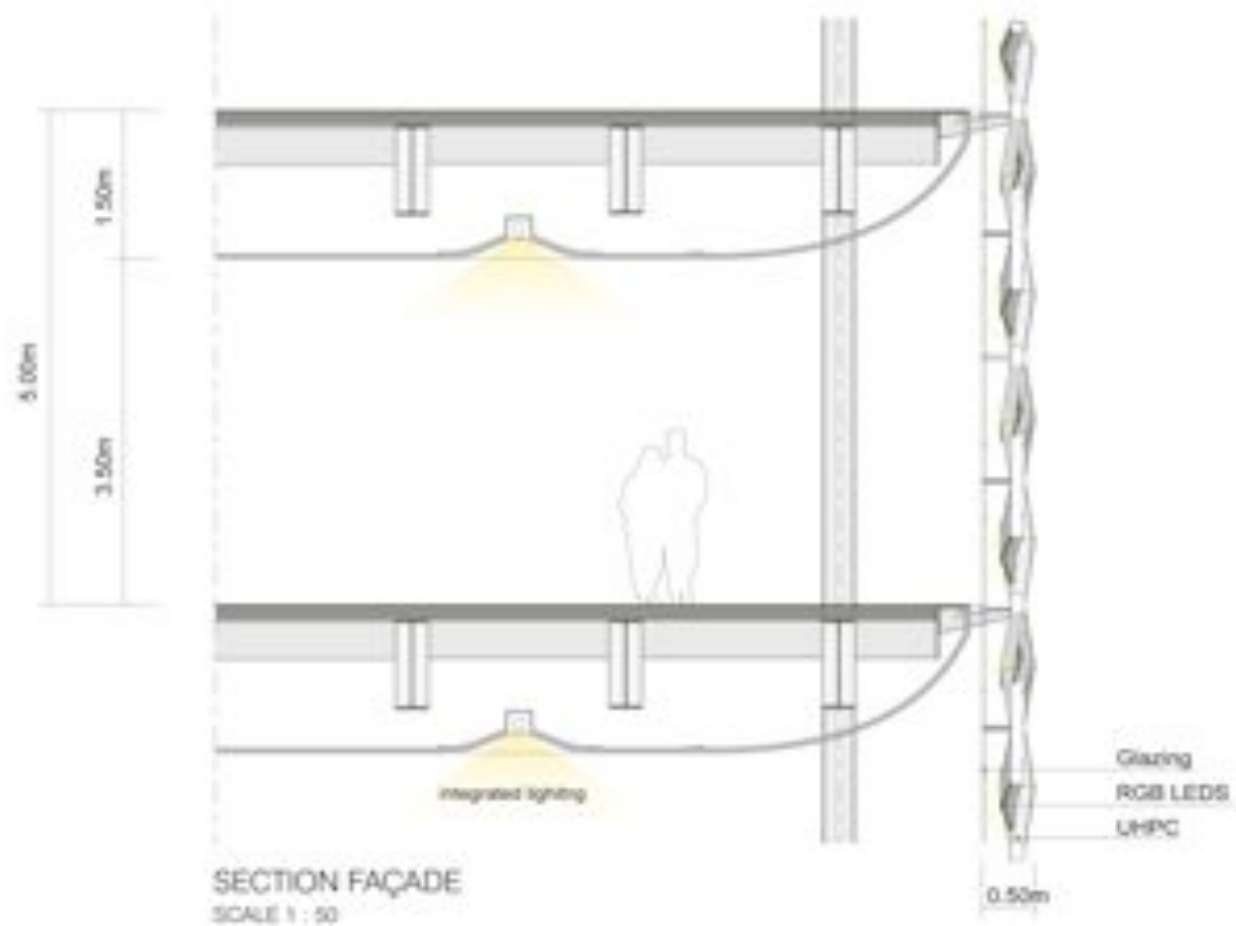












LIGHT CONSTRUCTION







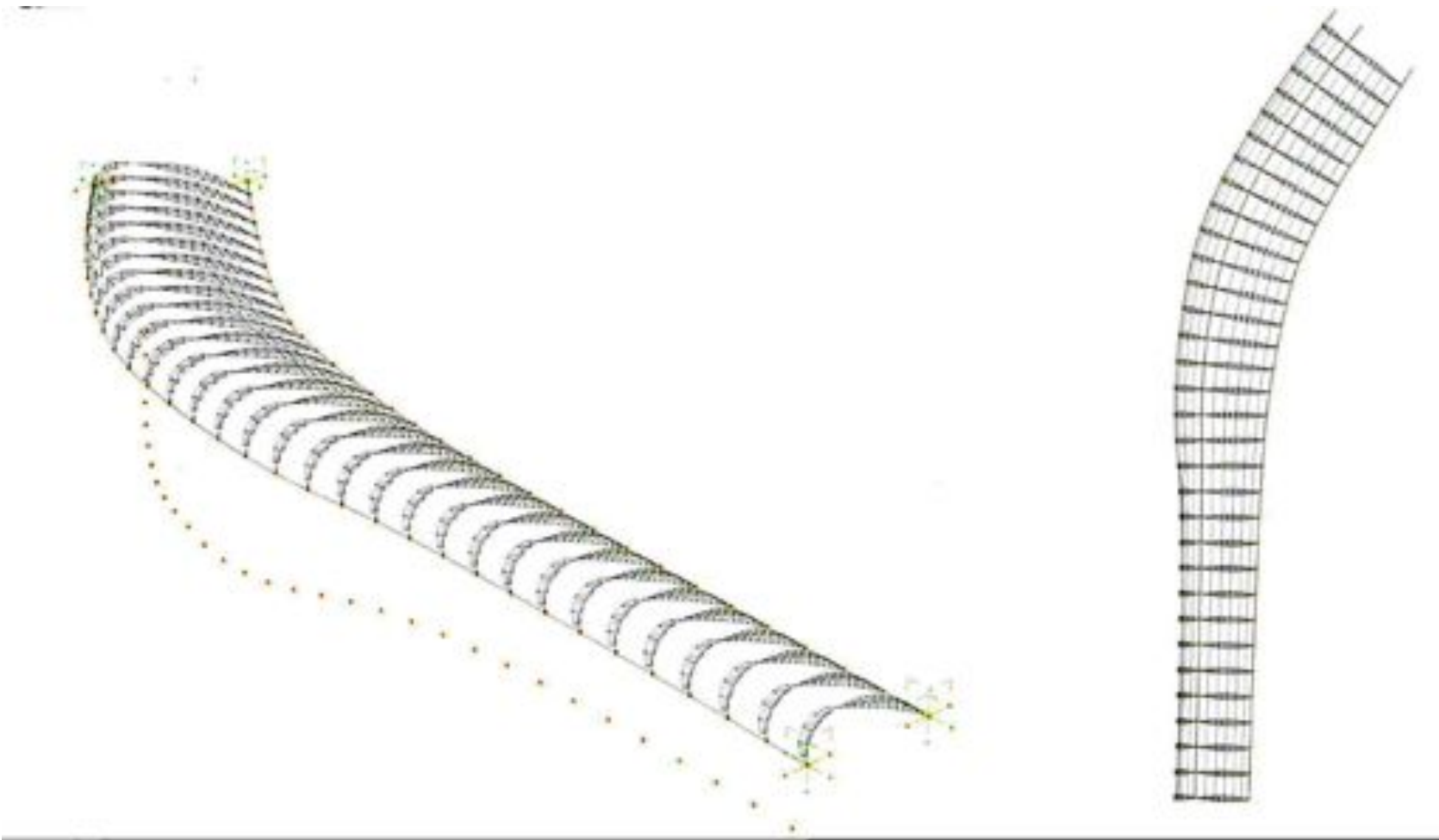


# Parametric modeling: examples

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Waterloo Station International Terminal by Nicholas Grimshaw



# Parametric modeling

Parametric Design  
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Guggenheim Museum, Bilbao, 1997  
Architect: Frank O. Gehry & Associates

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Frank O. Gehry, DG Bank, Berlin, Germany

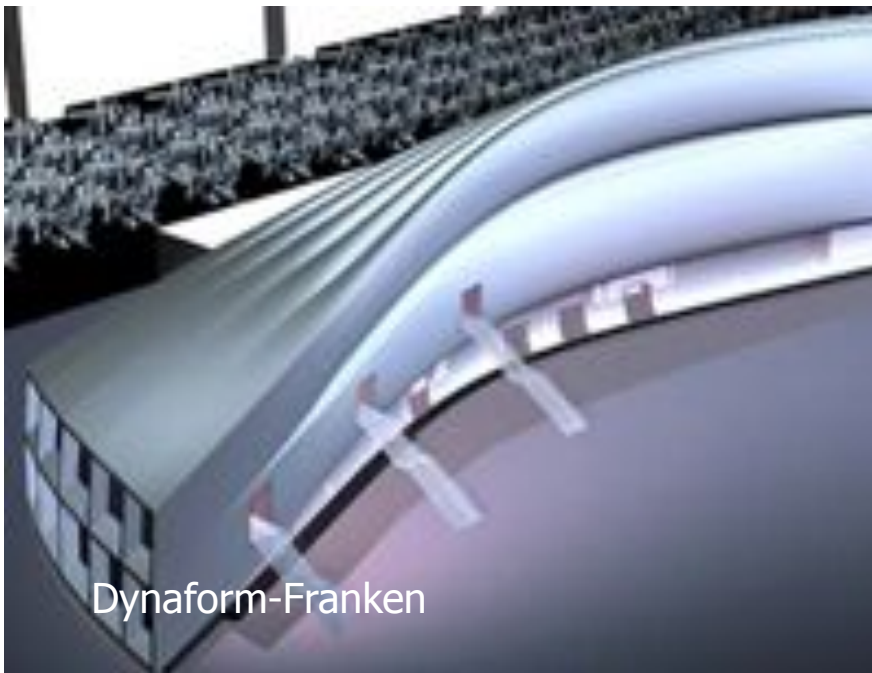


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# Parametric modeling

- It is the parameters of a particular design that are declared, not its shape. By assigning different values to the parameters, different objects or configurations can be created.
- Parameters shaping the form of the exhibition space were the movement of the visitors and the cars, in the form of 'curves'.

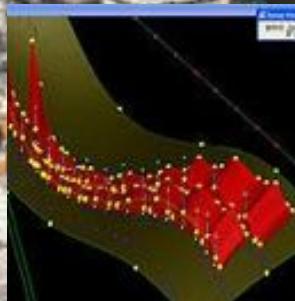


# Lars Hesselgren (KPF)

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BishopsGate Tower, London, Kohn  
Pedersen Fox Associates



[http://www.architectureweek.com/2008/0924/tools\\_1-2.html](http://www.architectureweek.com/2008/0924/tools_1-2.html)

skyscrapernews.com

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# Kas Oosterhuis (ONL)

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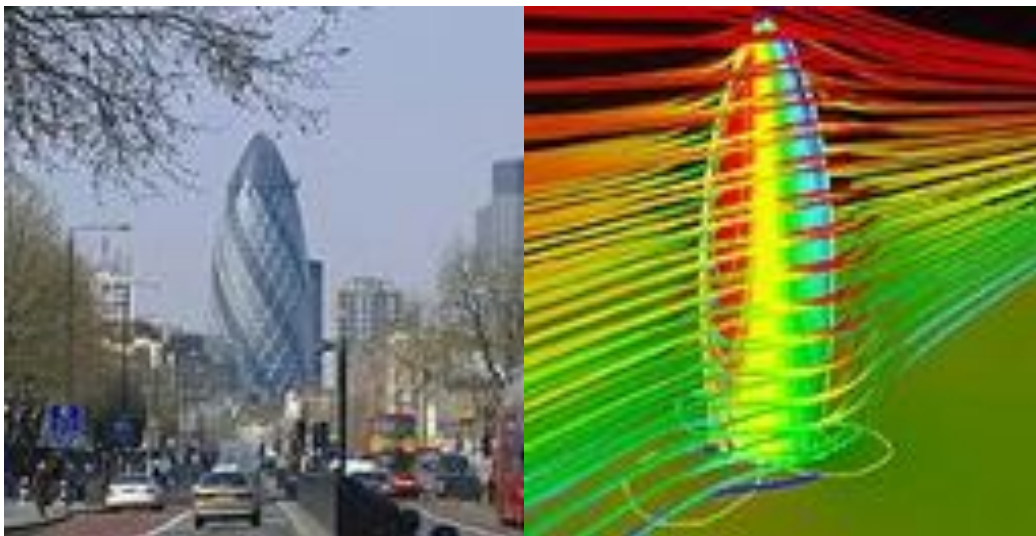
 **TU Delft**



# Parametric modeling

Parametric Design  
Lezing week 1.1  
Informatica L - BK4070

Swiss Re Tower, Foster, London  
"The Gherkin"

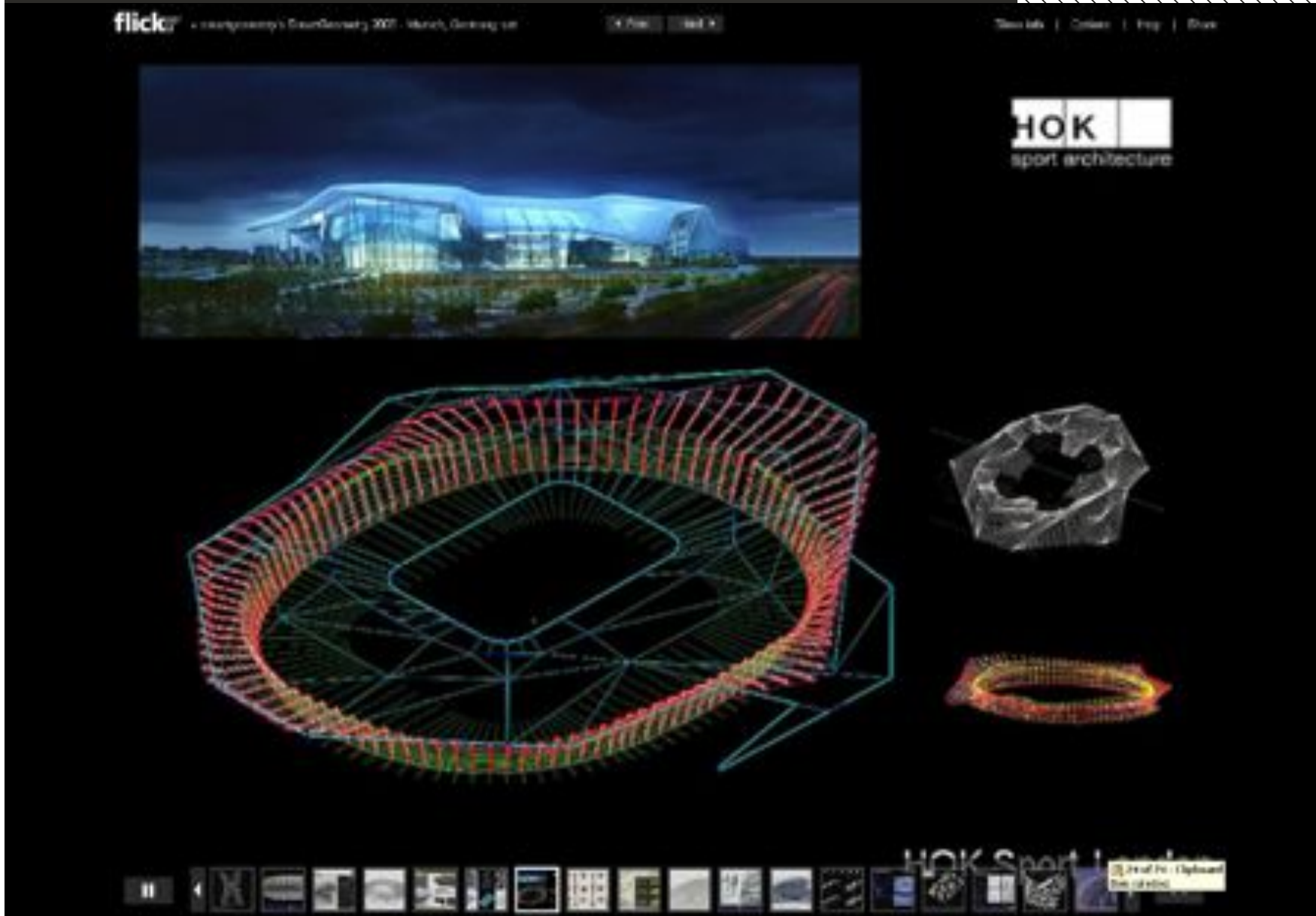


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# Generative components (Microstation)

Parametric Design  
Lezing week 1.1  
Informatica L - BK4070

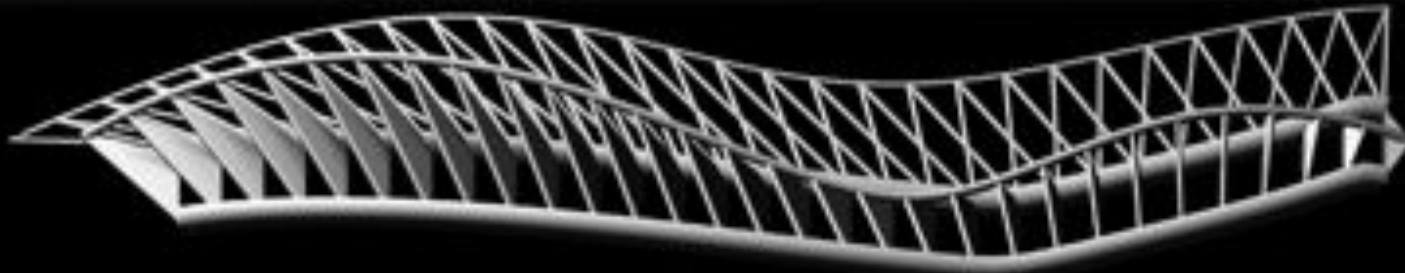


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# Grasshopper (Rhino)

Parametric Design  
Lezing week 1.1  
Informatica L - BK4070



<http://www.grasshopper3d.com/photo/ghcomp-1?context=featured>

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# Parametric modeling

## SmartGeometry

Home | Workshop 1 - Components | About us | Blog | Feedback | Contact

### SG Fall Event: Open Platform application process now closed



The application process for the SmartGeometry Fall Event Open Platform, is now closed. Those who applied will be notified of acceptance or otherwise soon.

We have created a page devoted to you over here

[Click here to see the page devoted to you over here for the 2008 application](#)

This page contains content a limited schedule for training in reverse direction and other support. More information will be posted regularly.

### Open Platform - Tutors List Announced

We will continue to present to interested tutors for the 2008 fall event.

#### Open Platform

at TU Delft

#### Generative Components (GComp)

Tomas Muehle  
Lars Math Poysens

#### Grasshopper (GhMesh)

David Rutten  
Stijn Florant  
Rijkus Rijkus

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- About us
- SG Comp
- Links
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- Contact

#### User login

Username \*

Password \*

#### CAPTCHA

This number is for testing whether you are a human visitor and to prevent automated spam submissions.

Math question \*

2 + 3 =

Click this small field to obtain and enter the result. E.g. for 2+3, enter 5.

Login

[Forgot your account](#)  
[Forgot your password](#)

# Uses of parametric modeling

Parametric Design  
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- File to Factory processes
- Building Information Modeling (BIM) – to be covered in last lecture in 2<sup>nd</sup> quarter

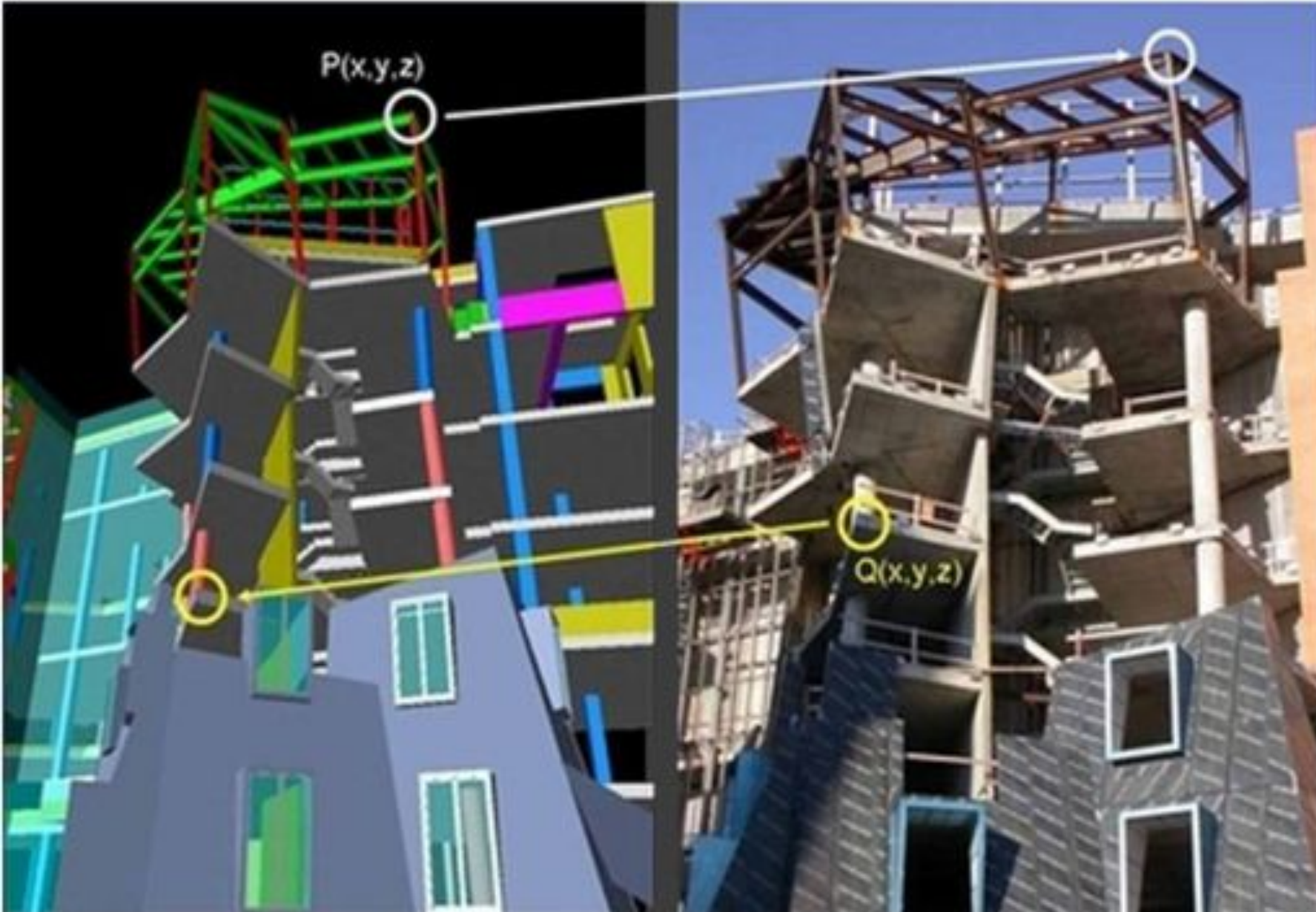
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77/97

# BIM

Parametric Design  
Lezing week 1.1  
Informatica L - BK4070



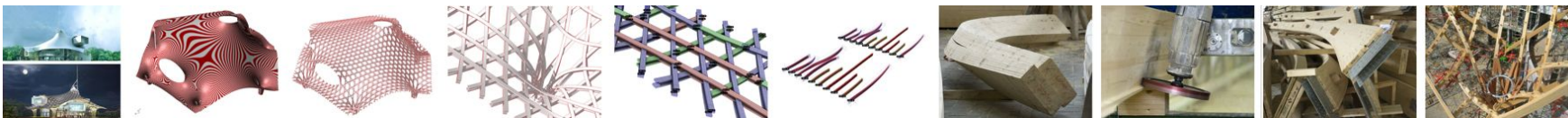
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# File to Factory

Designing – Calculating – Producing by using the computer  
(Tekenen – Rekenen – Maken)

Applied to complex (form) buildings where traditional design and  
production methods are inadequate or too expensive



# File to Factory

- Complex geometry buildings
- Generation depends on computer programs
- Materialization calls for new logics, techniques, means and equipment of construction/fabrication – CNC
- Difficult to be represented by conventional drawings to enable constructors/fabricators to accurately 'translate' them into actual spatial products
- A need to make connections between designers and the industries for information to be exchanged

[ <http://f2f-continuum.eu/f2fDefinitions.html> ]



# Parametric modeling example

Parametric Design  
Lezing week 1.1  
Informatica L - BK4070

[ movie ]



**Mercedes Benz Museum**  
UN Studio, Stuttgart 2005

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# Parametric modeling example

Parametric Design  
Lezing week 1.1  
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[ movie ]



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# Parametric modeling example

Parametric Design  
Lezing week 1.1  
Informatica L - BK4070

[ movie ]



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Centre  
Pompidou-Metz



Parametric Design  
Lezing week 1.1  
Informatica L - BK4070

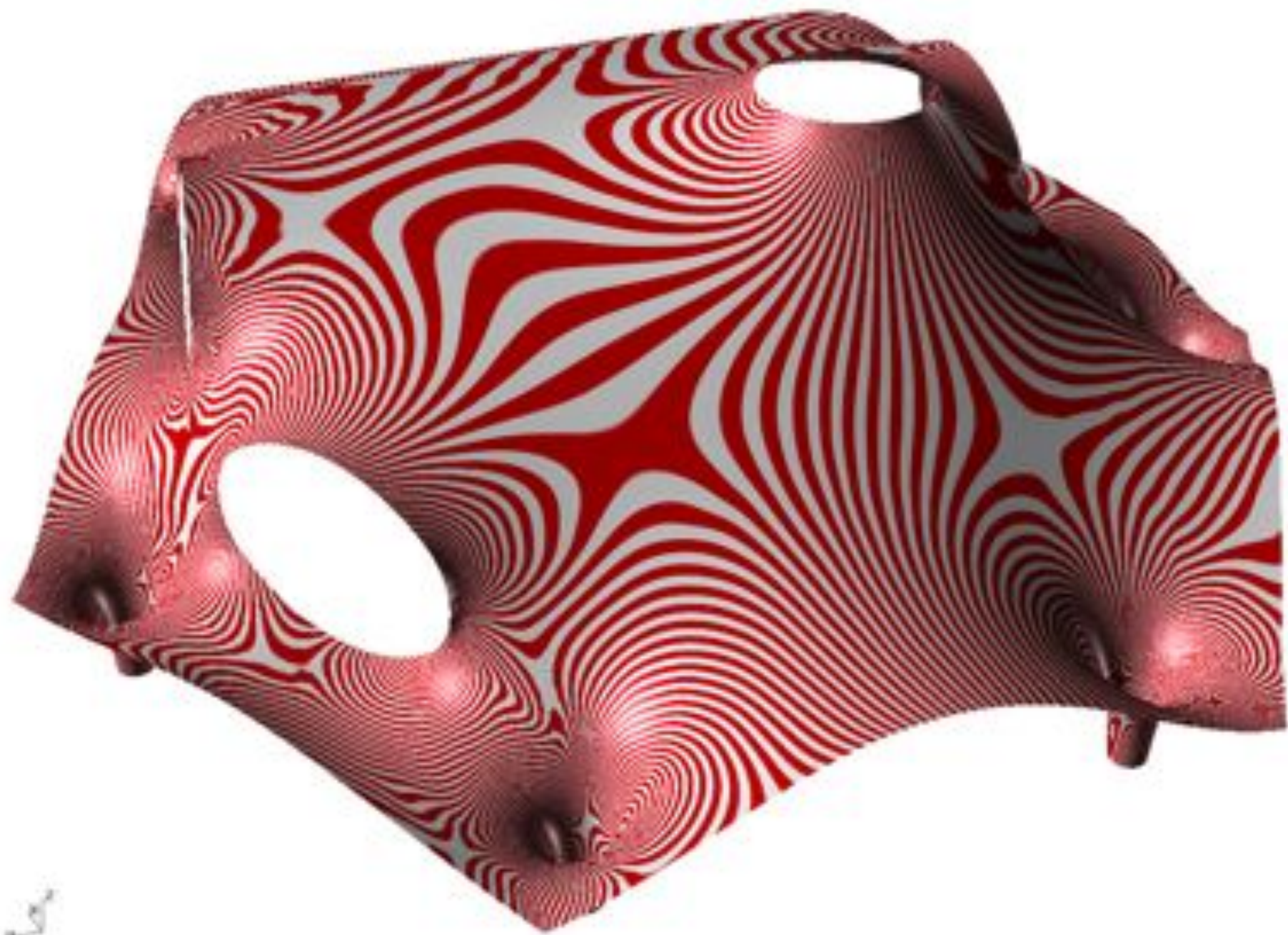
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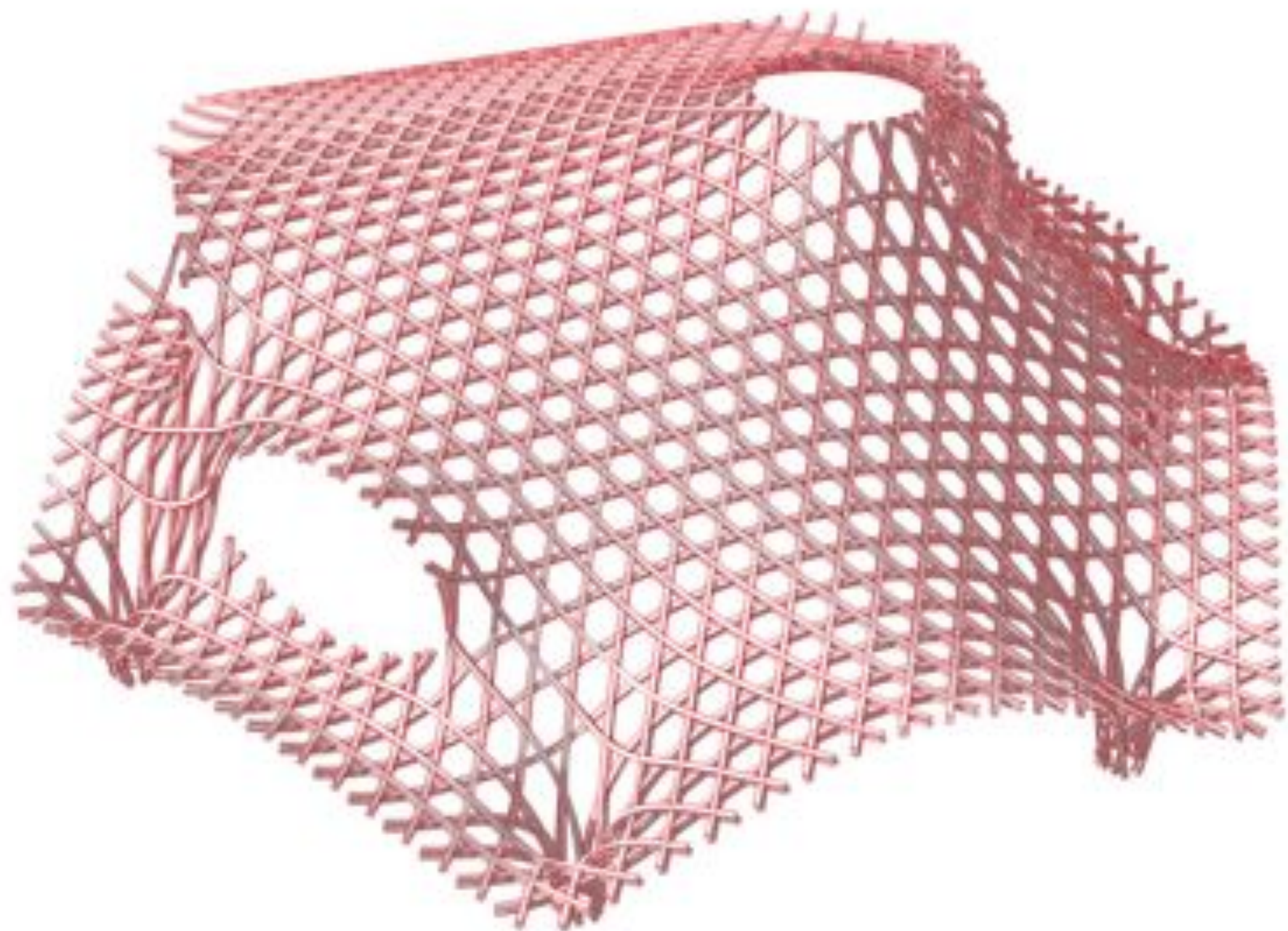
84/97



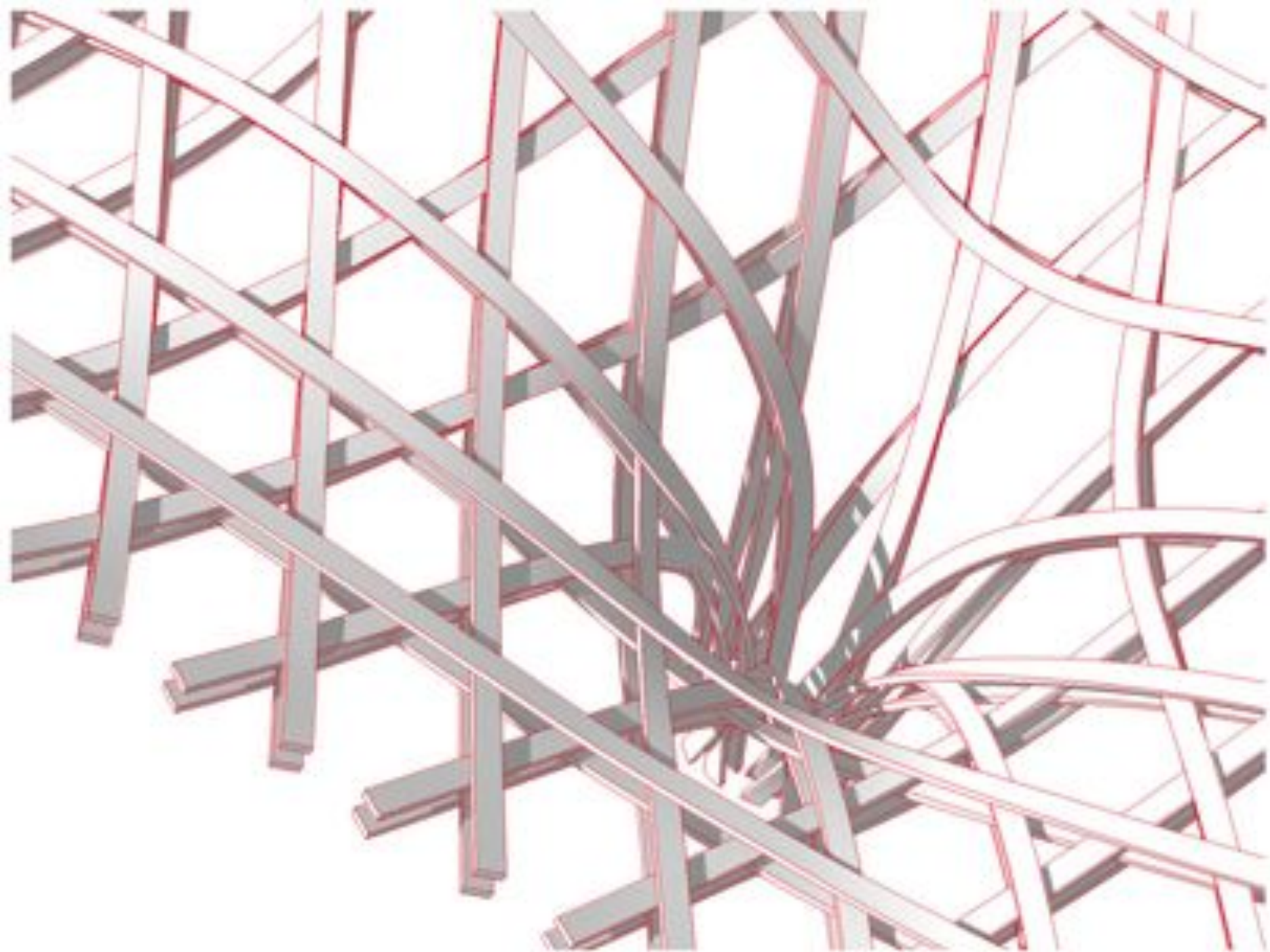


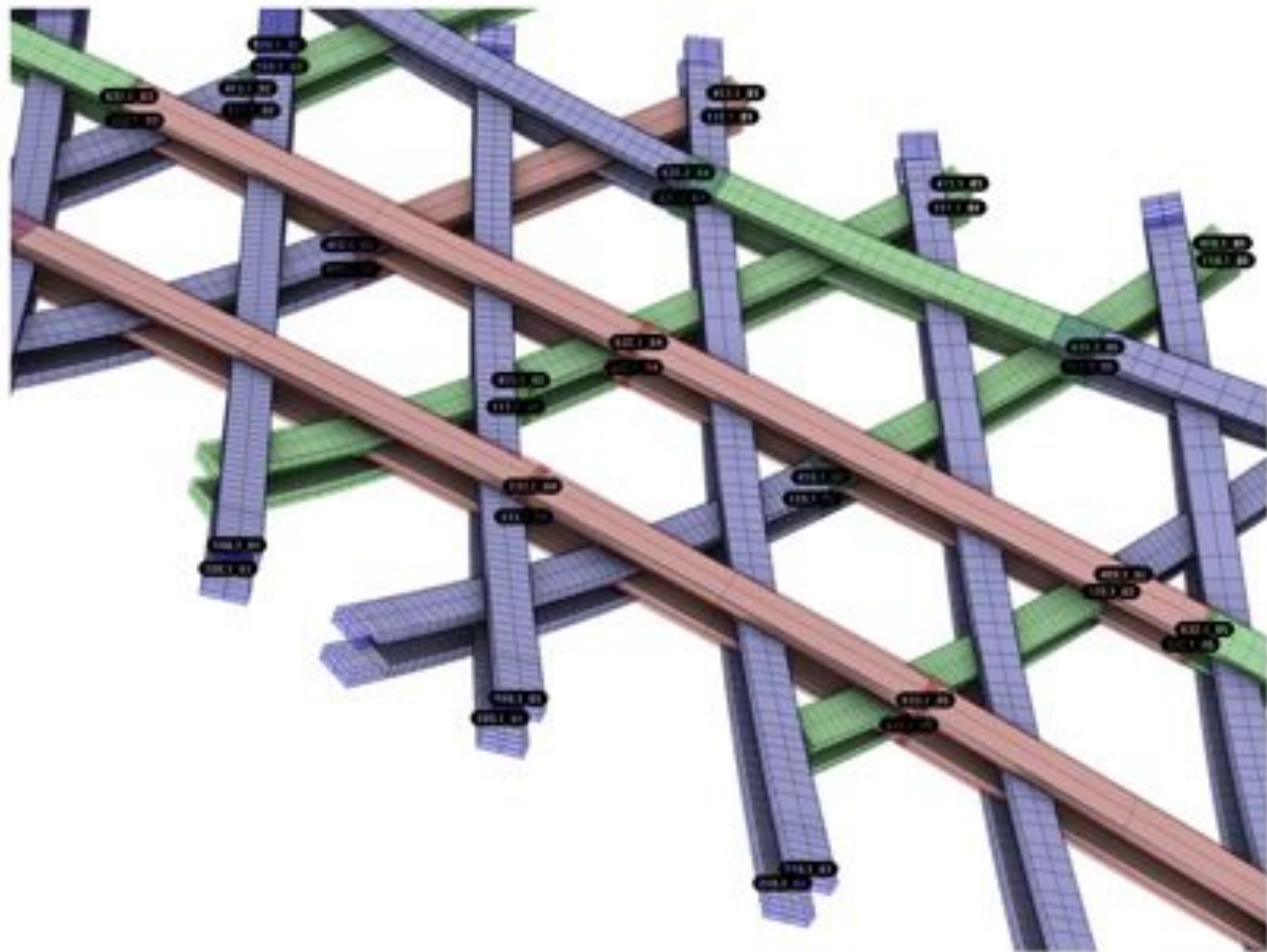


10













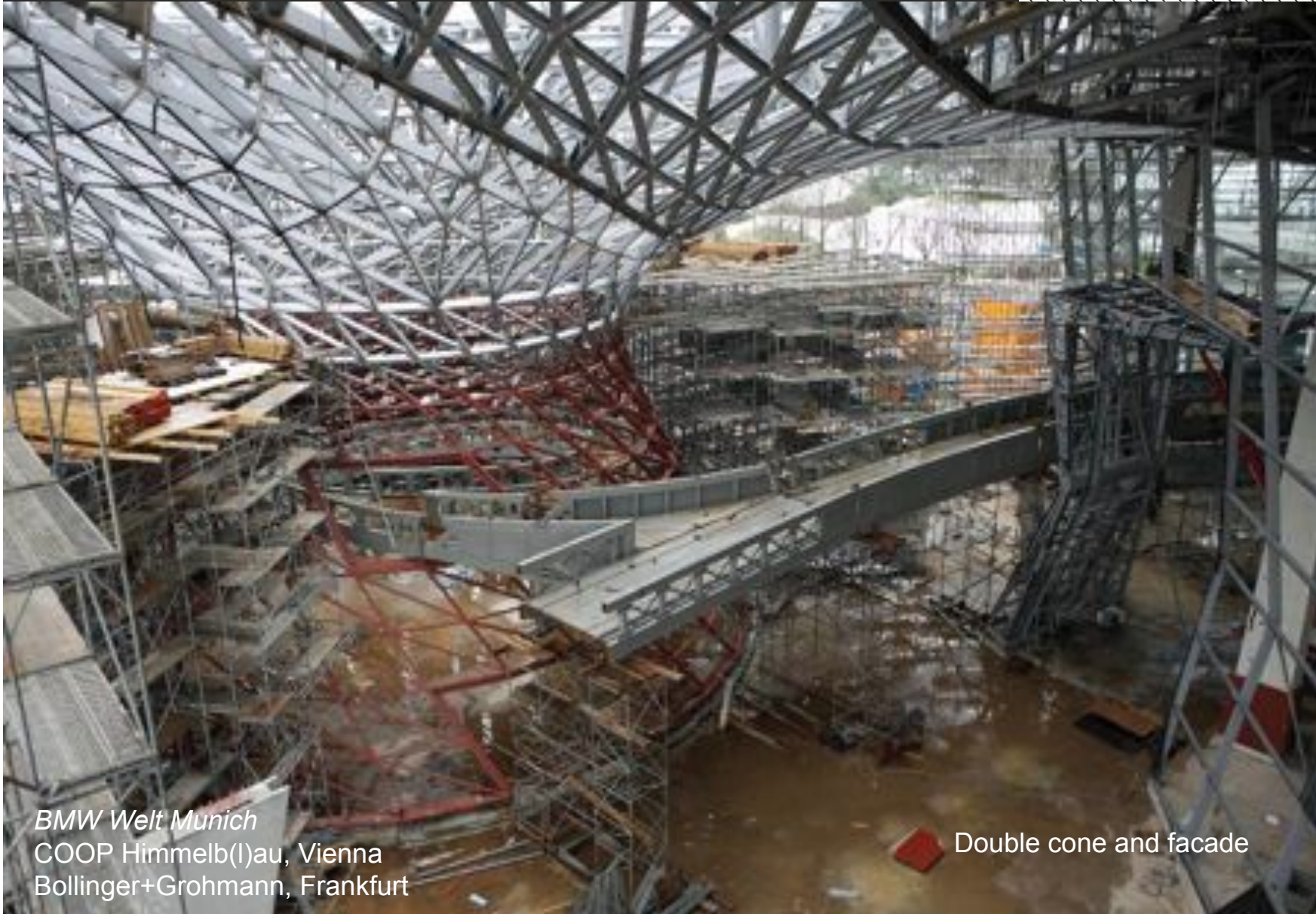






# Assembly

Parametric Design  
Lezing week 1.1  
Informatica L - BK4070



*BMW Welt Munich*  
COOP Himmelb(l)au, Vienna  
Bollinger+Grohmann, Frankfurt

Double cone and facade

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# Autonomy of Architecture

Parametric Design  
Lezing week 1.1  
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[ movie ]

Anyone can make simple things complicated.  
Making complicated things simple, awesomely simple, that's creativity.

Charles Mingus

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97/97

# Robot arm, Gramazio & Kohler, ETH Zurich

Parametric Design  
Lezing week 1.1  
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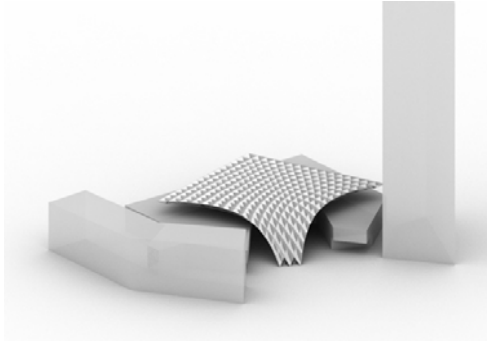
# THREE EXAMPLES OF PARAMETRIC MODELLING FOR PERFORMANCE ORIENTED DESIGN

**Michela Turrin**

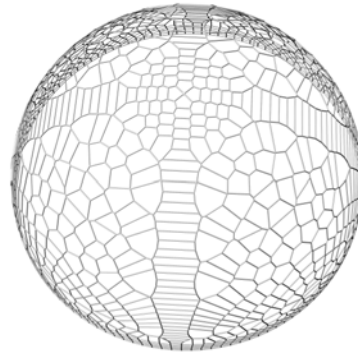
TU Delft / Building Technology

[M.Turrin@tudelft.nl](mailto:M.Turrin@tudelft.nl)

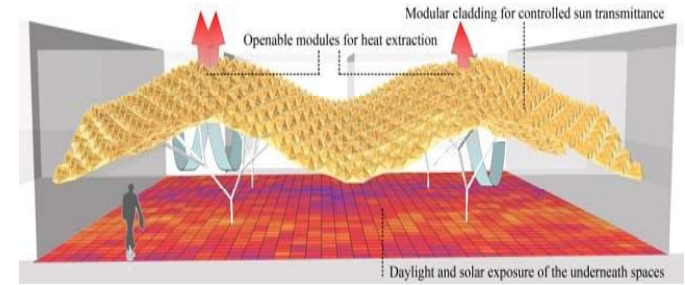
# THREE EXAMPLES OF PARAMETRIC MODELLING



**The Vela roof**



**RadioDome**



**SolSt**

**PARAMETRIC MODELLING**

**Generation of design alternatives**



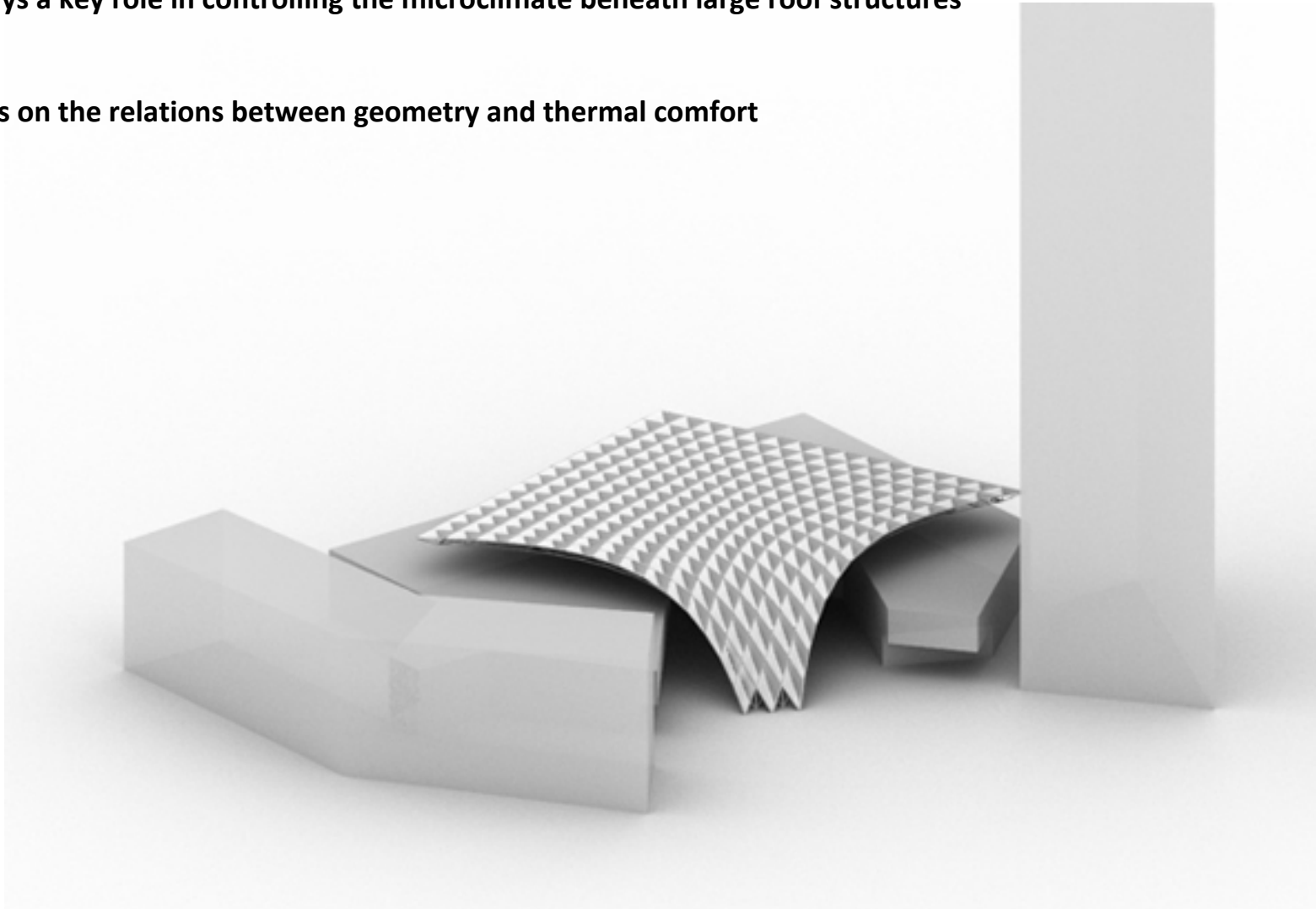
**Evaluation of design alternatives  
based on performance simulations**

# THE VELA ROOF

- **Large roof designs:**

- geometry plays a key role in controlling the microclimate beneath large roof structures

- The example focuses on the relations between geometry and thermal comfort



# THE VELA ROOF

Architects:

Client:

Structural Engineers:

Summer Passive Thermal comfort:

Open Project Office s.r.l

Unipol Gruppo Finanziario S.p.A.

Studio Tecnico Majowiecki

TU Delft, interdisciplinary team

- **Vela-Roof** is a 3.400 sqm structure partially covering the square and the low-rise buildings

➤ The roof's design takes into account on-site renewable energy resources



# GEOMETRY AND PASSIVE THERMAL COMFORT

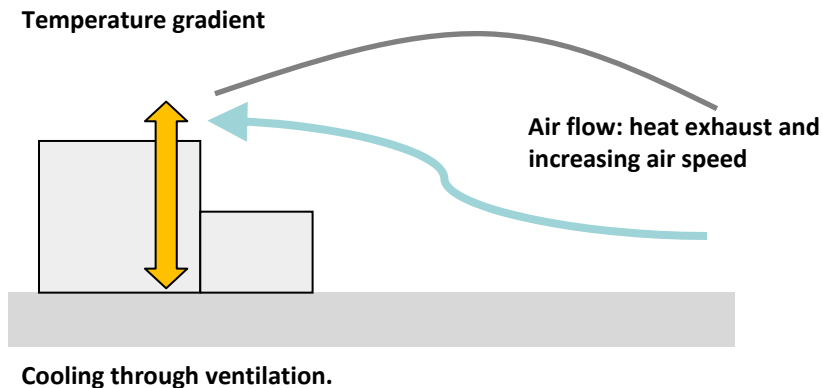
- **Summer conditions** are estimated the most critical

➤ Geometry is explored to improve summer thermal comfort with passive strategies

- **Geometry** is here investigated with respect to:

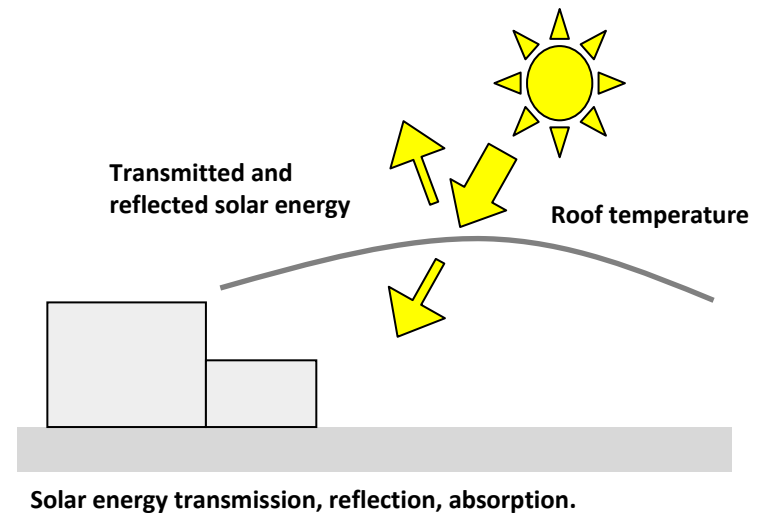
ventilation

(LARGE SCALE GEOMETRY)



solar energy transmission

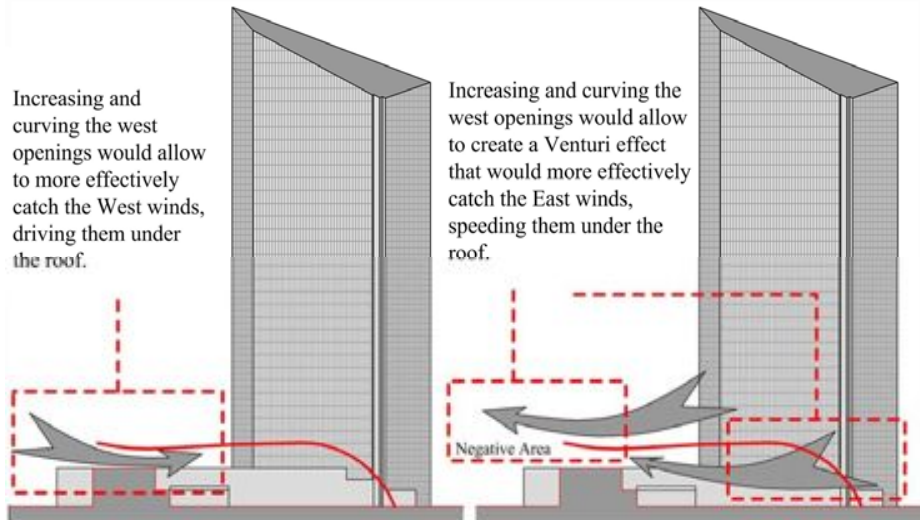
(SMALL SCALE GEOMETRY)



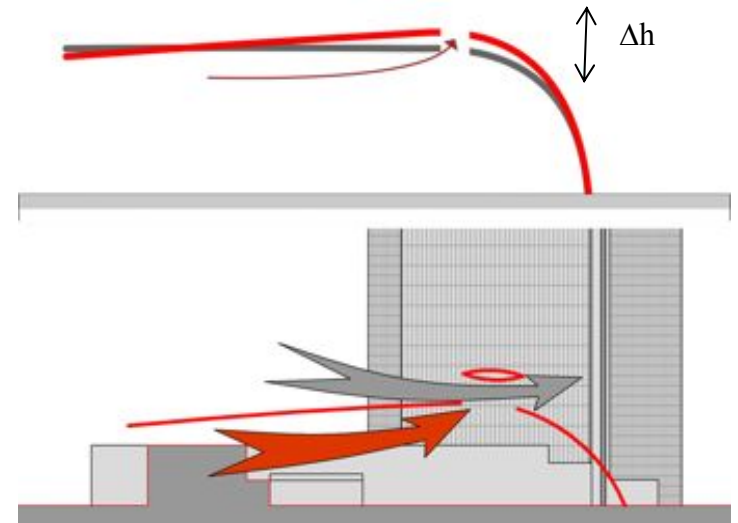
# LARGE SCALE GEOMETRY: INCREASING AND CONTROLLING AIR FLOW

- If **wind-driven ventilation** is going to be used for passive cooling, wind and drafts needs to be directed in order to provide some cooling effect
- alternatively, **stack effect-driven ventilation** can be induced

- **option1 - wind-driven ventilation**



- **option2 - stack effect-driven ventilation**





# LARGE SCALE – parametric overall geometry of the roof

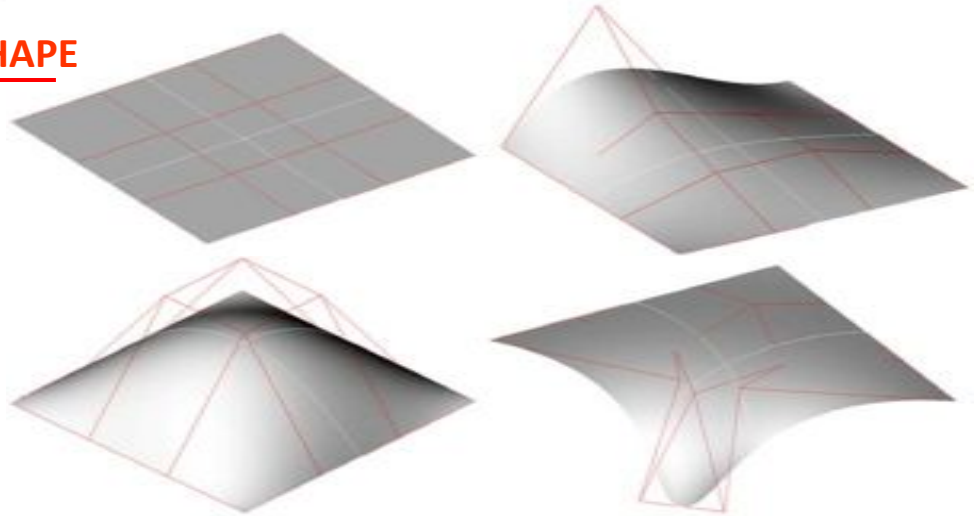
## SET OF VARIABLES



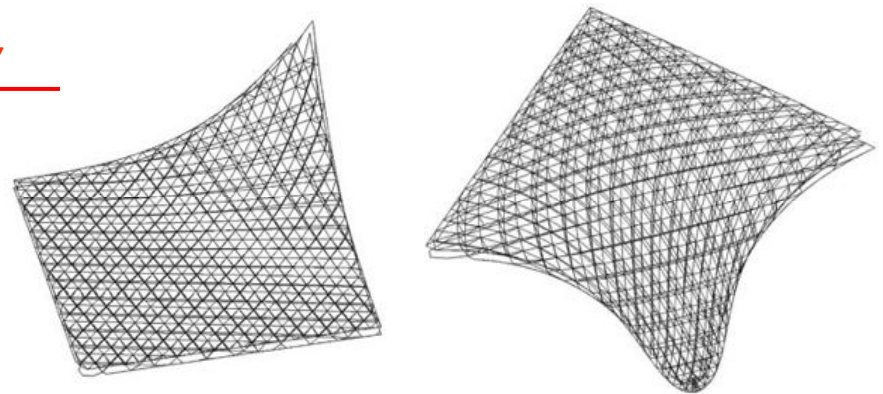
The screenshot shows a software interface with a list of variables and their values. The variables are listed in a table with columns for Name, Value, and Angle Value. The variables are numbered from 1 to 24, and their values range from 0 to 100. The interface also includes a toolbar with various icons and a status bar at the bottom.

Name	Value	Angle Value
OP_25,u	0	
OP_25,u	0	
OP_25,u	0	
OP_25,u	25	
OP_25,u	25	
OP_25,u	0	
OP_25,u	25	
OP_25,u	25	
OP_25,u	0	
OP_25,u	41	
OP_25,u	41	
OP_25,u	0	
OP_25,u	57	
OP_25,u	57	
OP_25,u	0	
OP_25,u	88	
OP_25,u	41	
OP_25,u	0	
OP_25,u	103	
OP_25,u	25	
OP_25,u	0	
OP_25,u	141	
OP_25,u	0	
OP_25,u	0	
OP_25,u	0	
OP_11,u	103	
OP_11,u	25	
OP_11,u	0	
OP_12,u	88	
OP_12,u	41	
OP_12,u	0	
OP_12,u	57	
OP_12,u	25	
OP_12,u	0	
OP_14,u	41	
OP_14,u	0	
OP_14,u	84	

## OVERALL SHAPE



## STRUCTURAL MORPHOLOGY

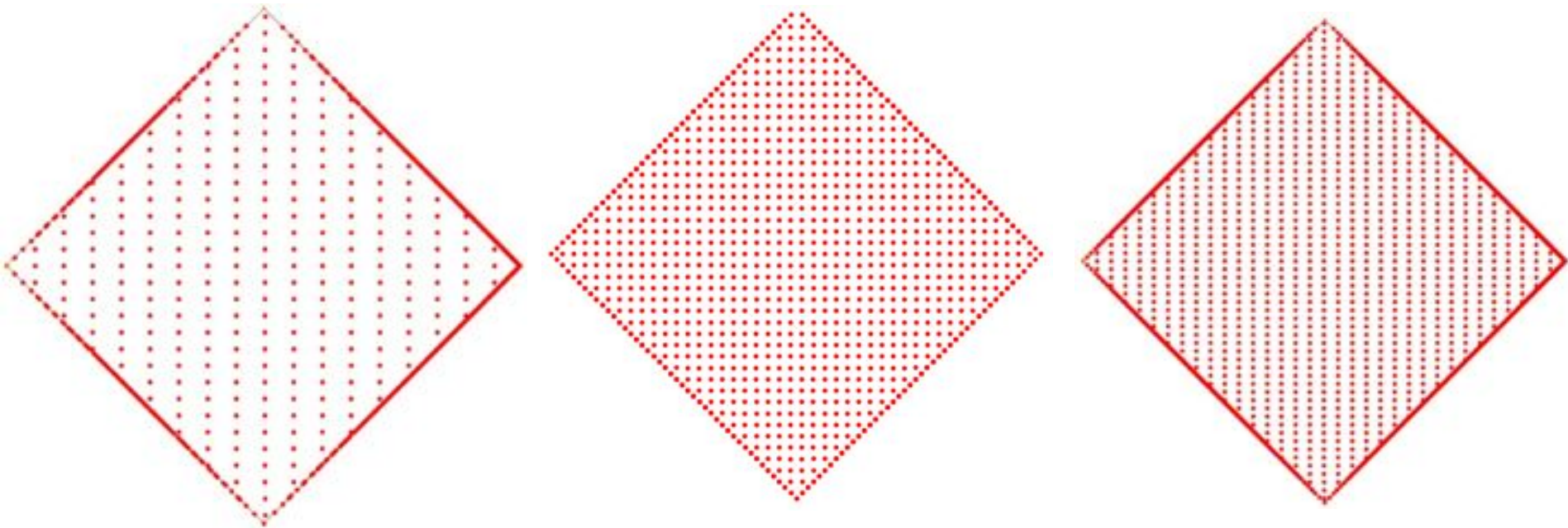




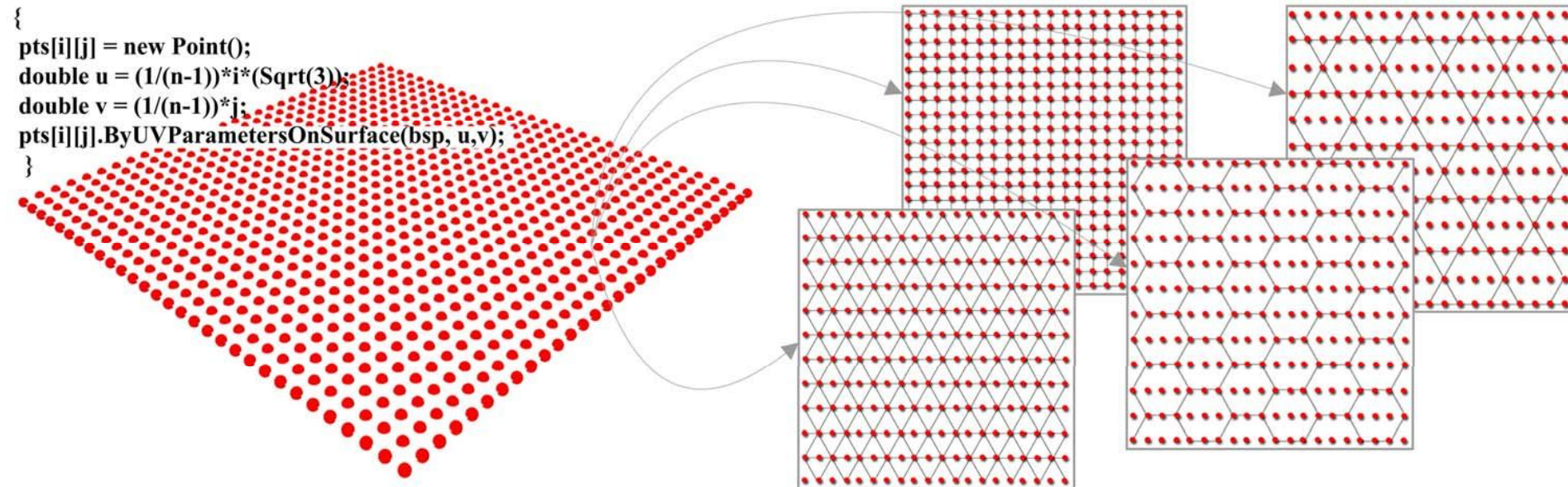
# LARGE SCALE – parametric structural morphology

(with Axel Kilian)

- Points are defined based on UV coordinates and are parametrically controlled
- Independent parameters are:
  - Density of the points in the U and V directions
  - Proportions between the 2 densities

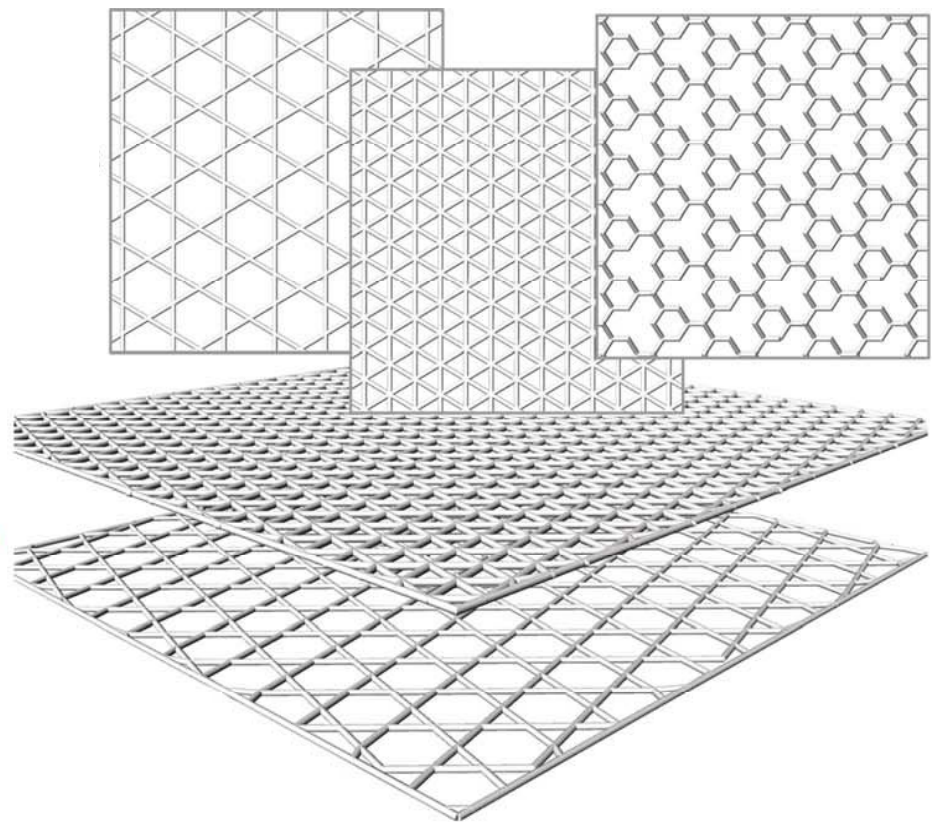
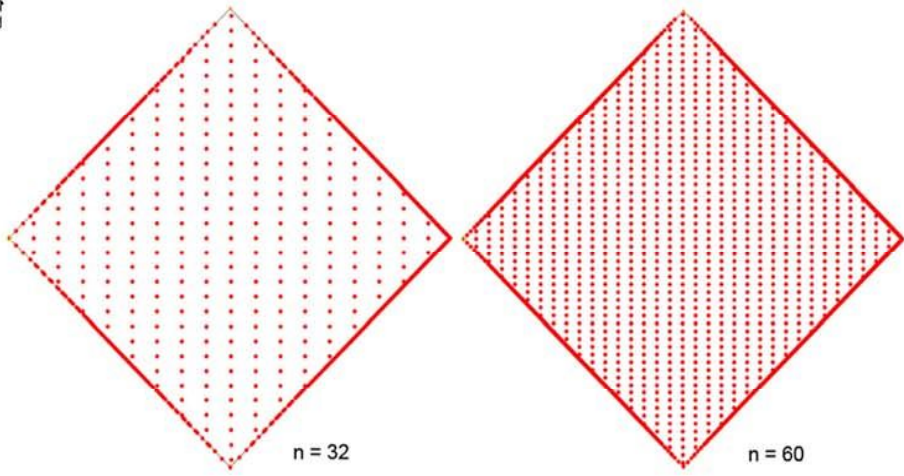


- By using the points as nodes, various structural tessellations can be explored based on different patterns
- Each pattern maintains the parametric variability given by the array of points



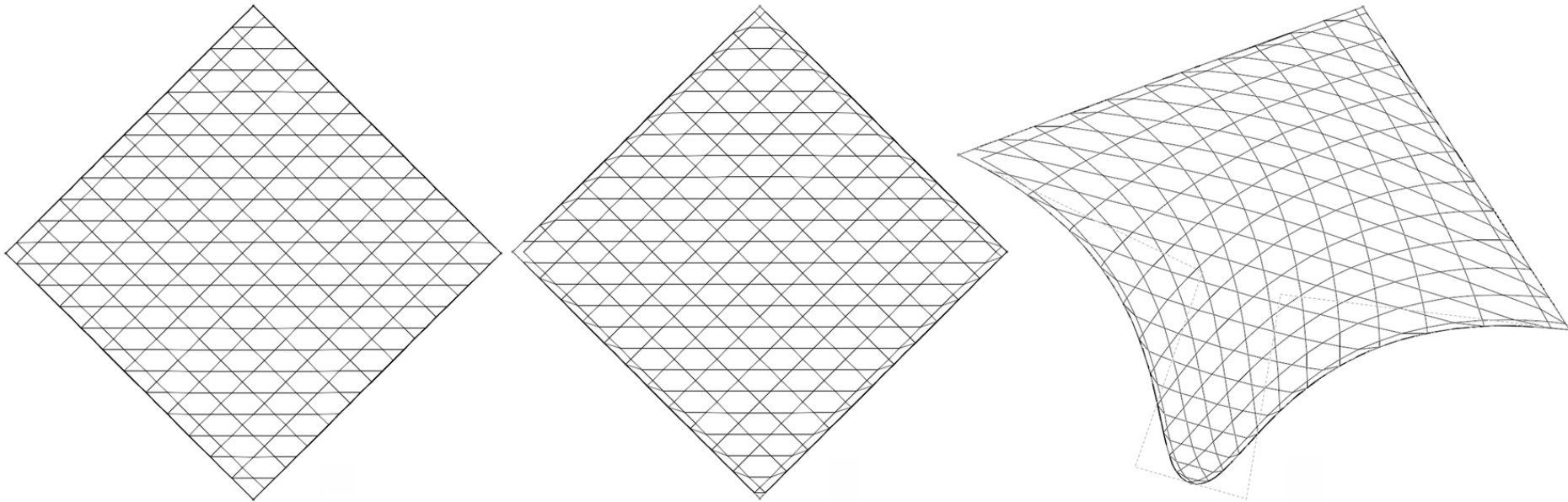
- The chosen structural geometry is diagonally oriented
- A script based on Pitagora's relations is used to re-orient the grid of pints

```
{  
pts[i][j] = new Point();  
double u = ((1/(row-1))*i*Sqrt(3))-0.5-(1/(2*(row-1)));  
double v = (1-(1/(col-1))*i*Sqrt(3))-0.5-(1/(2*(col-1)));  
u = u + (1/(col-1))*j;  
v = v + (1/(col-1))*j;  
pts[i][j].ByUVPParametersOnSurface(bsp, u,v);  
}
```



- Additional independent parameters are added to:
  - regulate the internal proportions of the tessellation polygons
  - move the tessellation grid on the surface allowing operations like the search for alignments

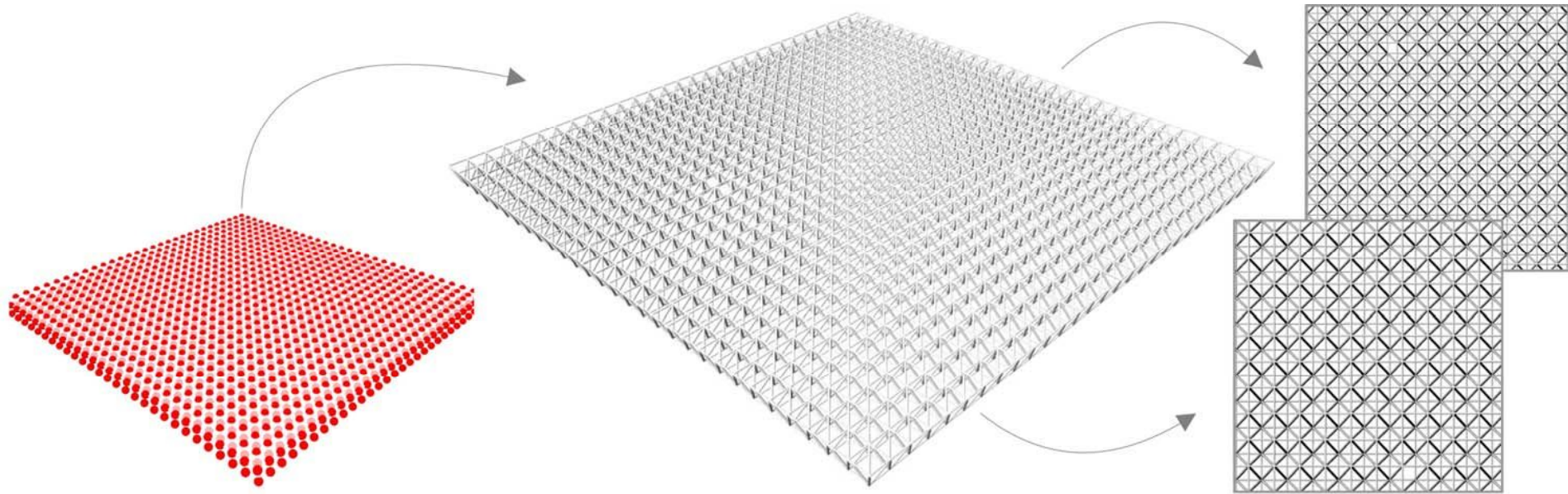
```
pptt[i][j] = new Point();  
double u = ((1/(row-1))*i*aFact)-0.5-(1/(2*(row-1))*bFact);  
double v = (1-(1/(row-1))*i*aFact)-0.5-(1/(2*(row-1))*bFact);  
u = u + (1/(row-1))*j;  
v = v + (1/(row-1))*j;  
pptt[i][j].ByUVParametersOnSurface(bsp, u,v);
```



# LARGE SCALE – parametric structural morphology

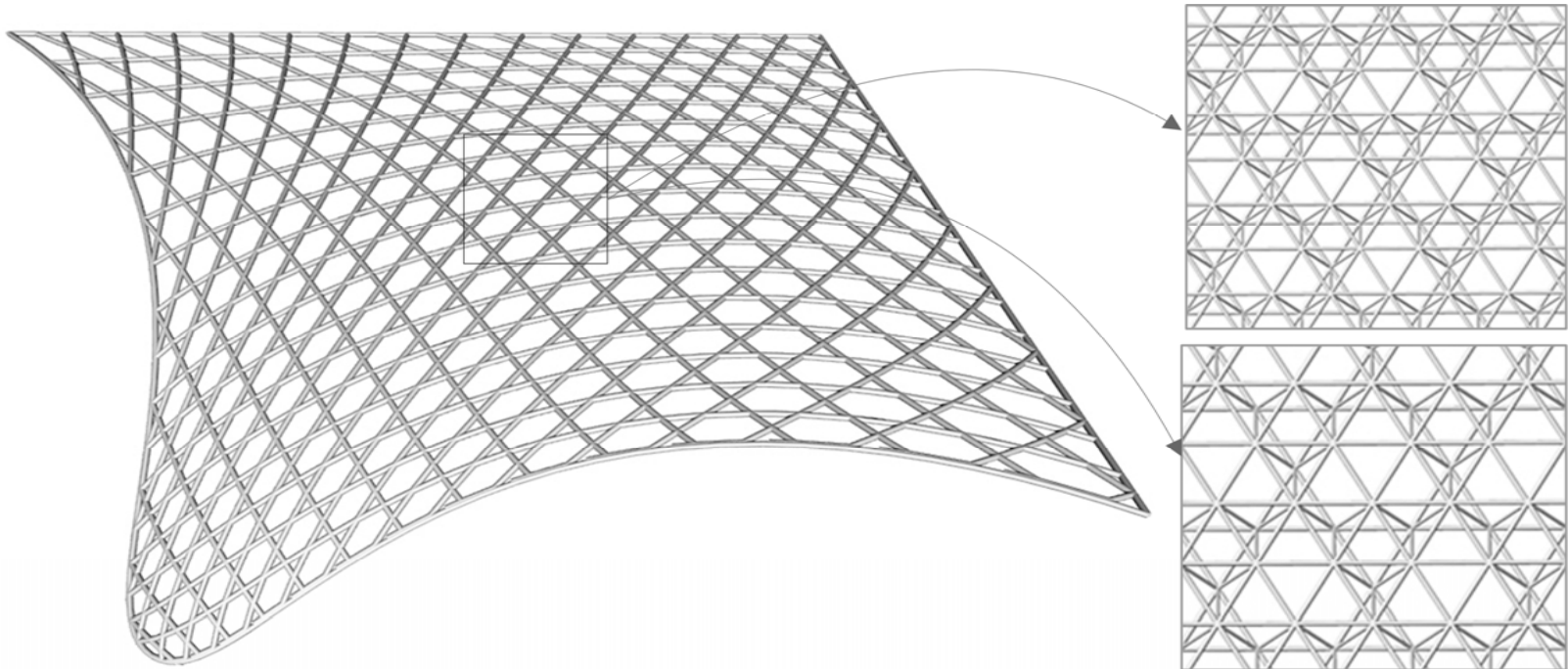
- **double layer space frame**

The approach can be duplicated in a second layer to generate a double layer space frame



# LARGE SCALE – conclusions

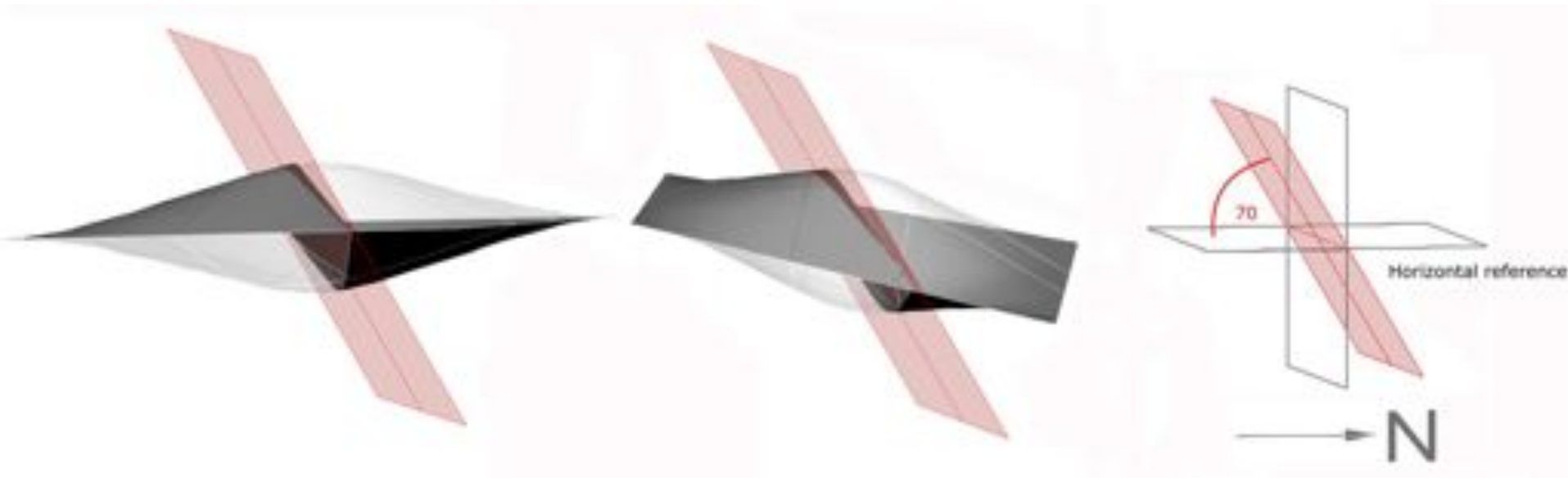
- The parametric model well supported the explorations of design alternatives of the overall shape of the roof in combination with its structural geometry
- However changes in the geometry suitable for ventilation for cooling resulted conflicting with other design requirements, such as:
  - structural stability in case of wind storm
  - proportions of the roof height to its surrounding





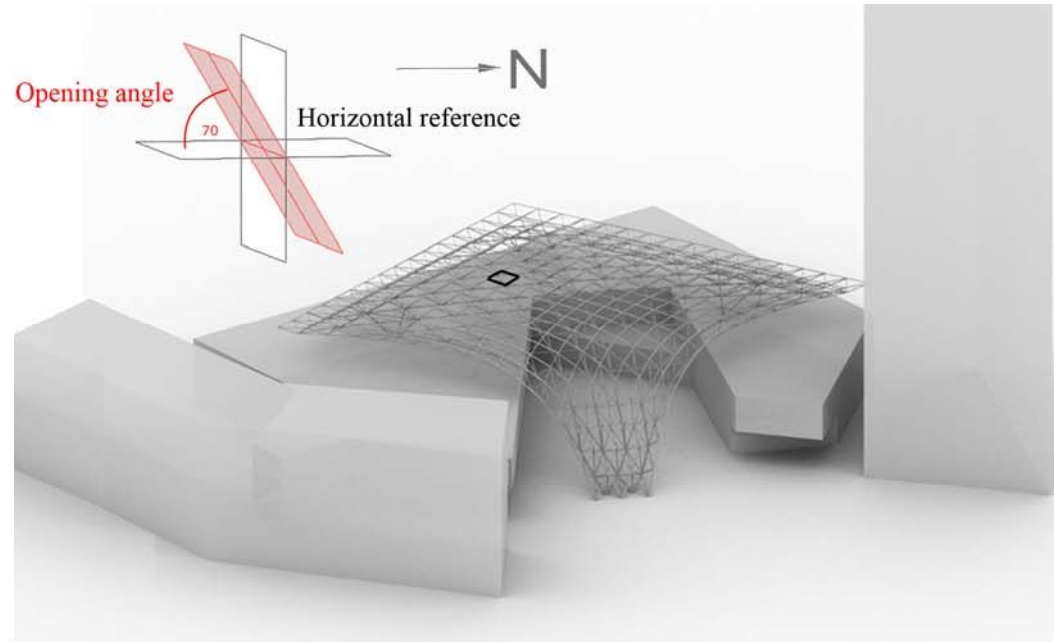
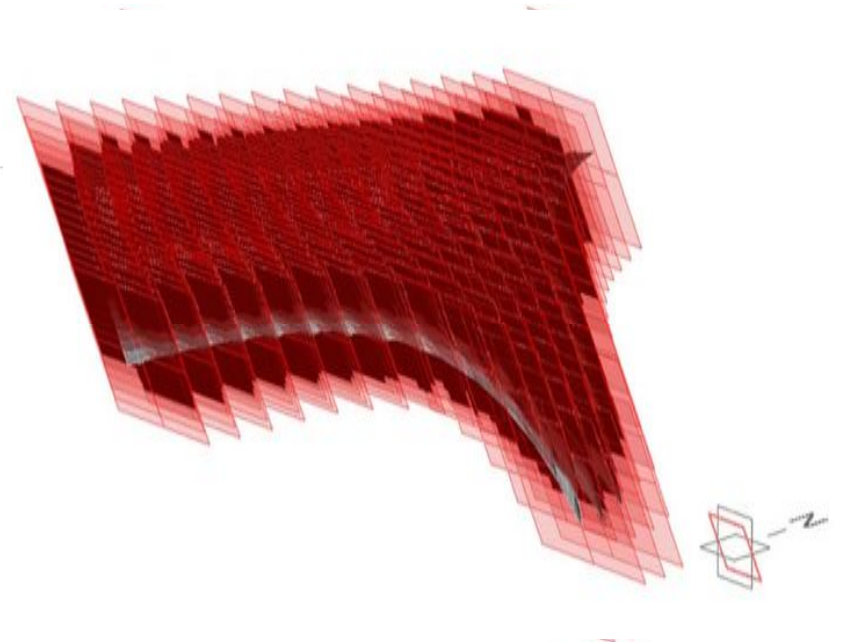
# SMALL SCALE – solar exposure and daylight

- The **cladding system** has to limit the roof's solar heat transmission by allowing sun light transmission
- **ETFE with printed North-South oriented pattern** is parametrically explored:
  - absolute orientation with respect to cardinal directions
  - independent parameter: opening angle



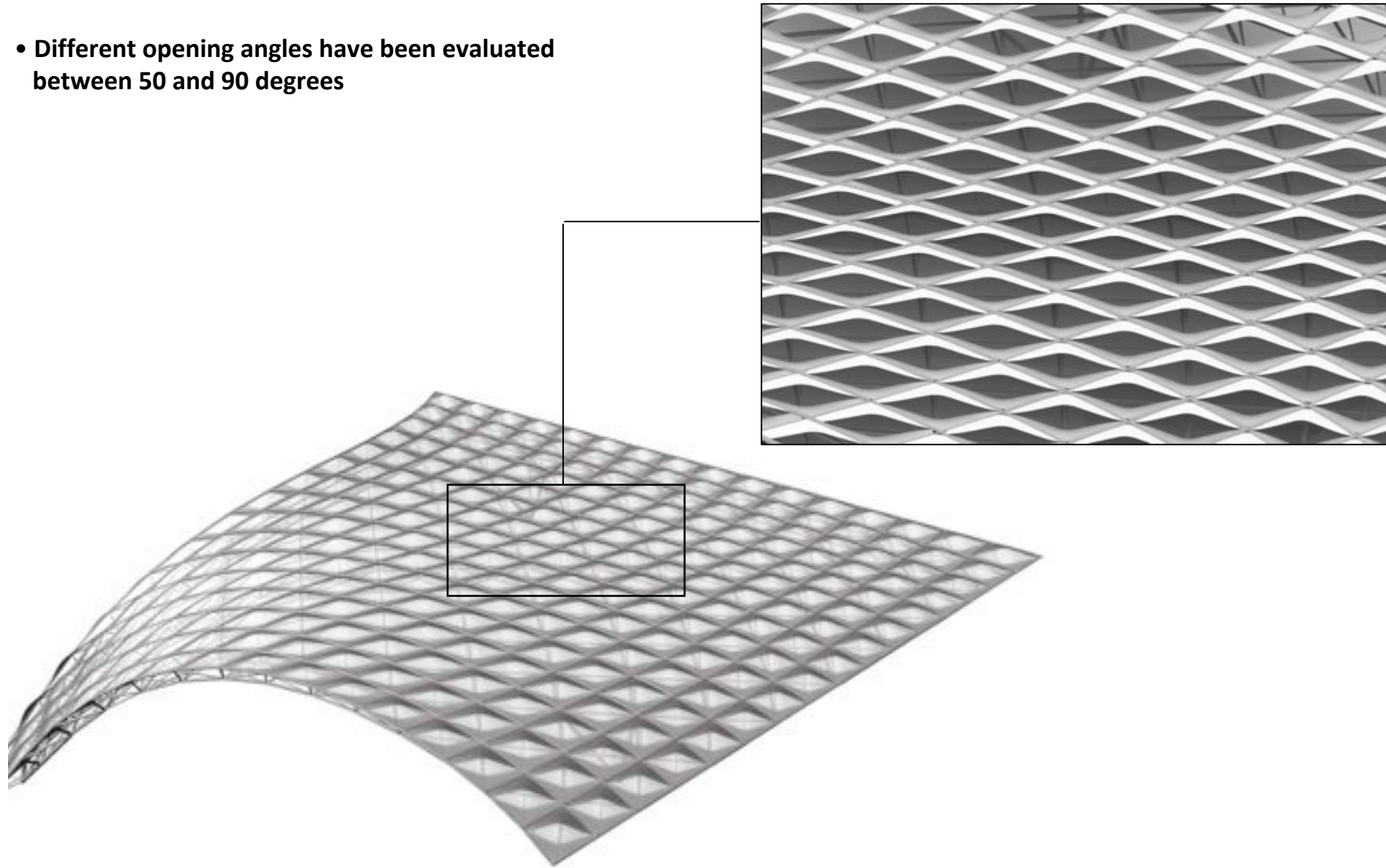
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  - independent parameter: opening angle

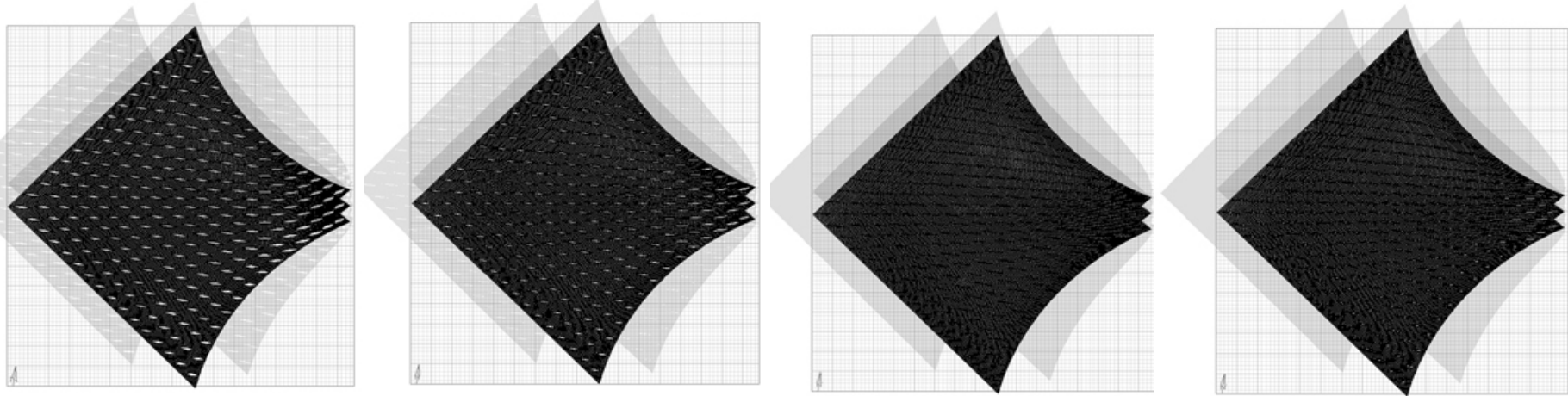


# SMALL SCALE – solar exposure and daylight

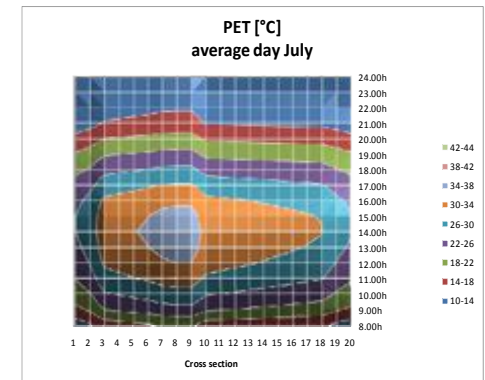
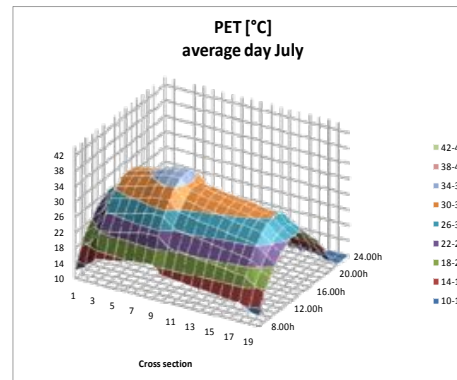
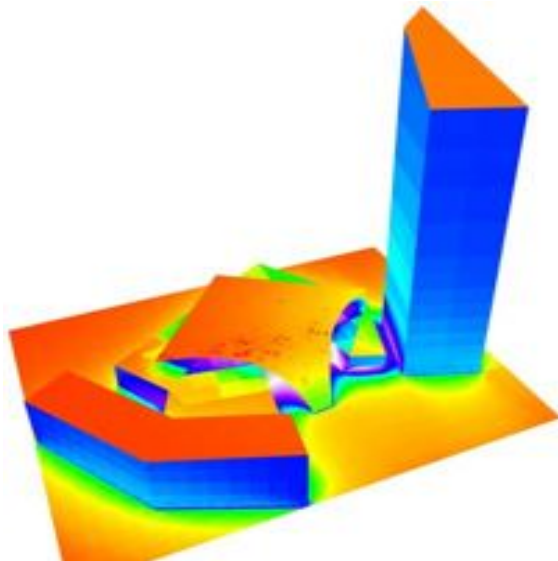
- Different opening angles have been evaluated between 50 and 90 degrees



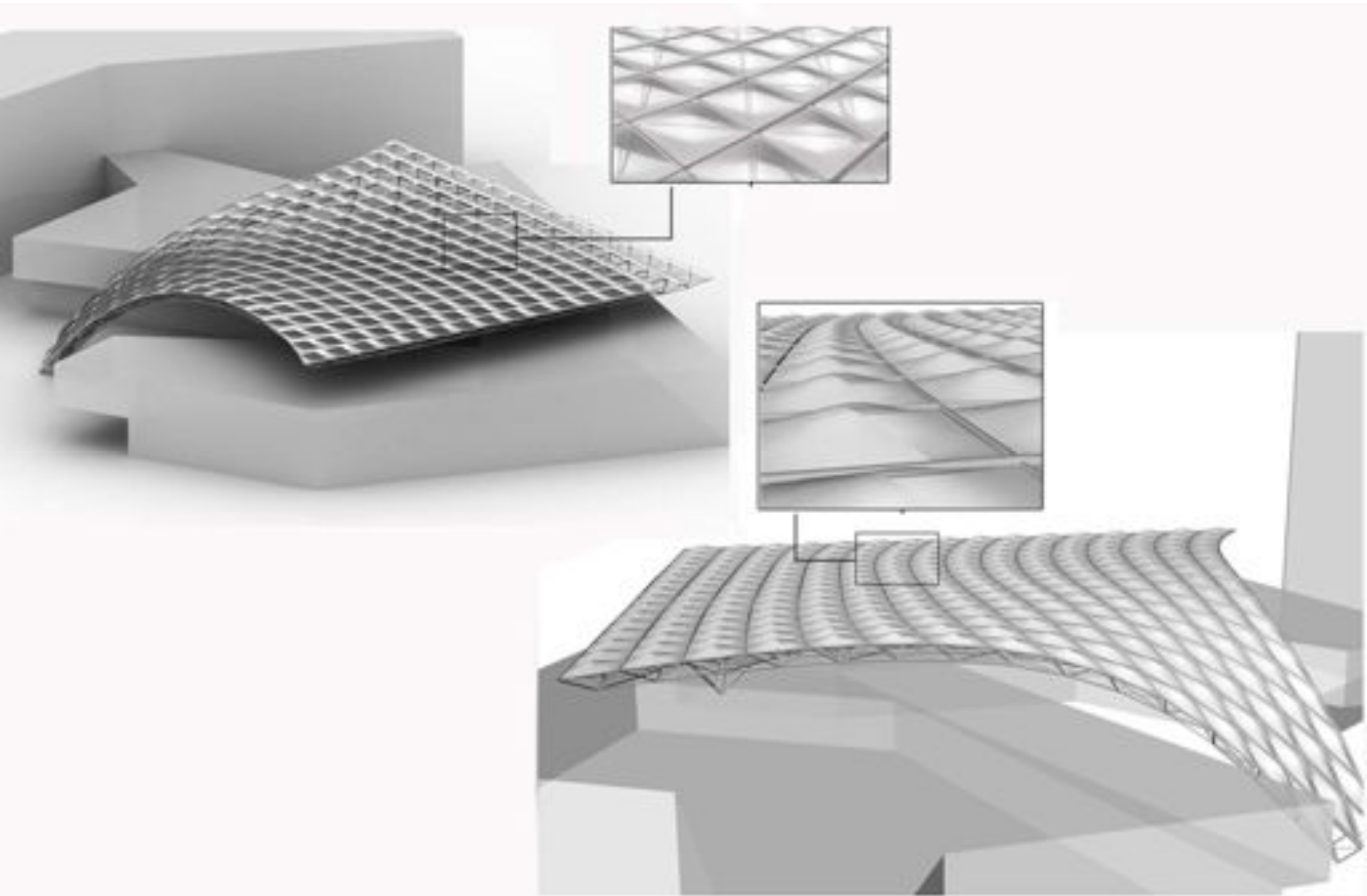
- Comparing different opening angles



- PET with selected ETFE (60 degrees)



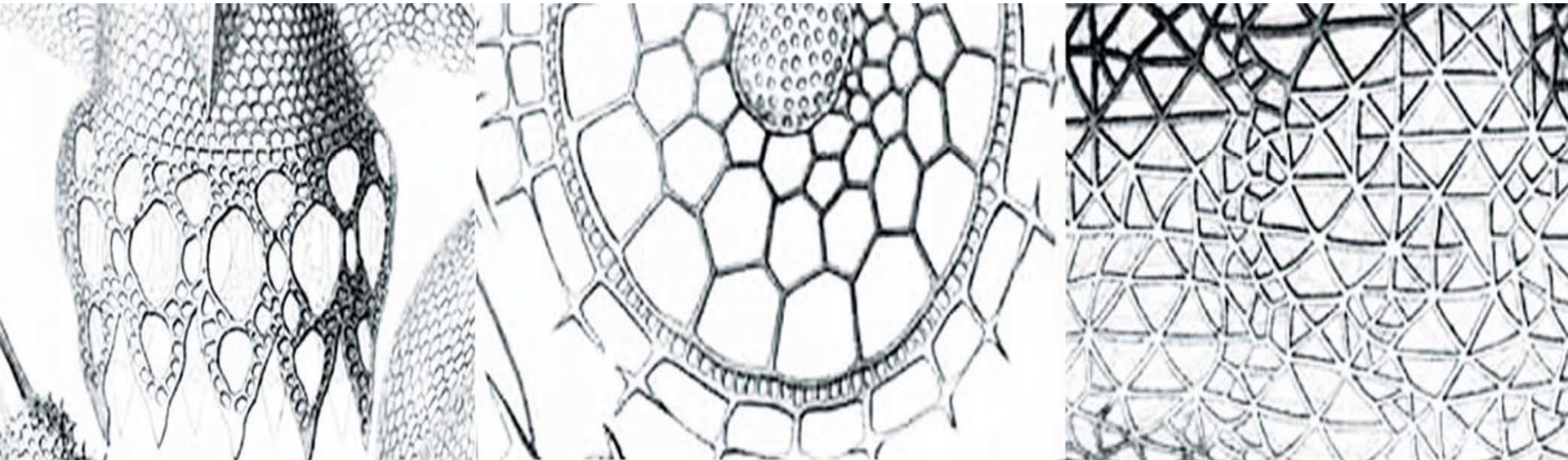
# SMALL SCALE – solar exposure and daylight



# THE RADIODOME

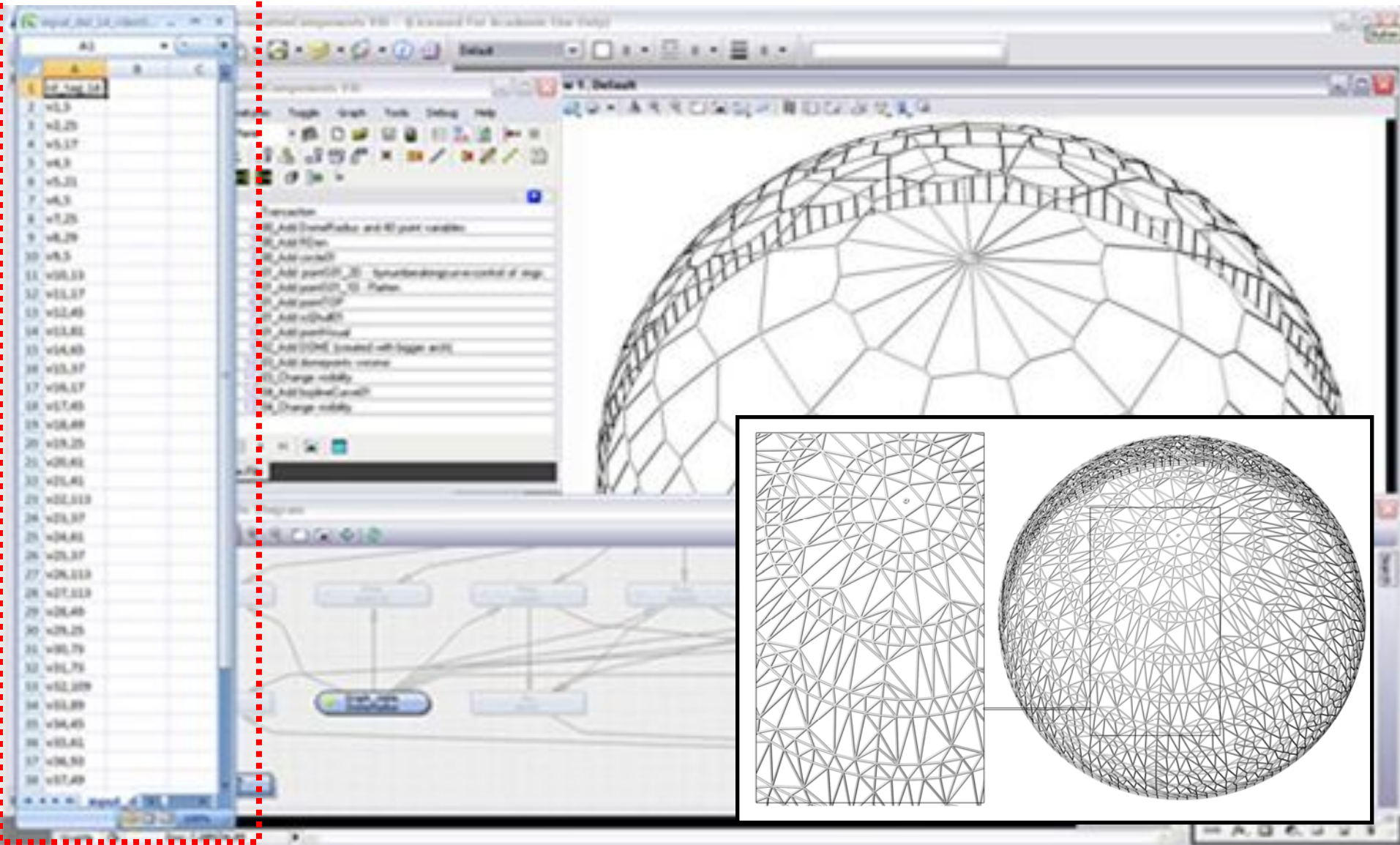
(With M.V. Van Embden Andres)

- The structural morphology of a dome is explored by taking natural structures as inspiration.
- The form is based on a logic extracted from radiolarian structures



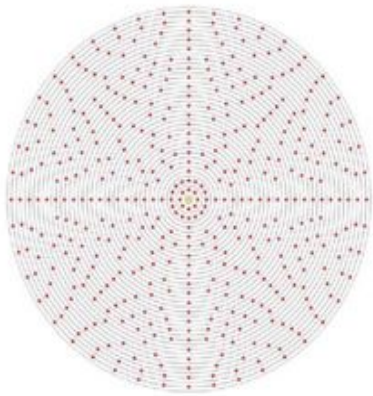
# PARAMETRIC MODEL

SET OF VARIABLES



# PARAMETRIC MODEL

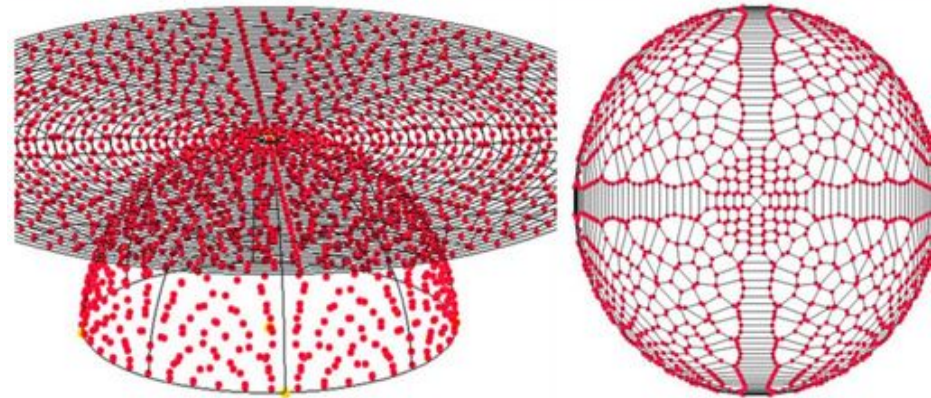
- The structural geometry of the dome is modelled based on points distributed along coplanar rings
- Independent parameters regulate:
  - the number of rings
  - the number of points per ring
- Alternatives patterns can be generated based on different densities and distributions of points
- Each alternative is projected onto the semispherical dome



Ring Number	Variable Name	Value 1	Value 2	Value 3	Value 4	Value 5	Value 6	Value 7	Value 8	Value 9	Value 10
Group 1	1	10									
	2	10									
	3	10									
	4	10									
Group 2	5	10									
	6	10									
	7	10									
	8	10									
Group 3	9	10									
	10	10									
	11	10									
	12	10									
Group 4	13	10									
	14	10									
	15	10									
	16	10									
Group 5	17	10									
	18	10									
	19	10									
	20	10									
Group 6	21	10									
	22	10									
	23	10									
	24	10									
Group 7	25	10									
	26	10									
	27	10									
	28	10									
Group 8	29	10									
	30	10									
	31	10									
	32	10									
Group 9	33	10									
	34	10									
	35	10									
	36	10									
Group 10	37	10									
	38	10									
	39	10									
	40	10									

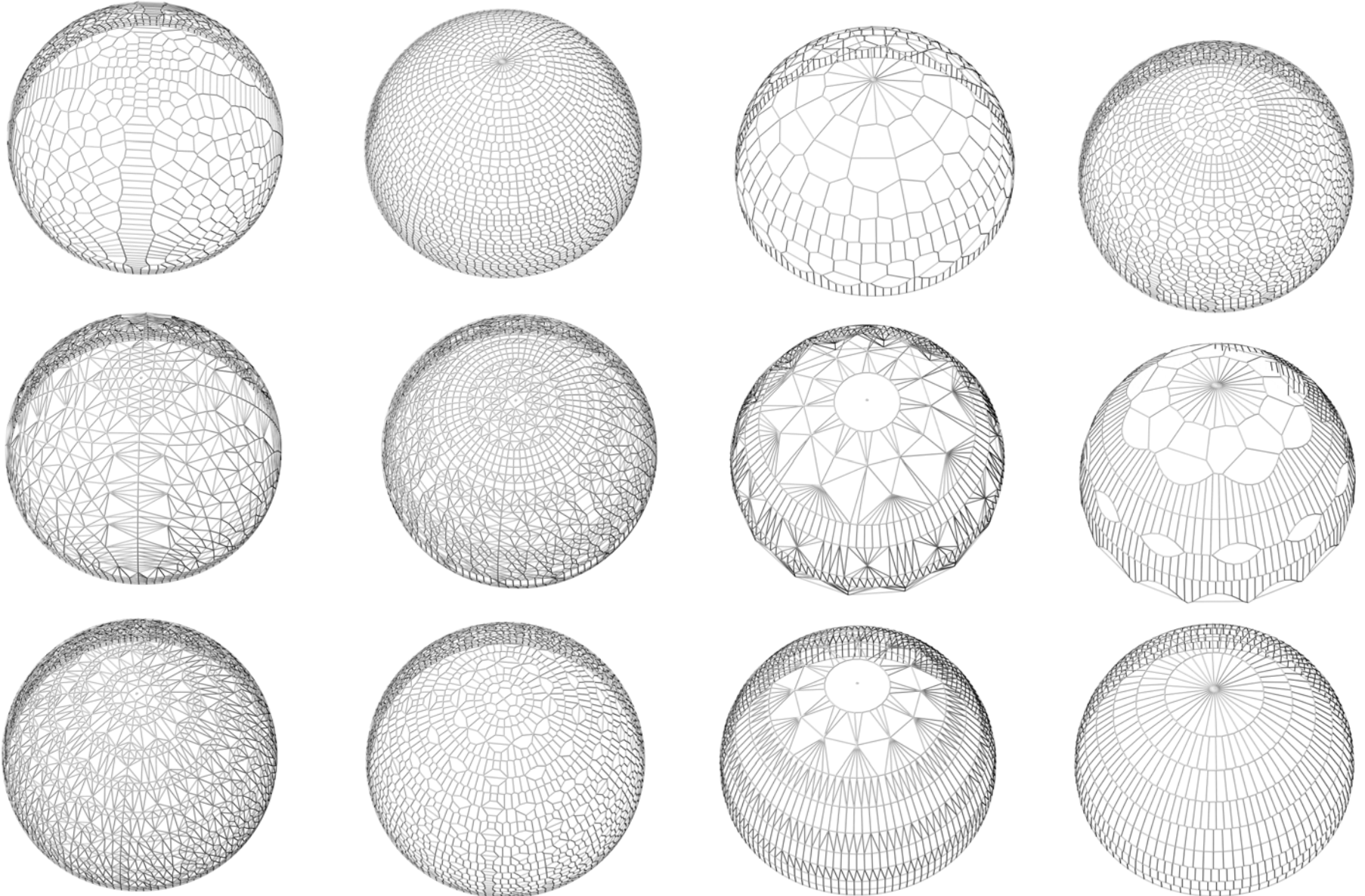
SET OF VARIBALES

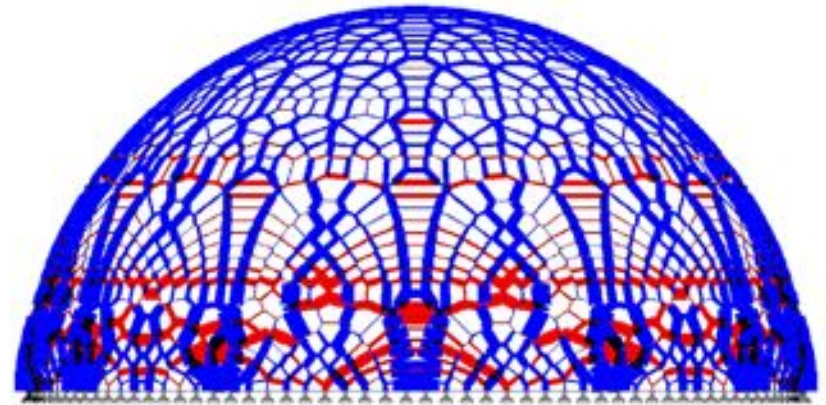
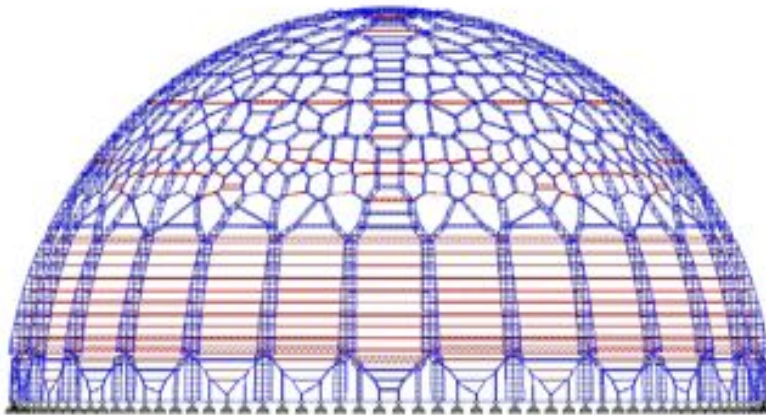
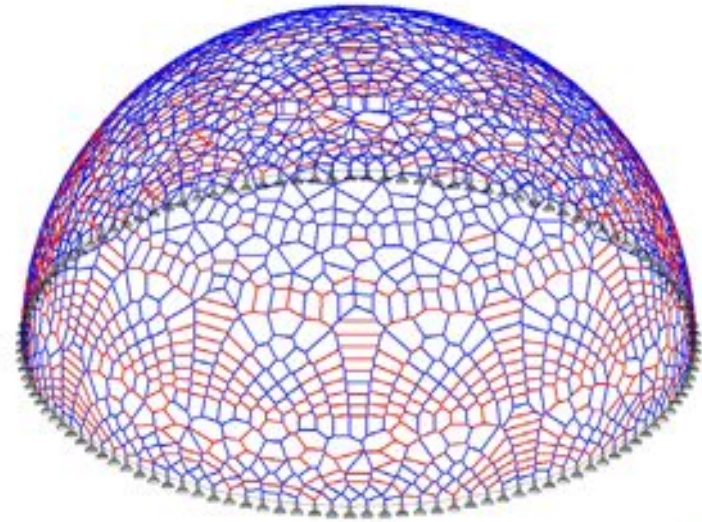
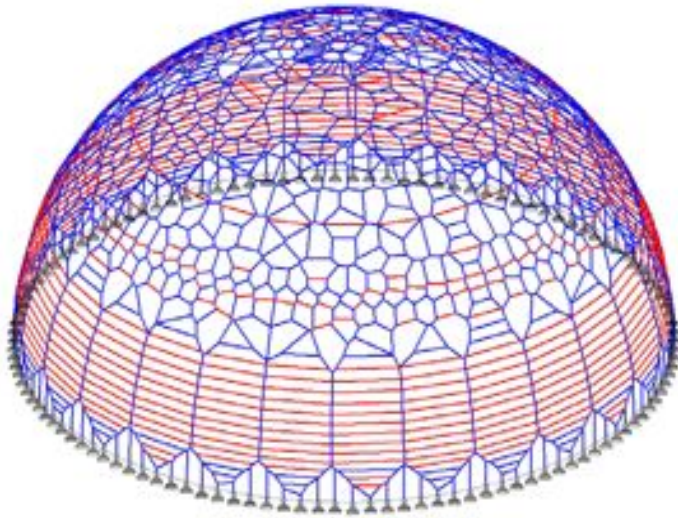
## STRUCTURAL MORPHOLOGY





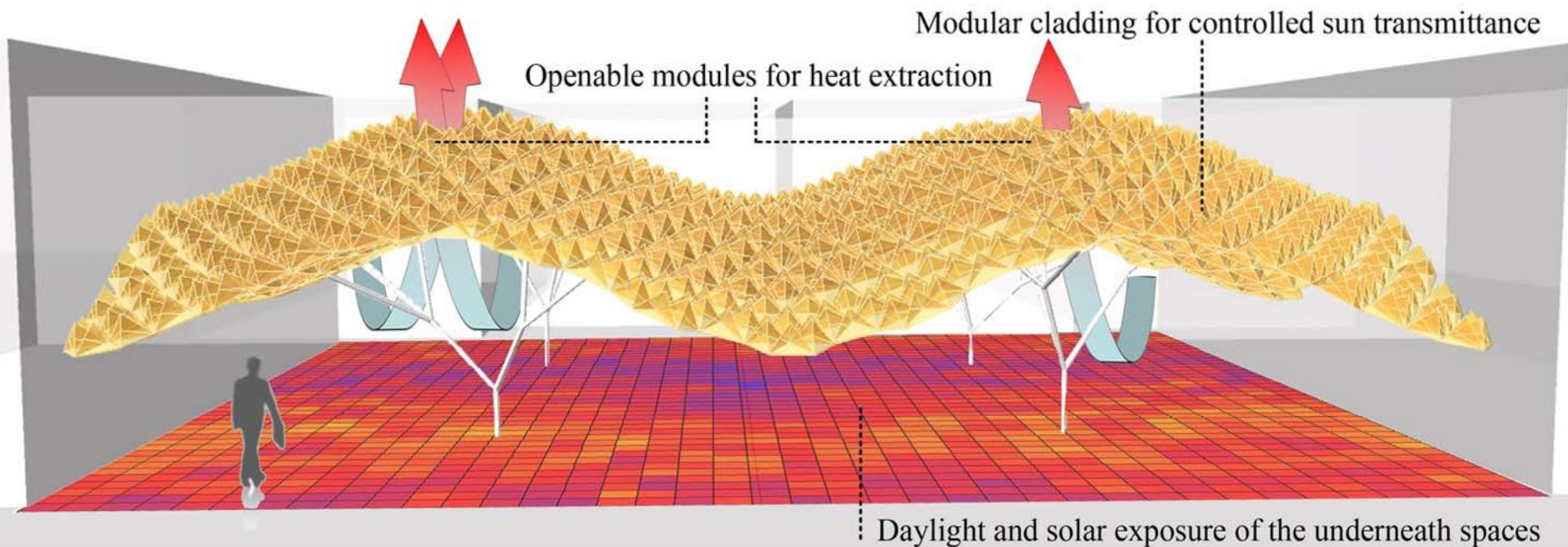
# PARAMETRIC MODEL - examples of generated alternatives





# SolSt – SOLAR ENERGY TRANSMISSION

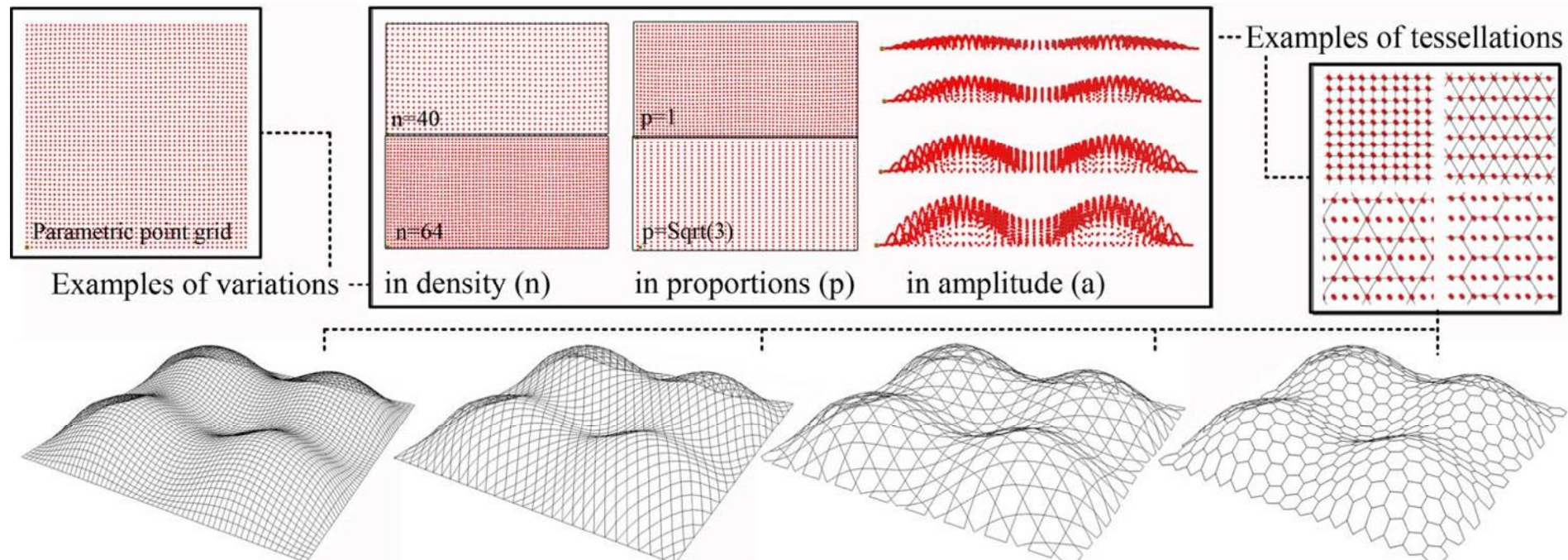
- SolSt is a free-form roof
  - covering an area approximately 50m x 50m
  - located in Milan, Italy
- SolSt is expected to contribute to the required thermal and daylight comfort in the covered spaces
  - Focusing on tempering the local climate to avoid the risk of summer overheating



# PARAMETRIC SHAPE AND STRUCTURAL GEOMETRY

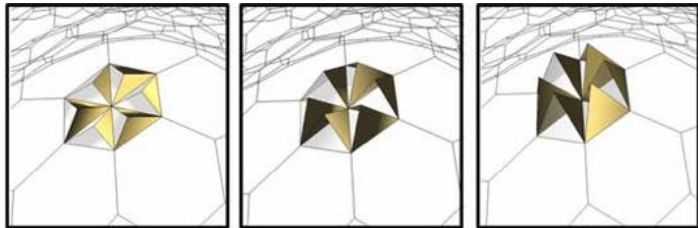
(with Axel Kilian)

- The structural geometry of the roof is modelled based on points
- The positions of the points are mathematically described based on Cartesian coordinates
- Independent parameters regulate:
  - the density of the point grid
  - the distribution of points in the two directions
  - the height of the peaks
- The points are used to tessellate the roof based on quadrangular, triangular, hexagonal polygons or combinations

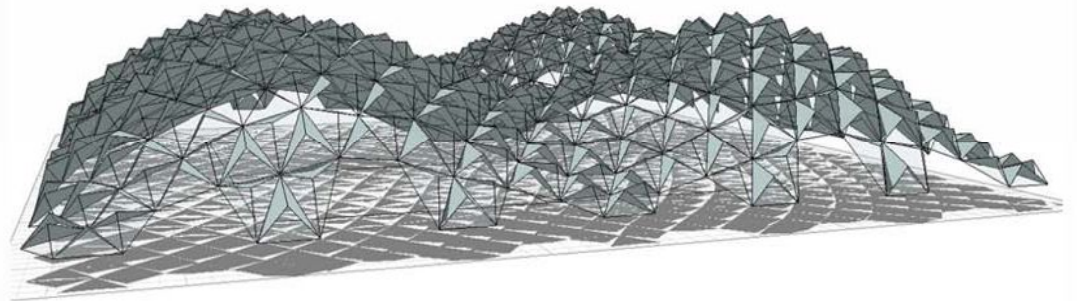
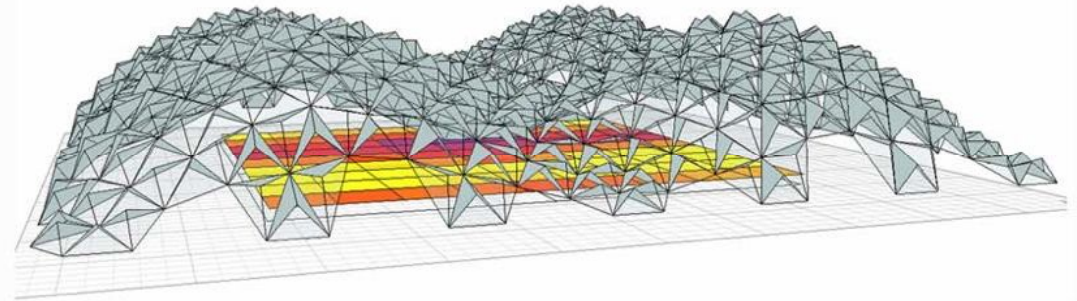
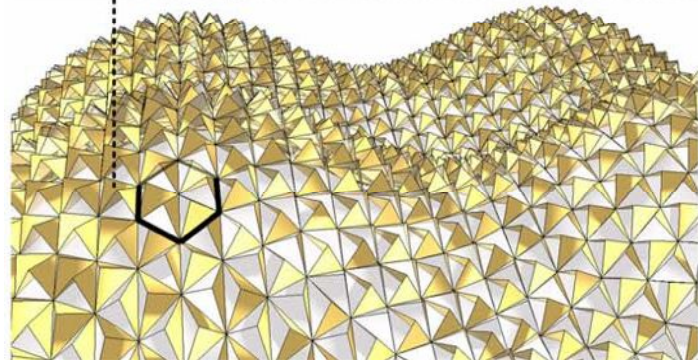


# PARAMETRIC CLADDING

- The cladding is a modular system, propagated based on the structural tessellations
  - it aims at limiting the incident radiations on the covered spaces by allowing the income of indirect light
- Various cladding options are explored based on:
  - different tessellations
  - different topologies of modules for each single tessellation
  - different geometrical variations of each single topology
- Here an example based on hexagons
  - with parametric height



Examples of variations in inclination



# PAERFORMANCE EVALUATIONS

(with Peter von Buelow)

