MSc Architecture, Urbanism and Building Sciences
Building Technology Track

Re-De-Form

An interactive tool
for the design and fabrication of grid shells structures.

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Mentors
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Olga Ioannou | Building Product Innovation

“De-Form”

Able to change shape

“Re-Form”

Able to do it multiple times

Research Question

How to develop a “design to fabrication” workflow that corresponds to the design process and materialization of a timber grid-shell structure, while also establishing an automation process to provide the Re-De-Form with more accuracy/precision in producing free-form surfaces?

Sub-Questions

1. How to study freeform surfaces through Re-De-Form?

2. How can Re-De-Form be upgraded towards a more fast and accurate mechanism for freeform exploration?

3. How to design a timber grishell and fabricate its panelization?

4. How can the Re-De-Form be utilized for gridshell design and panel fabrication?

Objectives

1. Perform an analysis of freeform surfaces and the challenges they pose towards their design.
2. Study the requirements of a timber grid-shell towards its form-finding, materiality, structural analysis, panelization.
3. Relate Re-De-Form to the designing and fabrication process of a grid shell structure.
4. Test the automated workflow using a prototype of Re-De-Form.

Methodology Steps

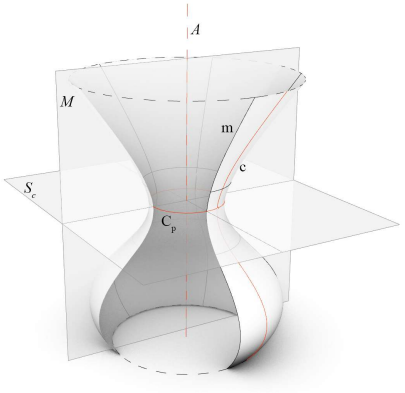
1. Literature review on freeform surfaces, flexible formworks and timber gridshells
2. Create the digital and physical environment of Re-De-Form and link it to the case study of a timber gridshell structure
3. Perform the Form Finding, Structural Analysis, Panelization and Physical Modelling
4. Prototype and Automate Re-De-Form to perform panel fabrication and physical modelling

Freeform Surfaces

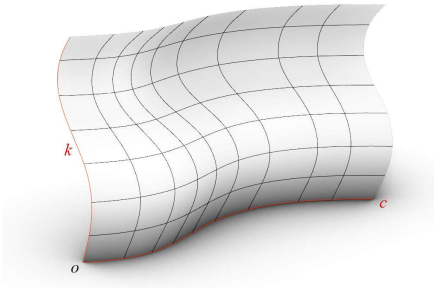
1. Freeform Surface Geometry
2. Panelization
3. Freeform Examples
4. Freeform Design and Context

Freeform Surface Geometry

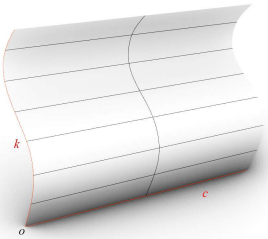
Traditional Surface Classes



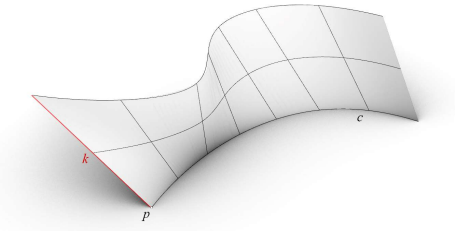
Rotational Surface



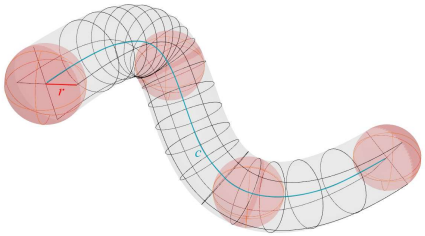
Translational Surface



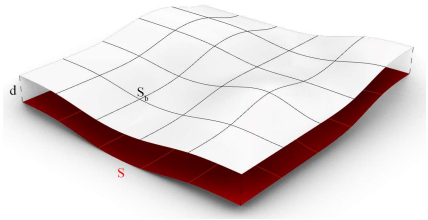
Extrusional Surface



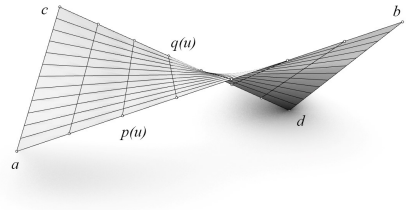
Ruled Surface



Pipe Surface



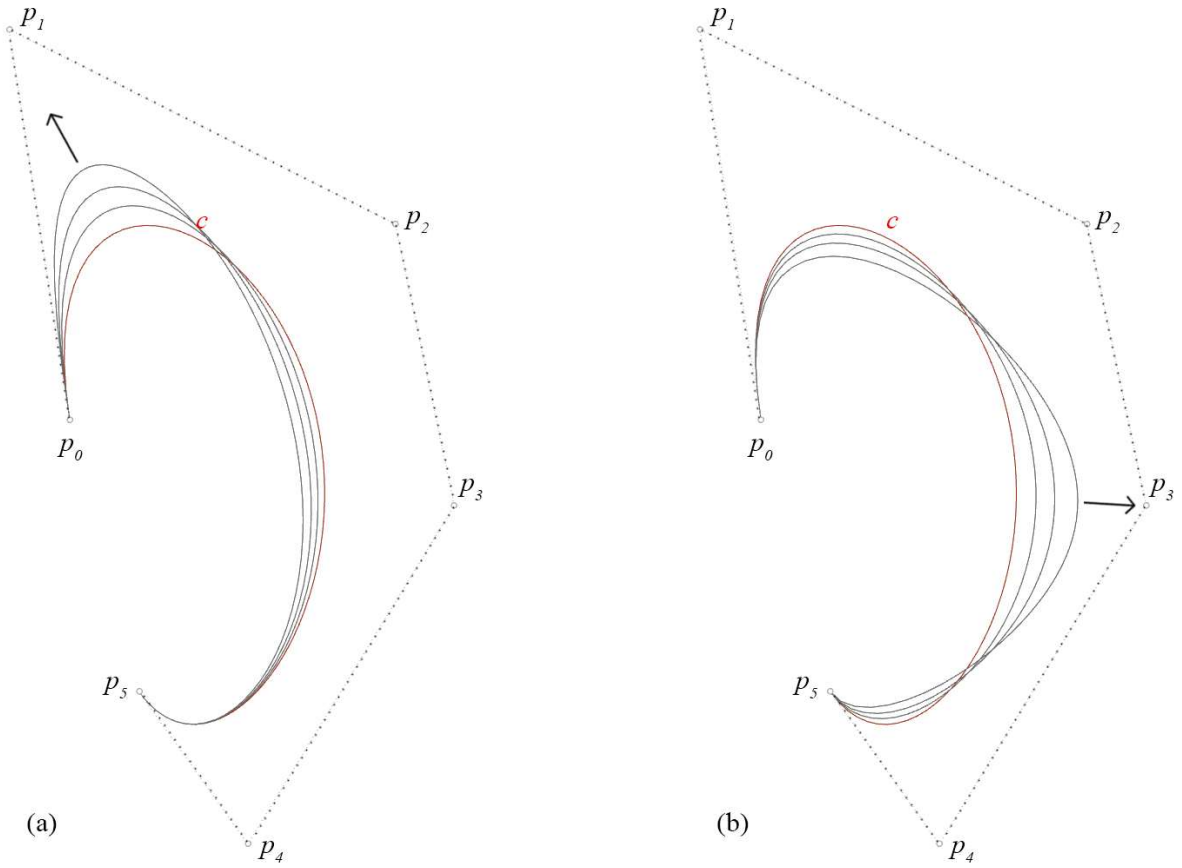
Offset Surface



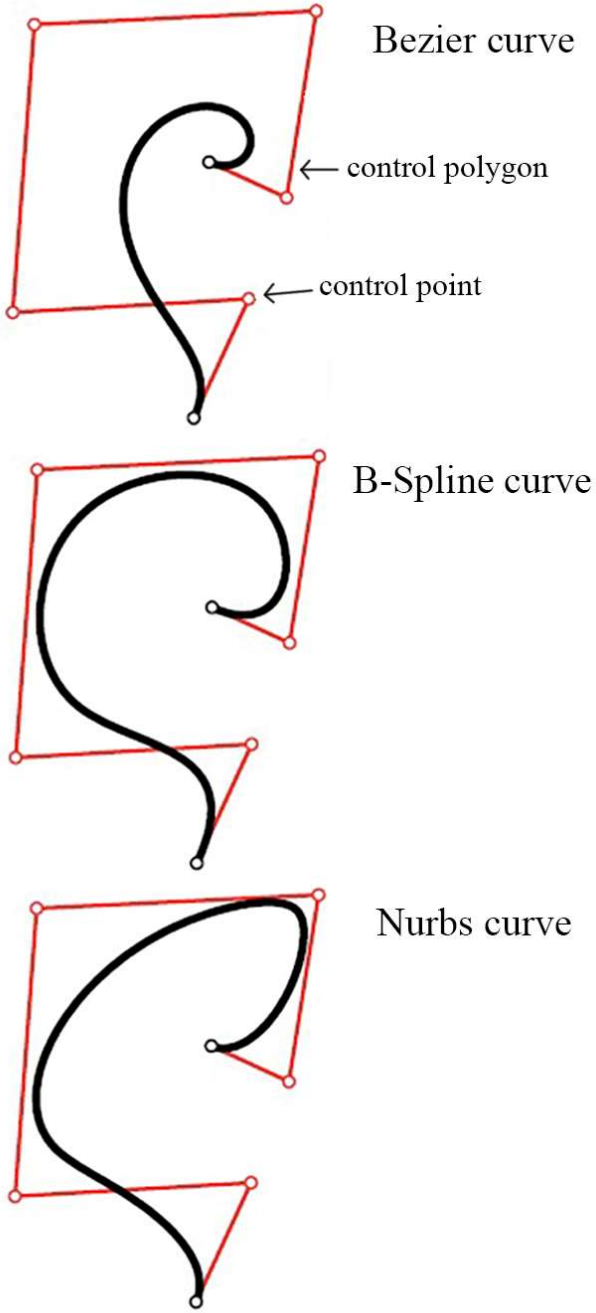
Hyperbolic Paraboloid

Freeform Curves

1. Bezier
2. B-Spline
3. NURBS

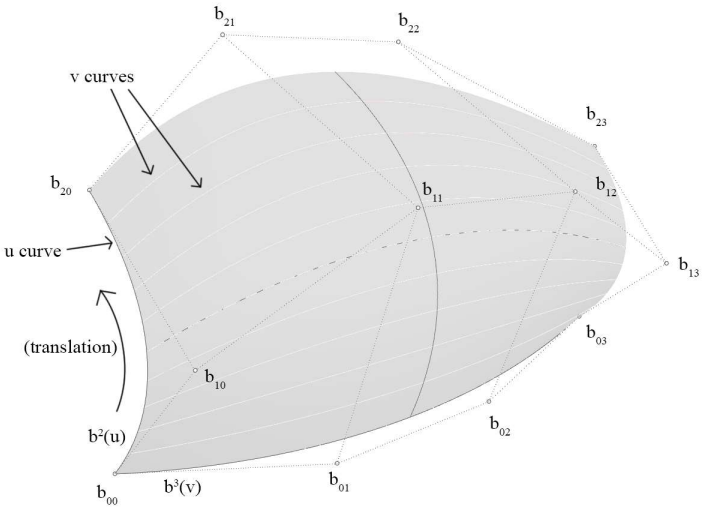


A NURBS curve with different weight increase towards P1 and P3

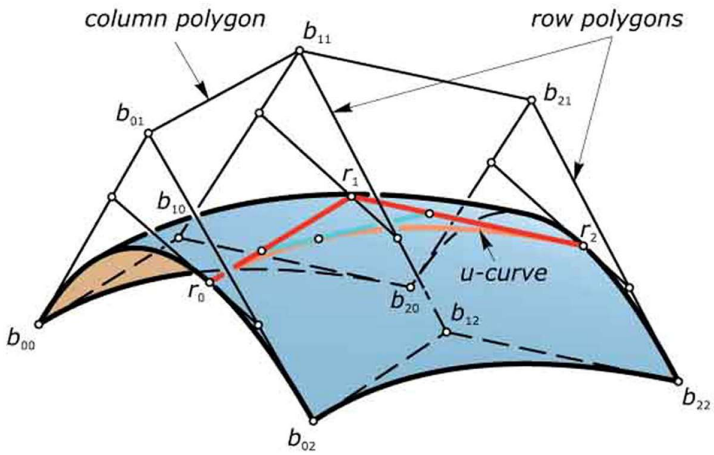


Freeform Surfaces

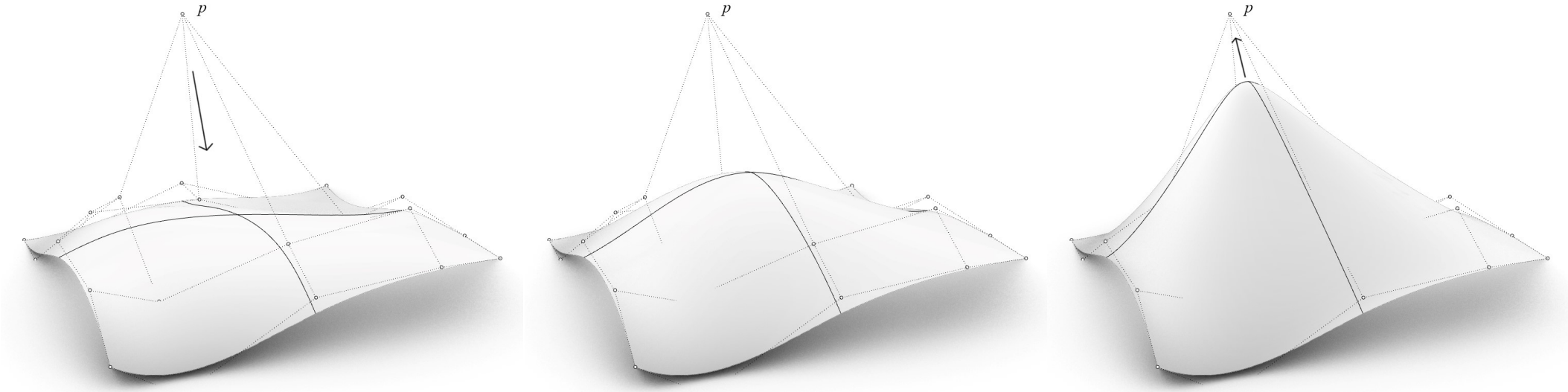
1. Bezier Surfaces
2. B-Spline
3. NURBS Surfaces



Translational Bezier Surface

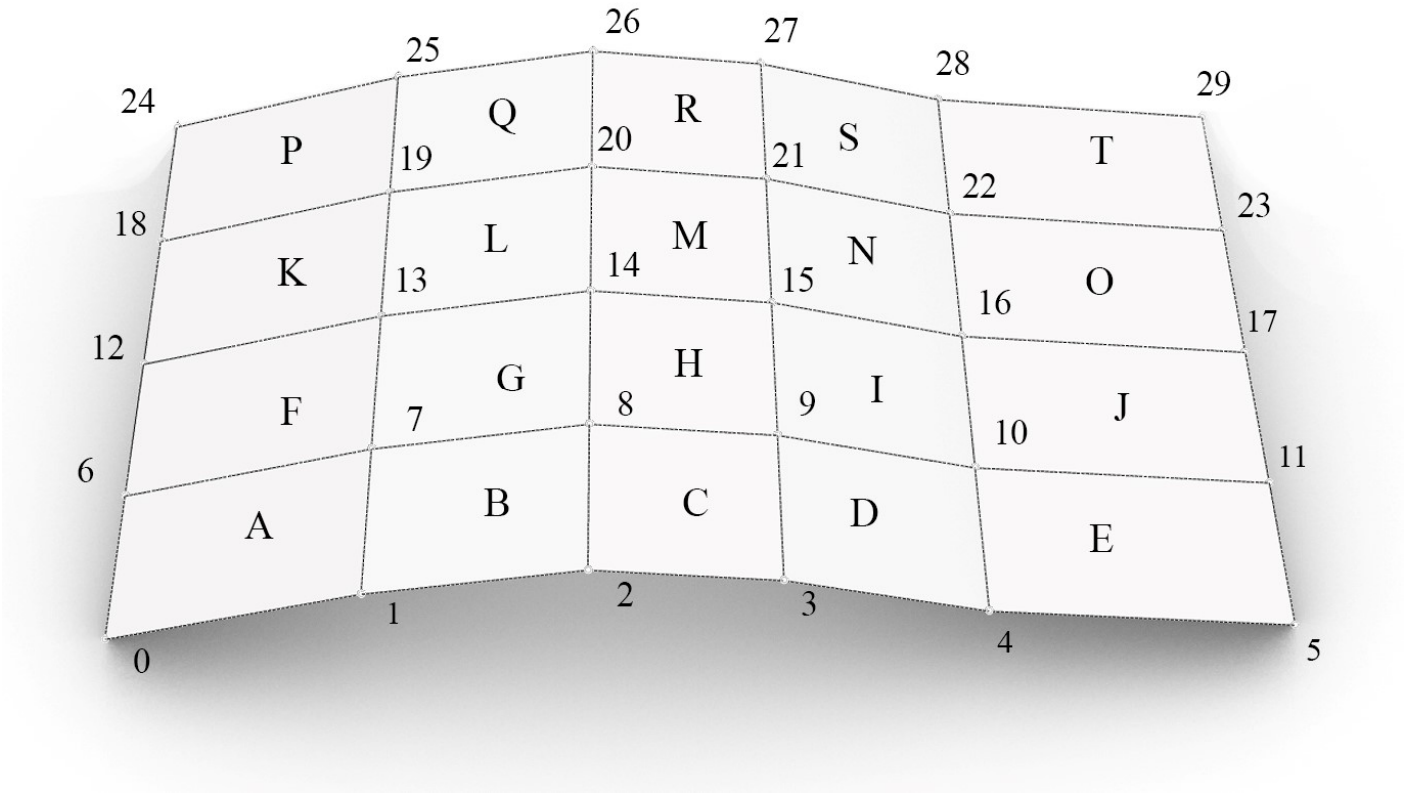


General Bezier Surface



NURBS Surfaces

Meshes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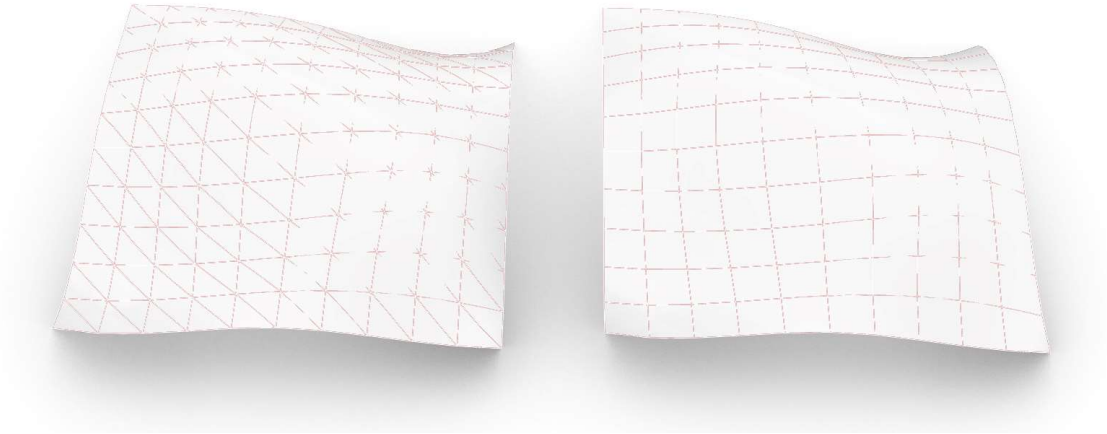
Panelization

1. Non-Rationalization
2. Pre-Rationalization
3. Post-Rationilization

Non-Rationalization

Pre-Rationalization



Post-Rationalization

Freeform Surface Examples

Antonio Gaudi

Frank Ghehry

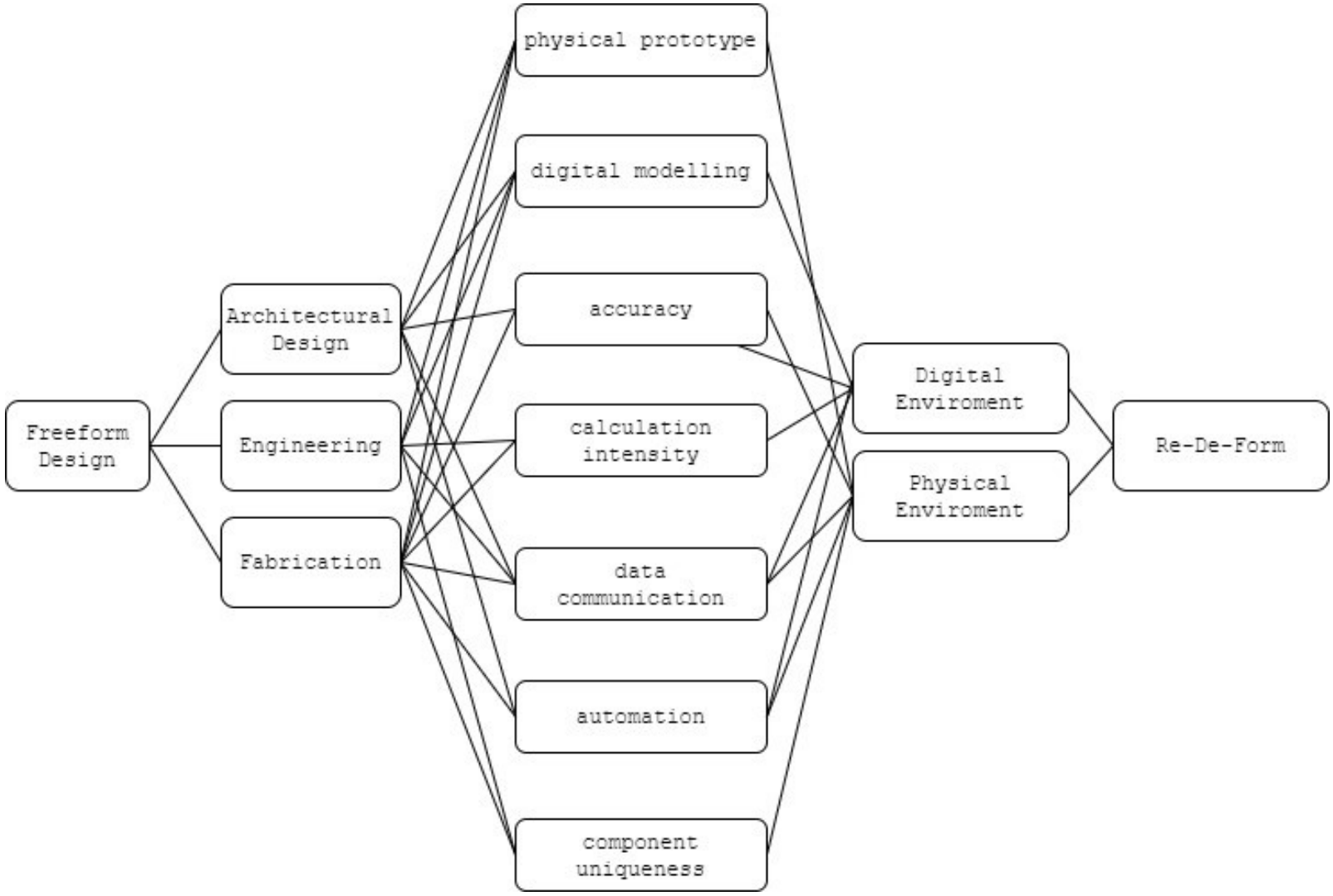
Freeform Design

is identified as a new and cross-disciplinary domain and is characterized as representative of the larger scale of impact of digital technologies on building design and production.

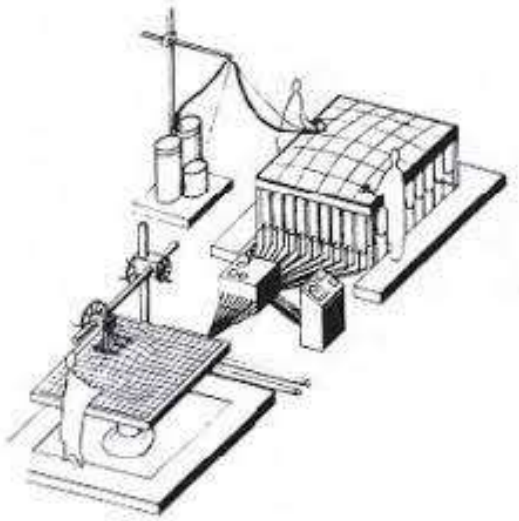
Challenges in:

1. Architectural Design
2. Engineering
3. Fabrication

Freeform Design Challenges | Re-De-Form



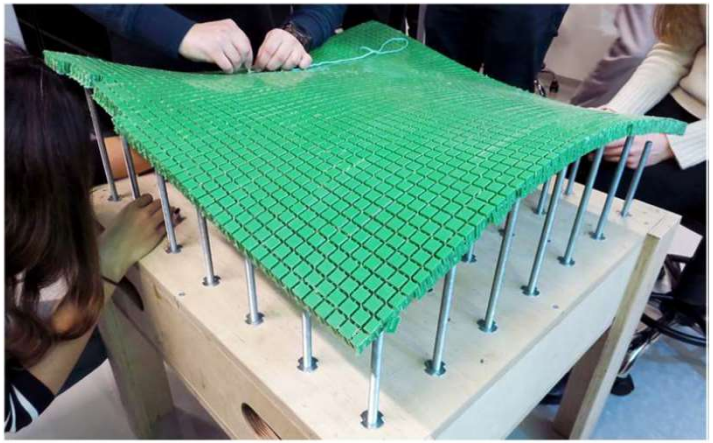
State of the Art on Flexible Molds

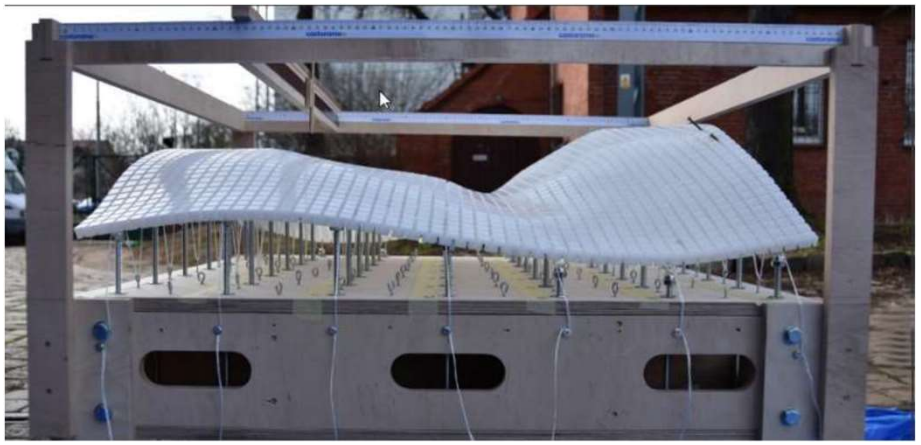


Renzo Piano

Spuybroek

Vollers and Rietbergen





The former FlexiMold

1st Upgrade

Automation of the manually adjusted formwork

2nd Upgrade

Integrate Human Computer Interaction (HCI)

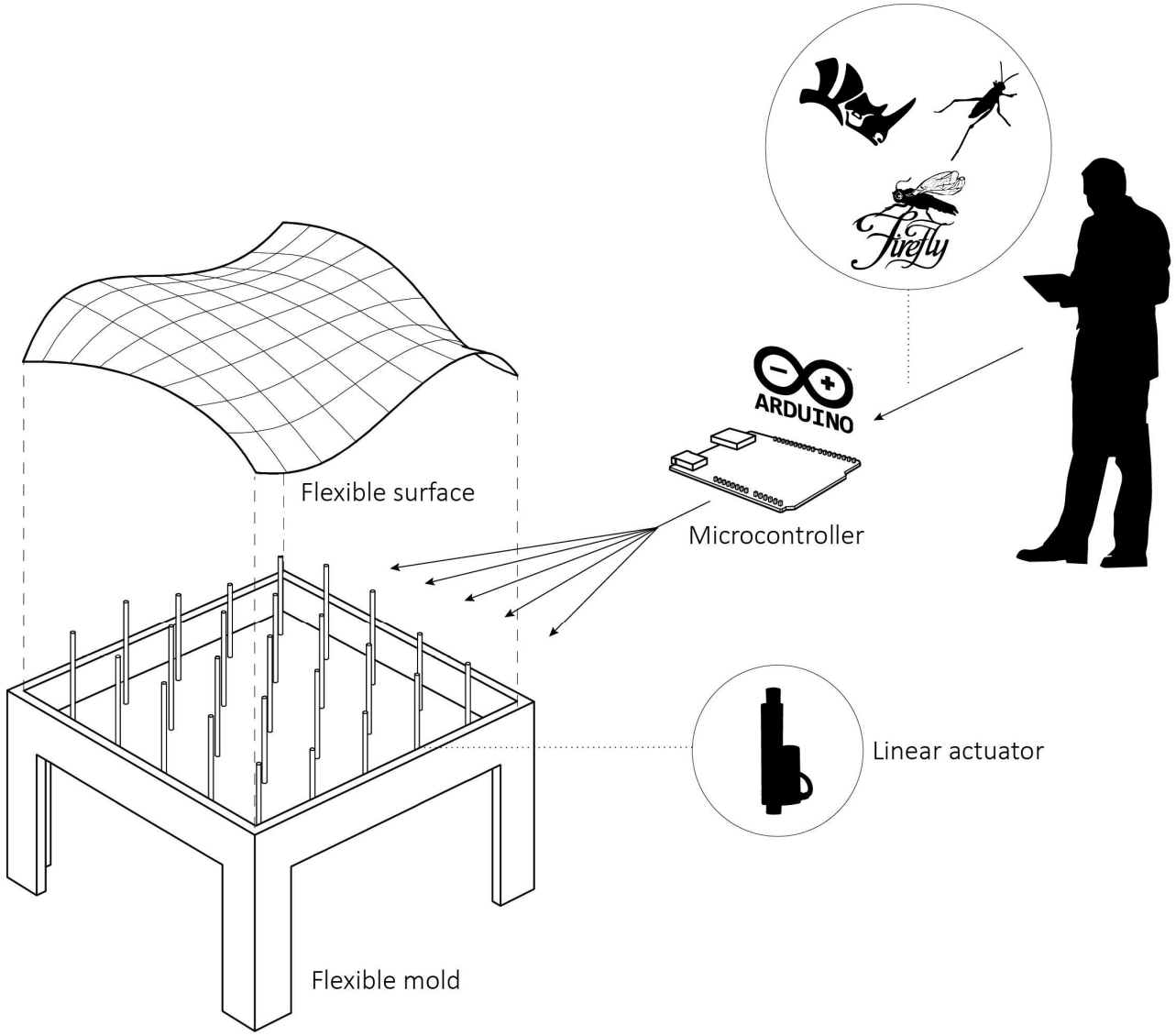
1st Upgrade

Automation of the manually adjusted formwork

2nd Upgrade

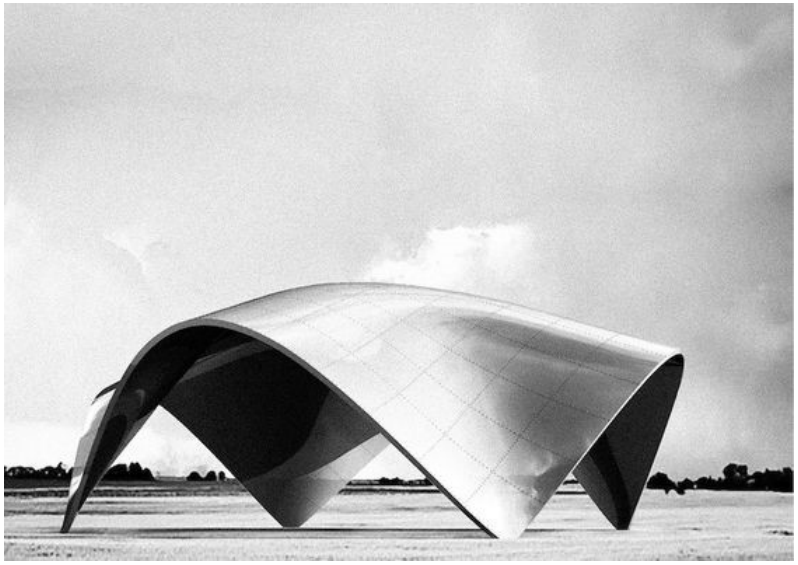
Integrate Human Computer Interaction (HCI)

The automation as it was originally envisioned

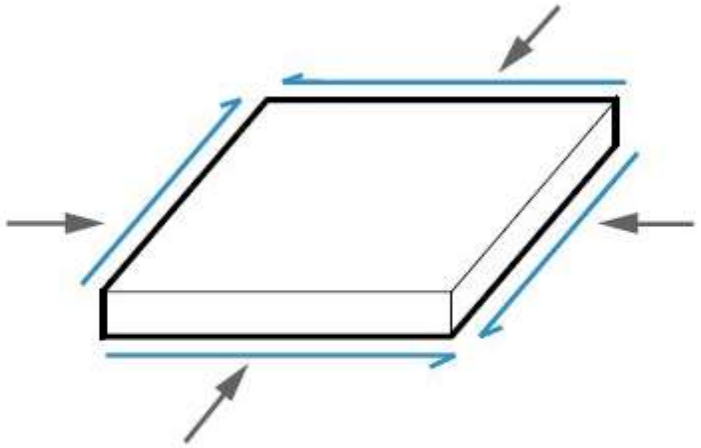


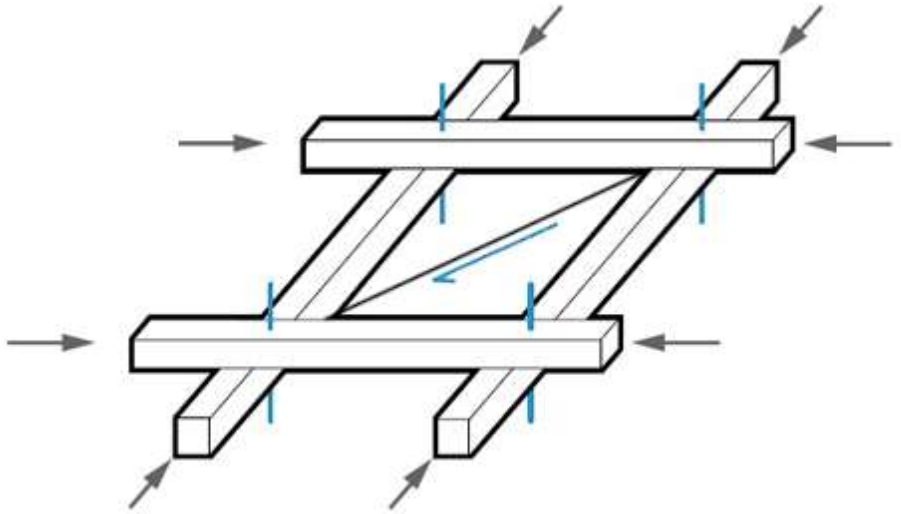
Timber Gridshell Structures

Shells

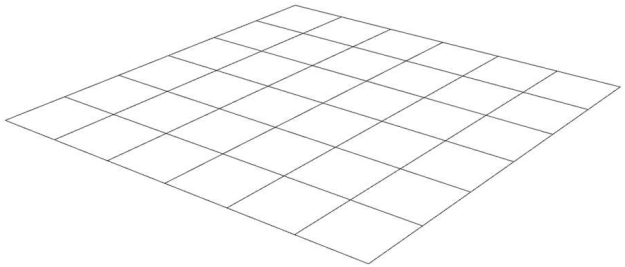


Gridshells

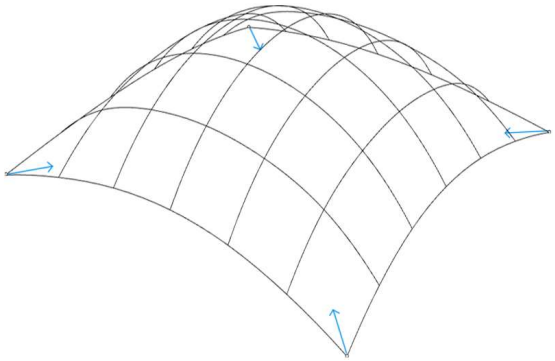




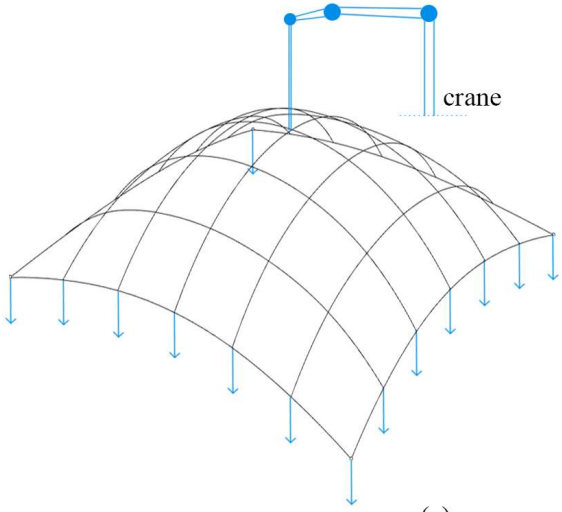
Timber GridShells



(a)

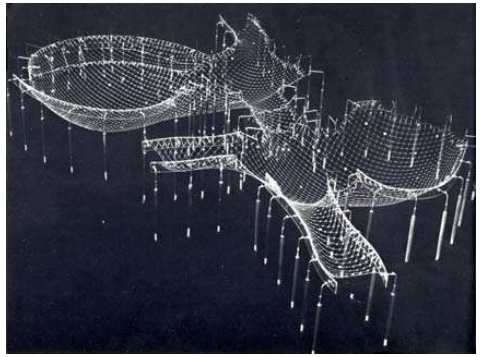


(b)



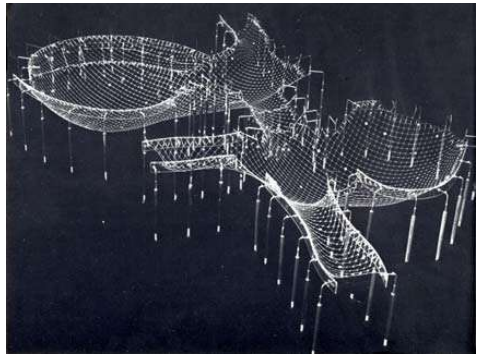
(c)

Timber GridShell examples



The Mannheim Multihalle

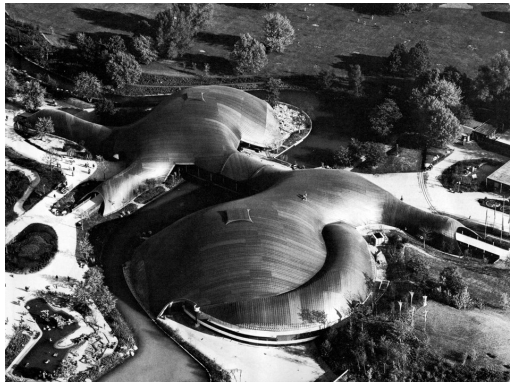
Timber GridShell examples

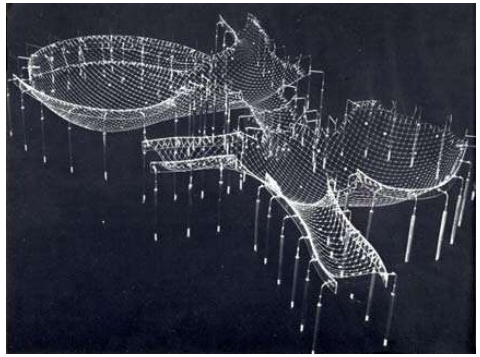


The Mannheim Multihalle

The Weald and Downland

Timber GridShell examples





The Mannheim Multihalle

The Weald and Downland

The Savil Garden

Pavilion ZA

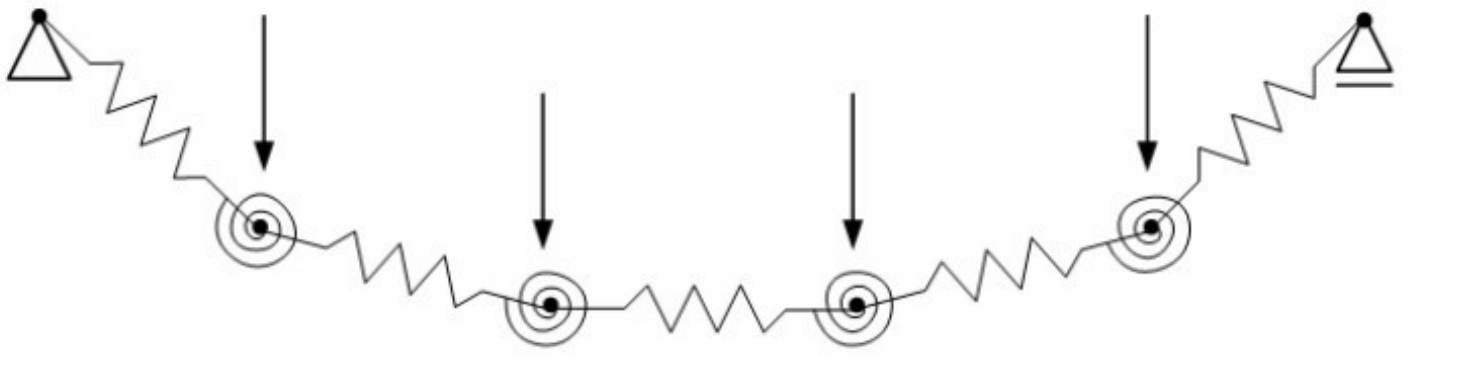
Form Finding Processes for shells

1. Stiffness Matrix Methods
2. Geometric Stiffness Method
3. Dynamic Equilibrium Methods

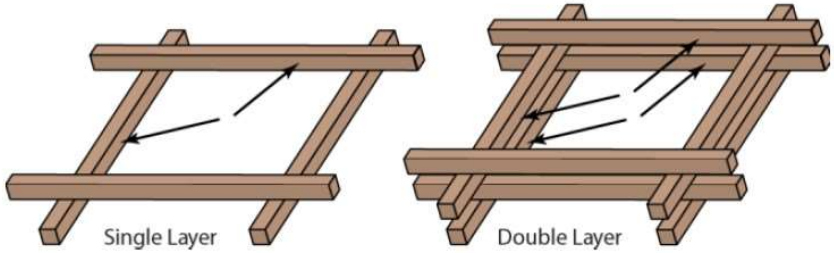
Form Finding Processes for shells

1. Stiffness Matrix Methods
2. Geometric Stiffness Method
3. Dynamic Equilibrium Methods

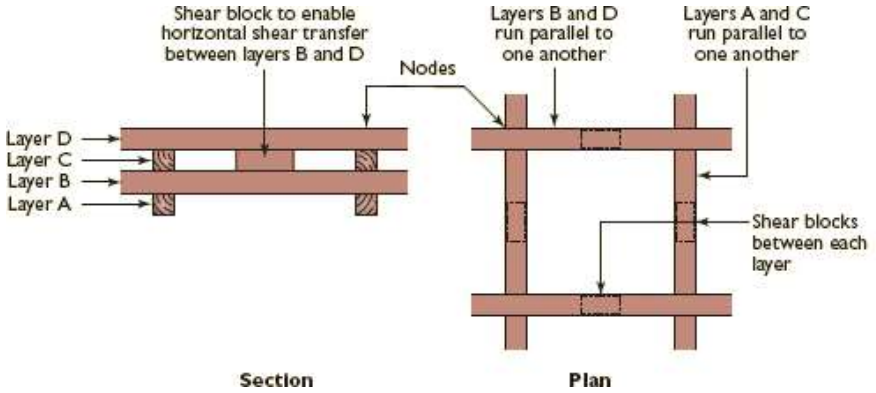
Particle Spring Method



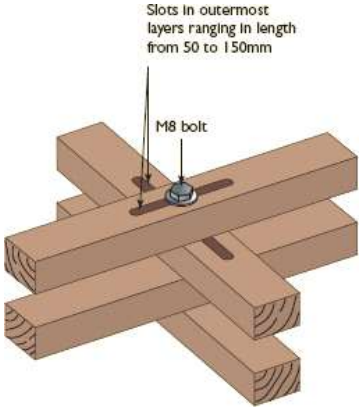
Timber Grid Details and Node Connections



Single-Double Layering



Double Layer System



Slotted node

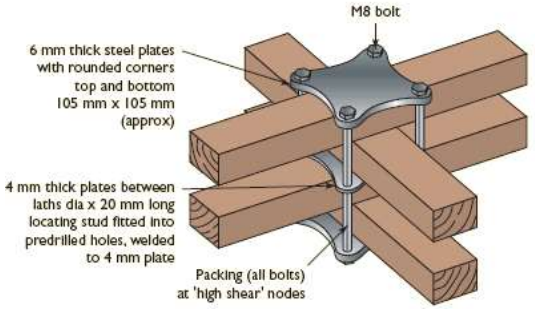
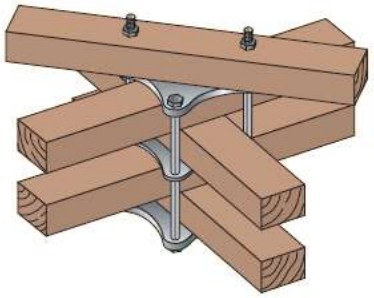
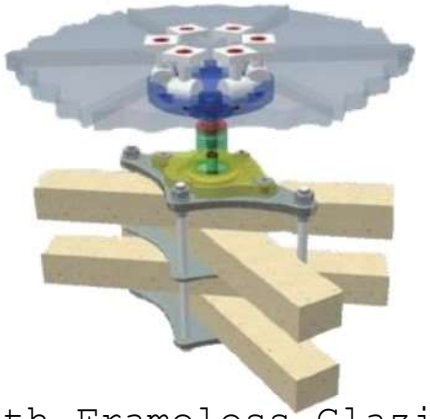


Plate-Bolt node



Diagonal Bracing



With Frameless Glazing

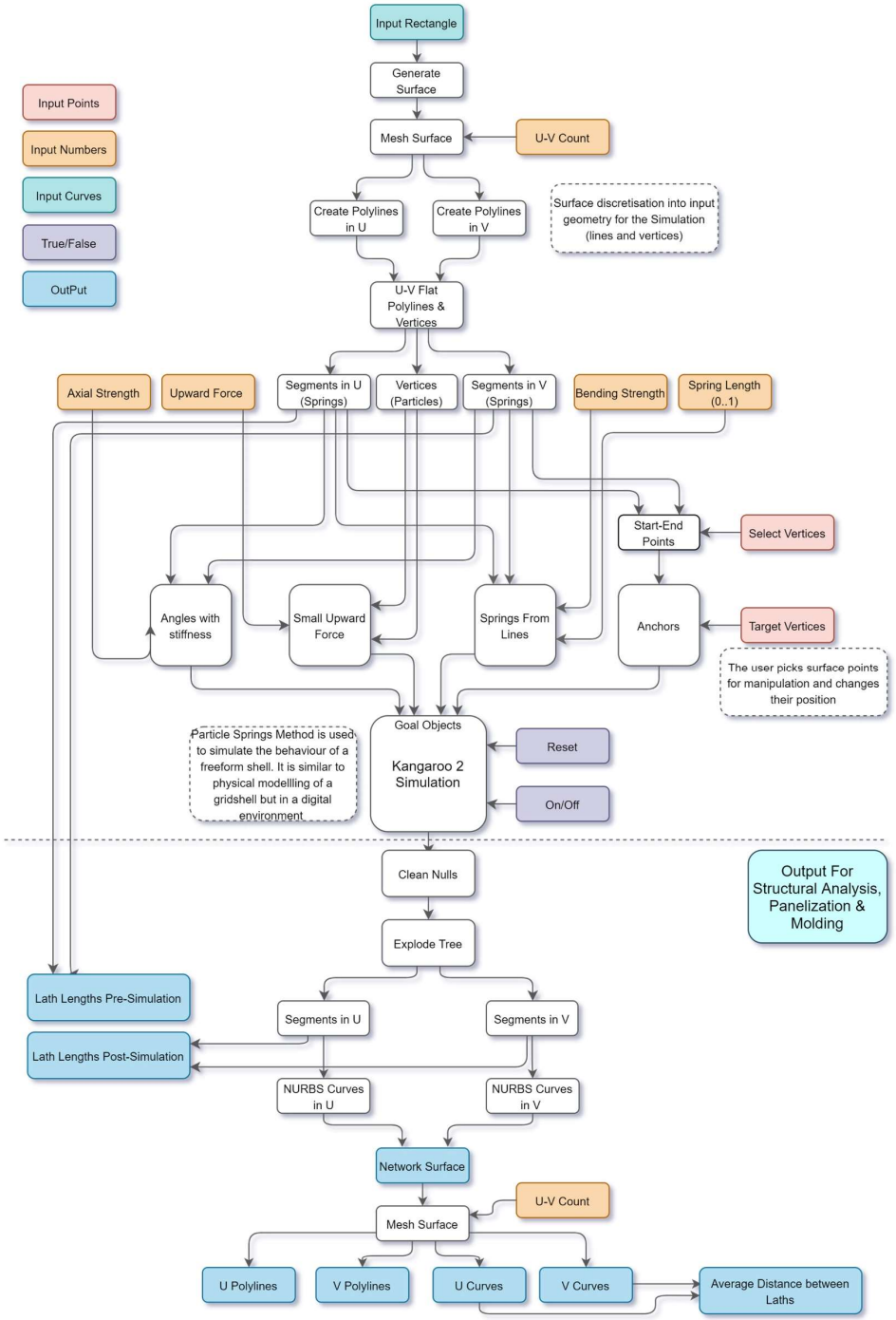
Re-De-Form

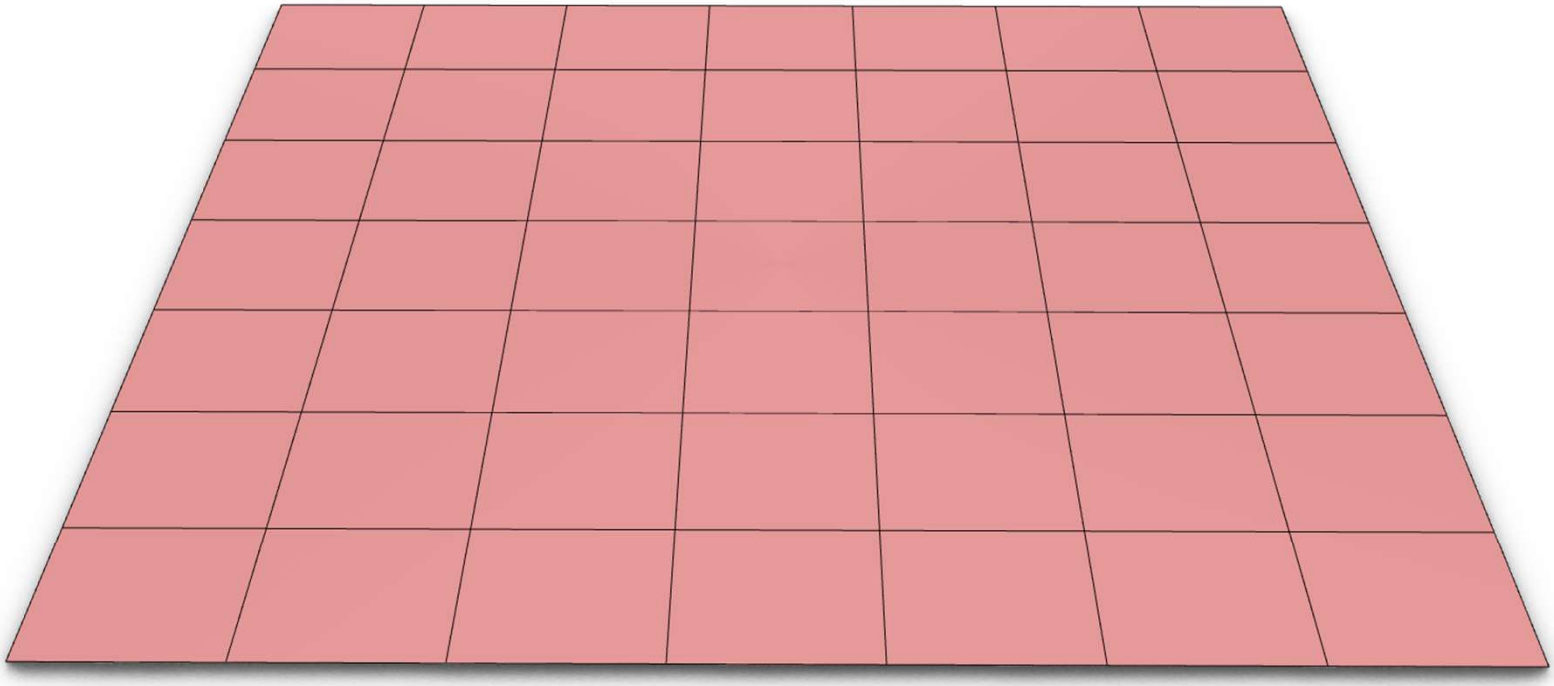
Designing the workflow

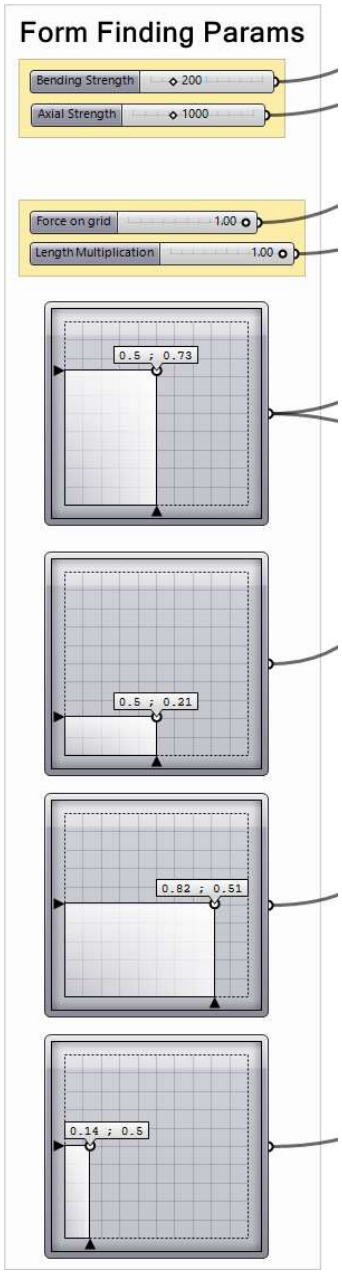
1. Form finding
2. Designing the Gridshell
3. Structural Analysis
4. Panelization and panel correction
5. The digital Re-De-Form
6. The Re-De-Form prototype

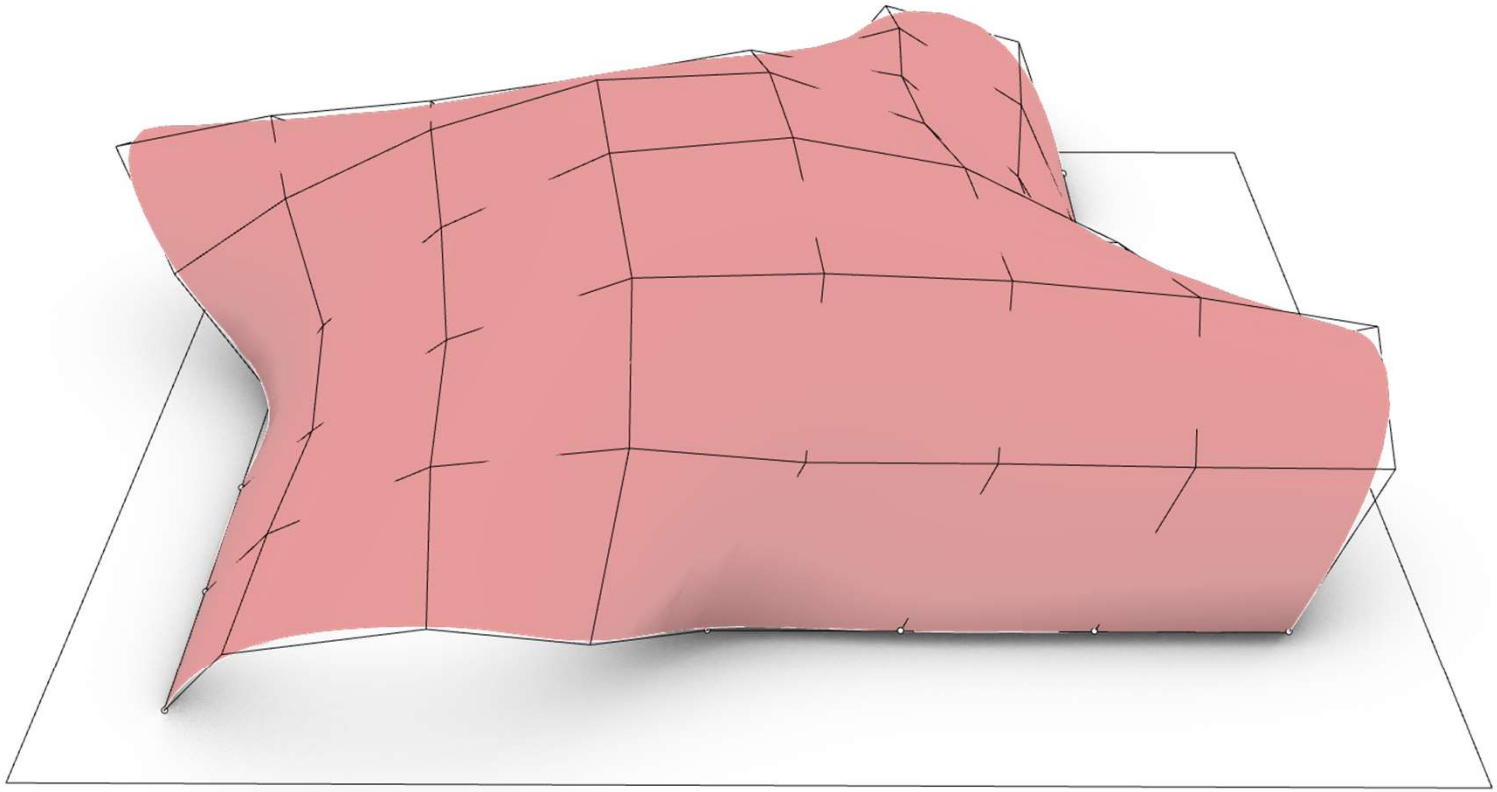
Form finding of a flat surface

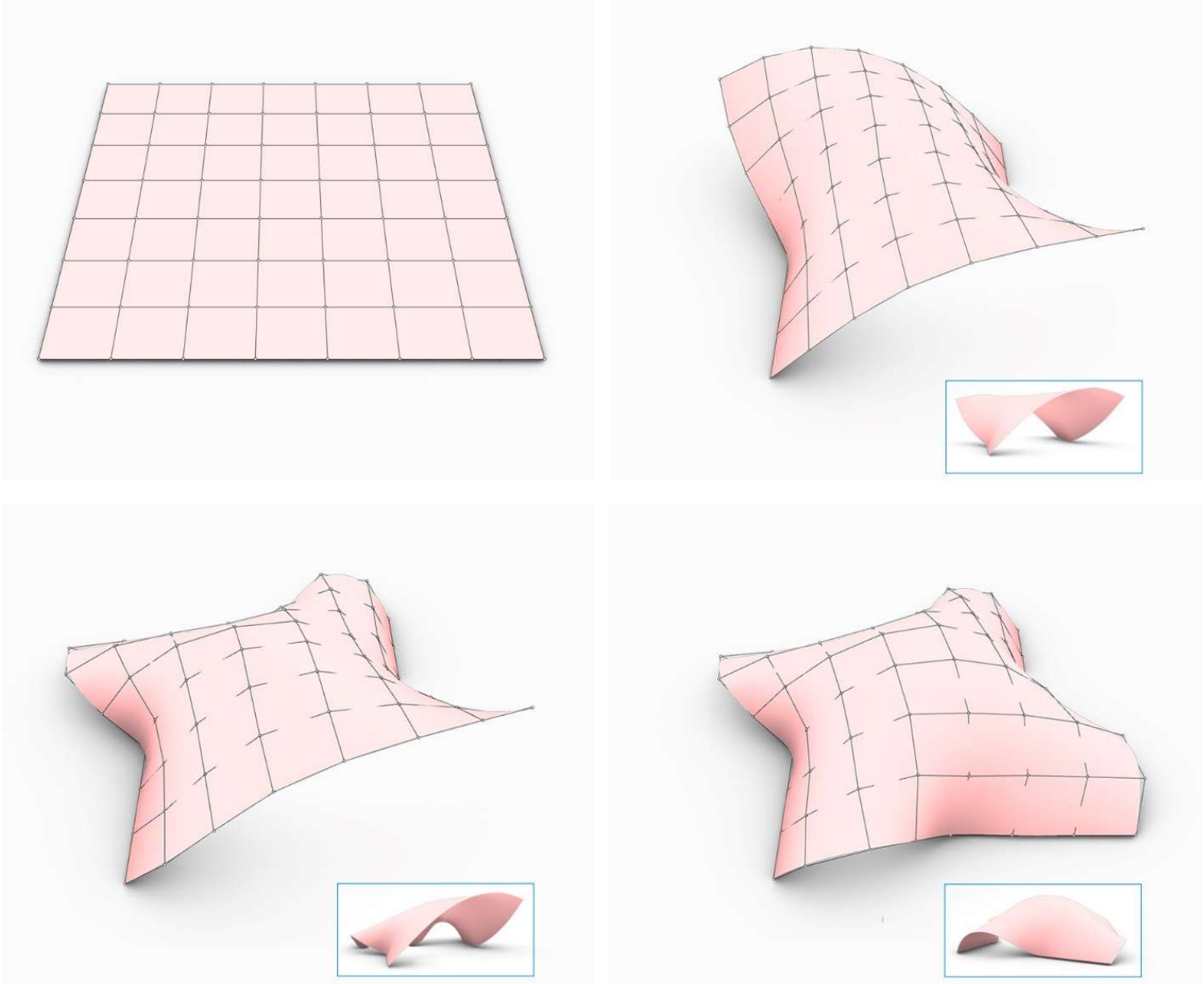
The Flowchart






Form Finding Params
Bending Strength
200
Axial Strength
1000
Force on grid
1.00
Length Multiplication
1.00
0.5 ; 0.73
0.5 ; 0.21
0.82 ; 0.51
0.14 ; 0.5





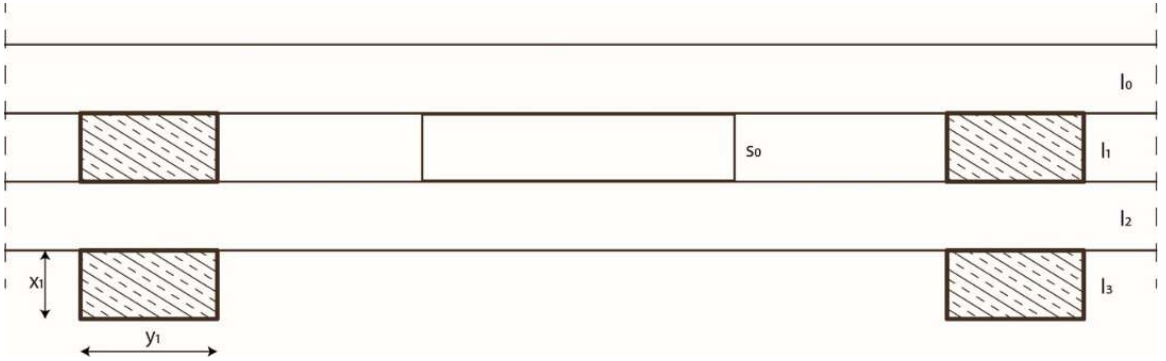
3 scenarios

U and V Polylines
for
structural analysis

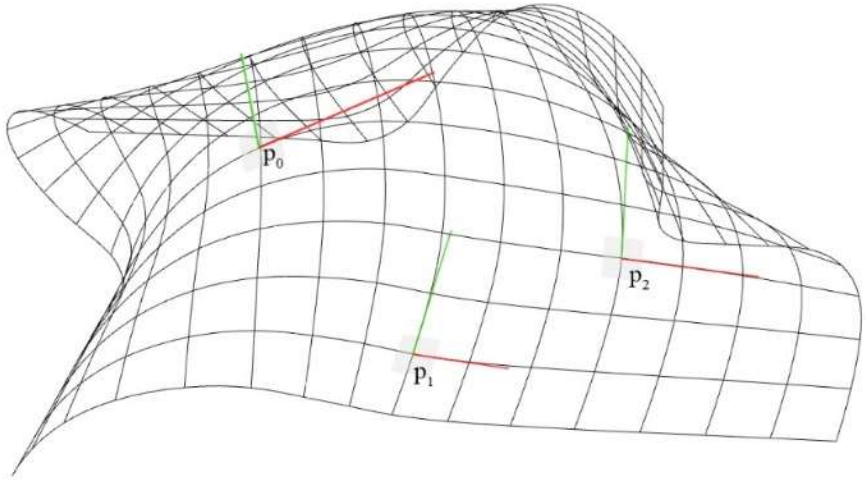
U and V Curves
For
gridshell design and panelization

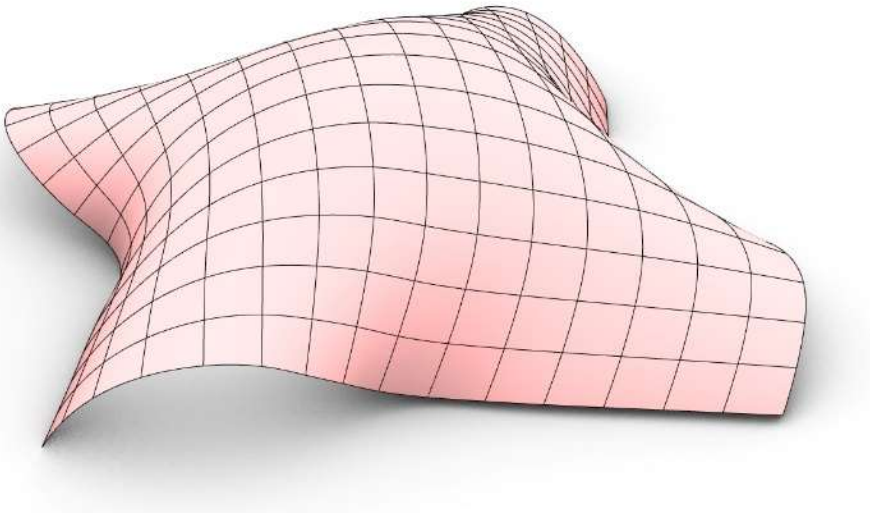
Designing the gridshell

Cross-section design and application



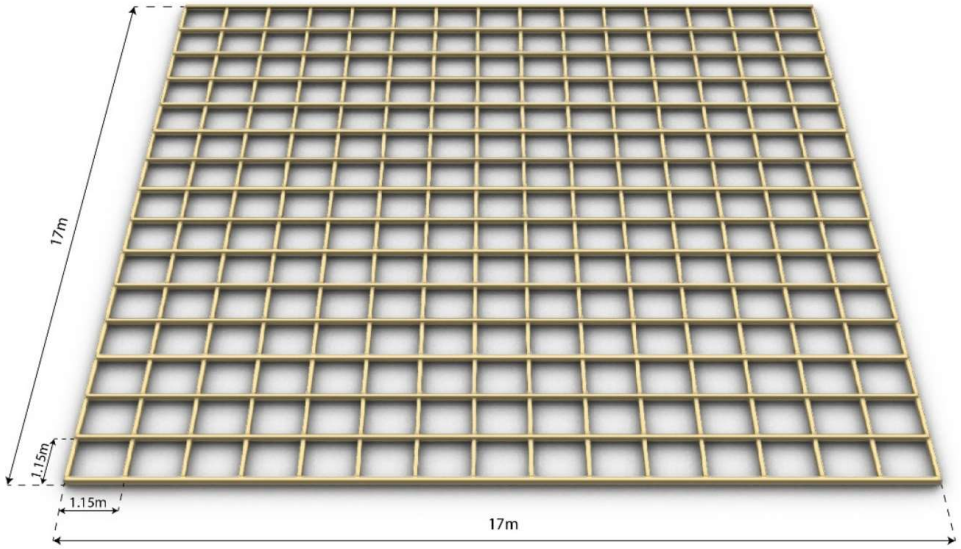
The cross-section design utilizes double-layer lath system

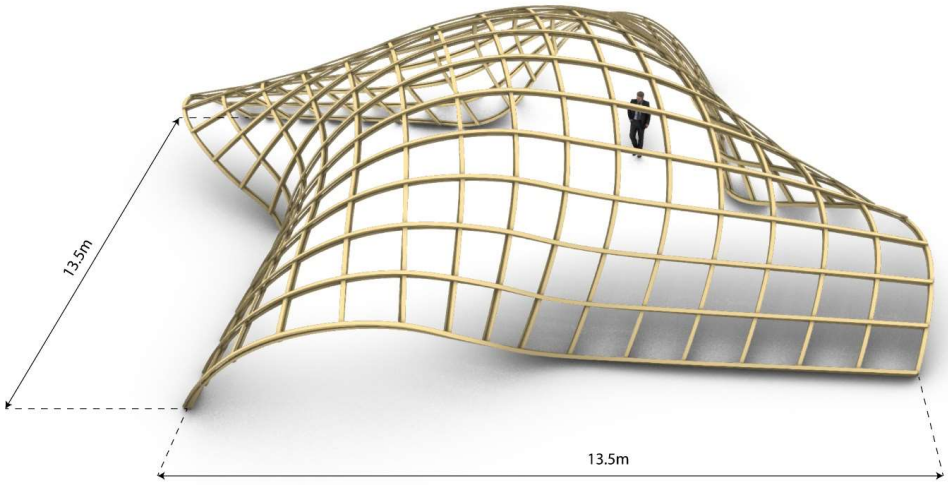




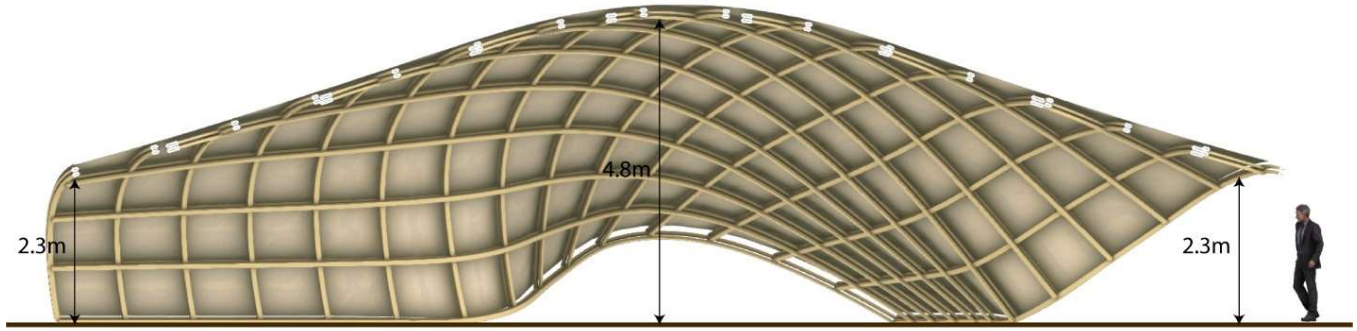
The cross-section was aligned to the local planes of the surface and lofted

The flat grid pushed inwards

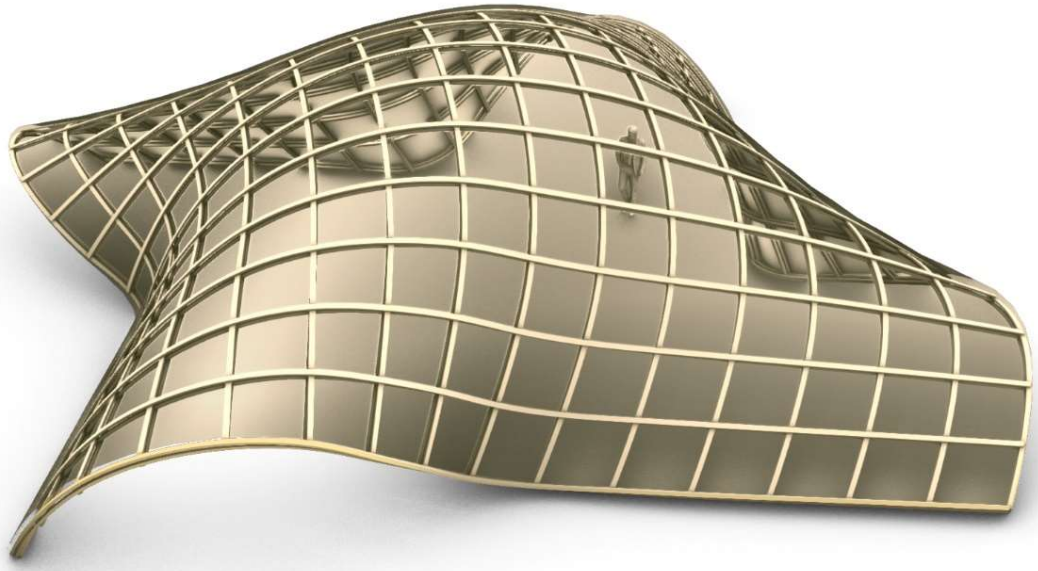




The panelization is placed on top of the structure

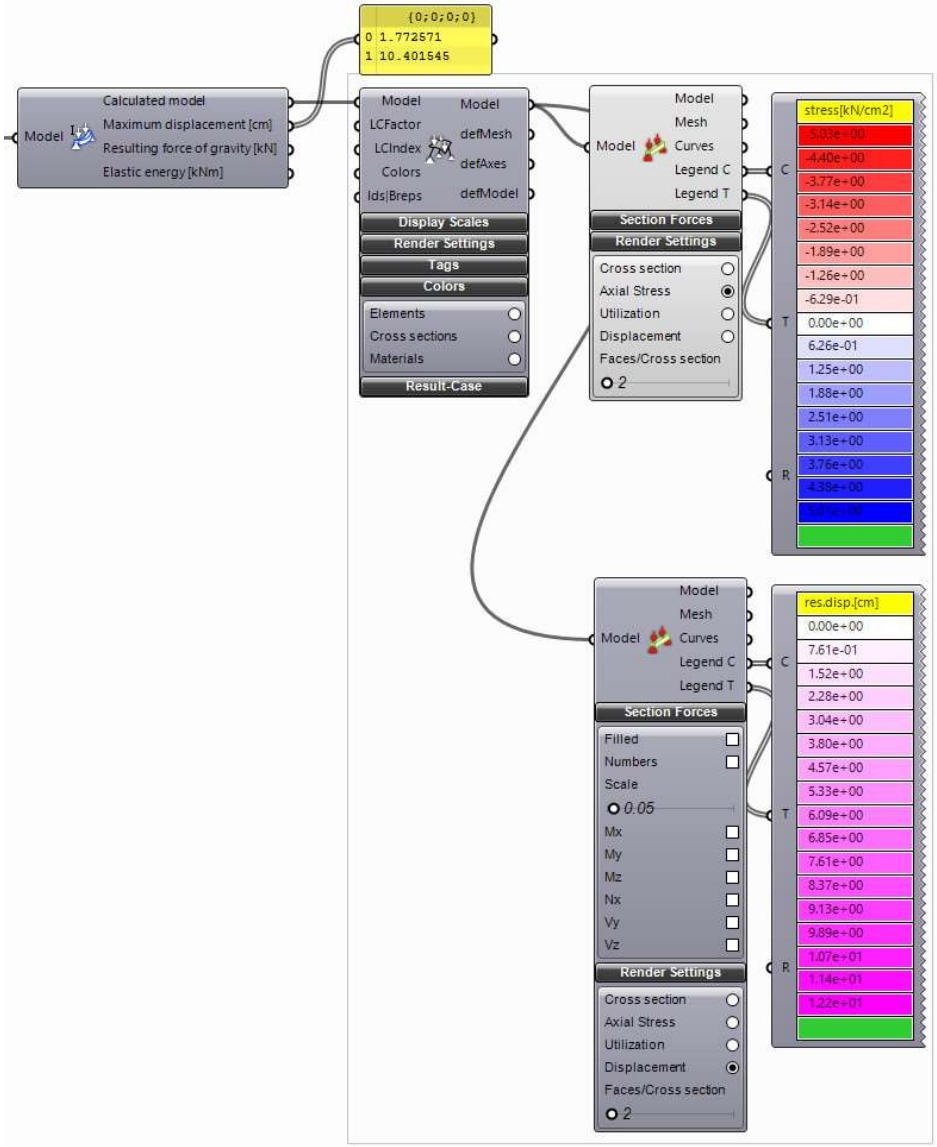


Section

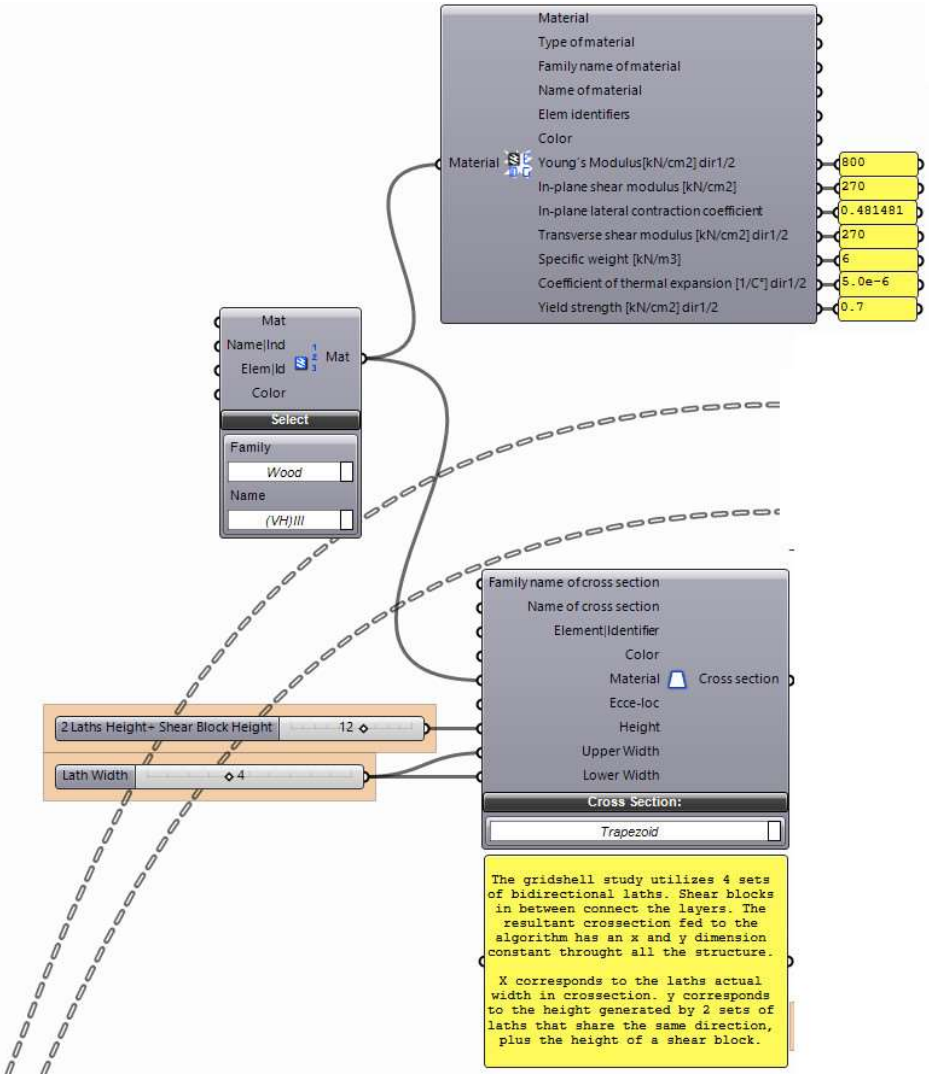


Final Model with freeform cladding surface

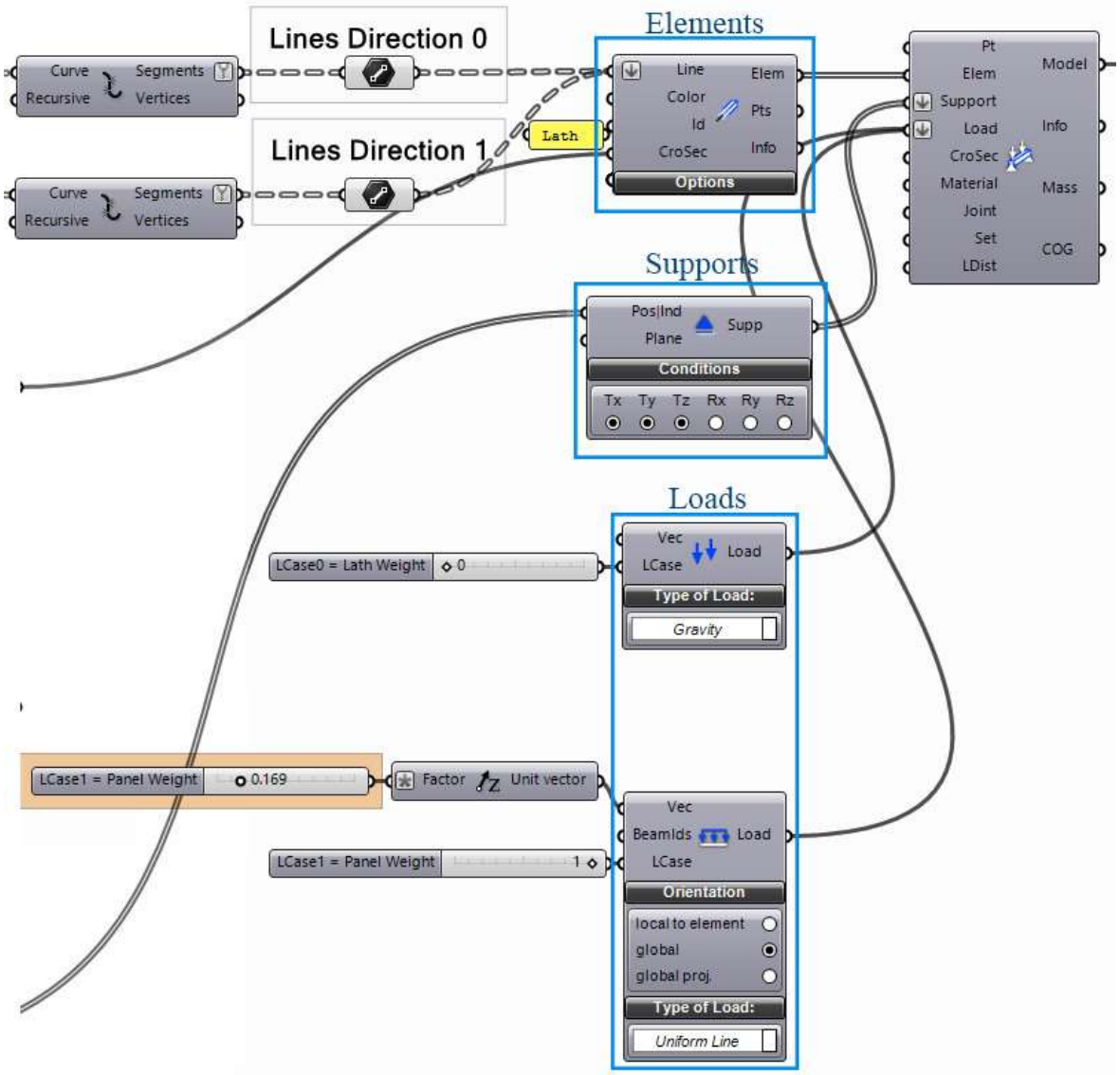
Structural Analysis



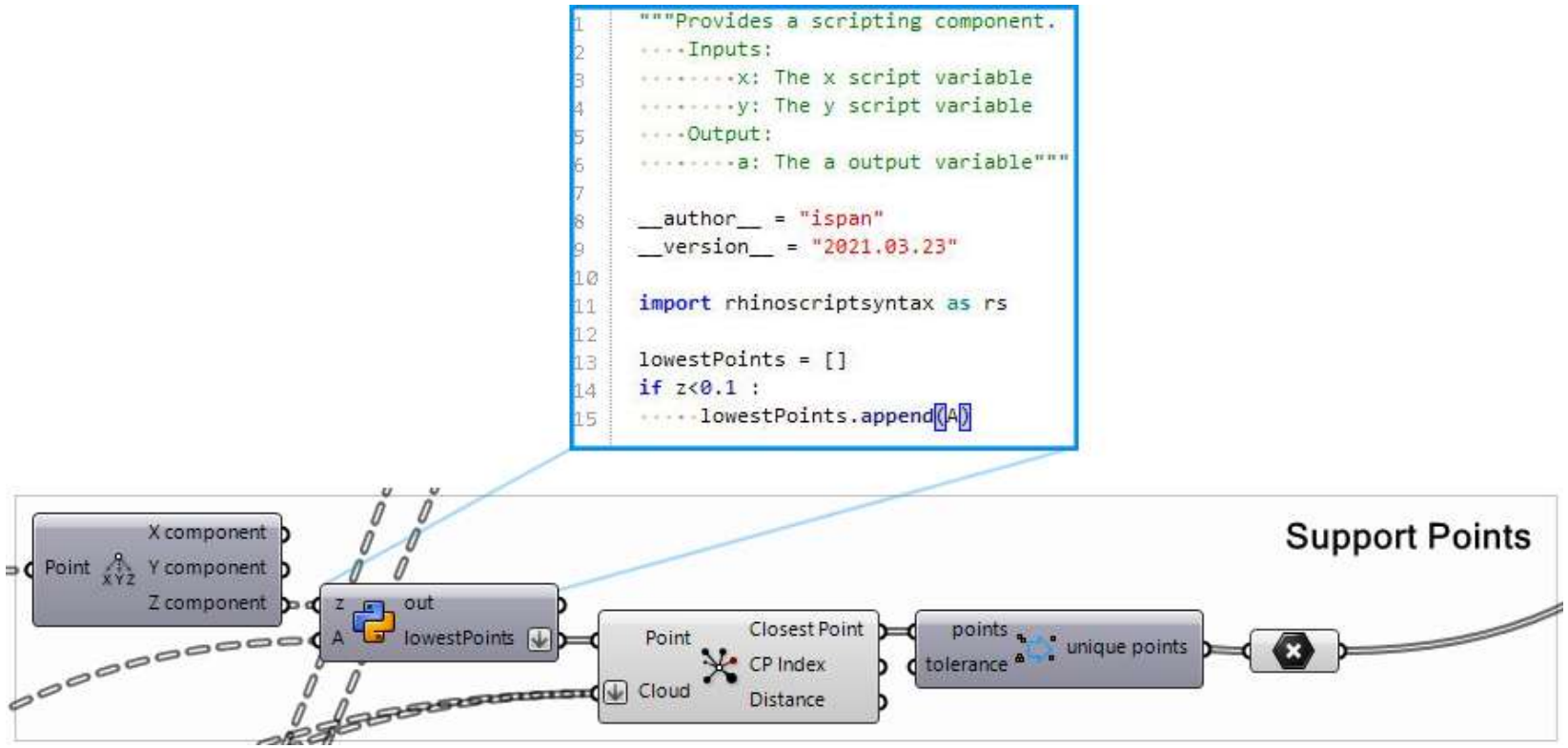
Calculation of Displacement and Axial Forces



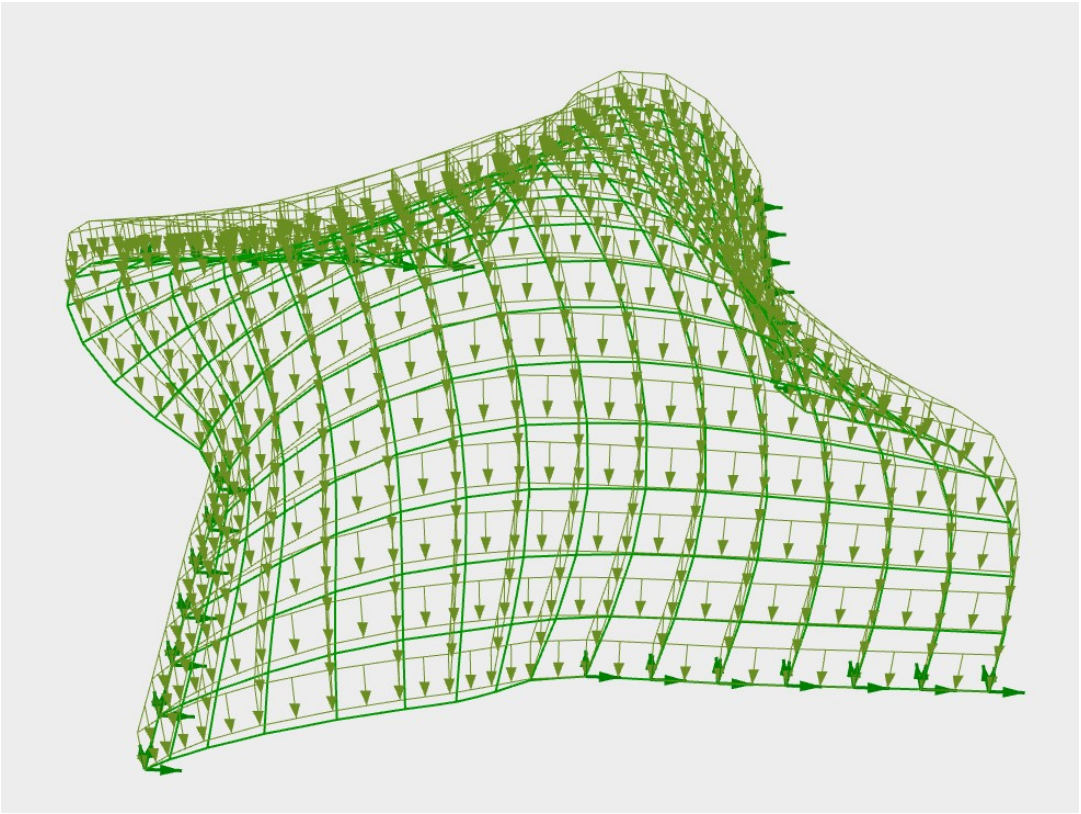
Wood Material from Karamba Library

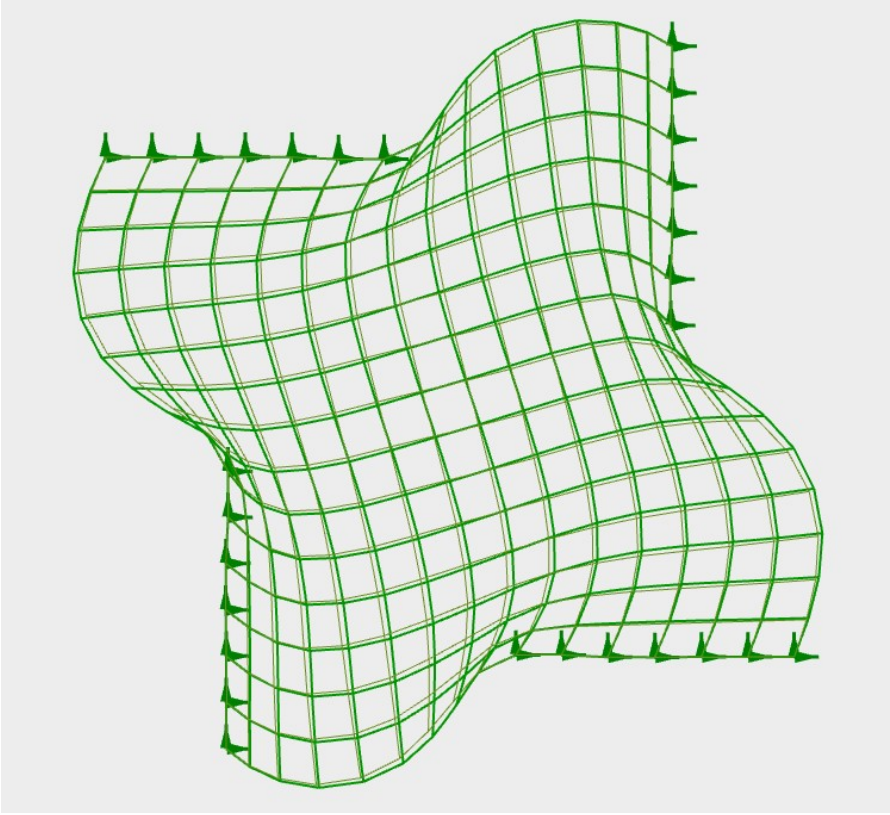


Assemble Model component

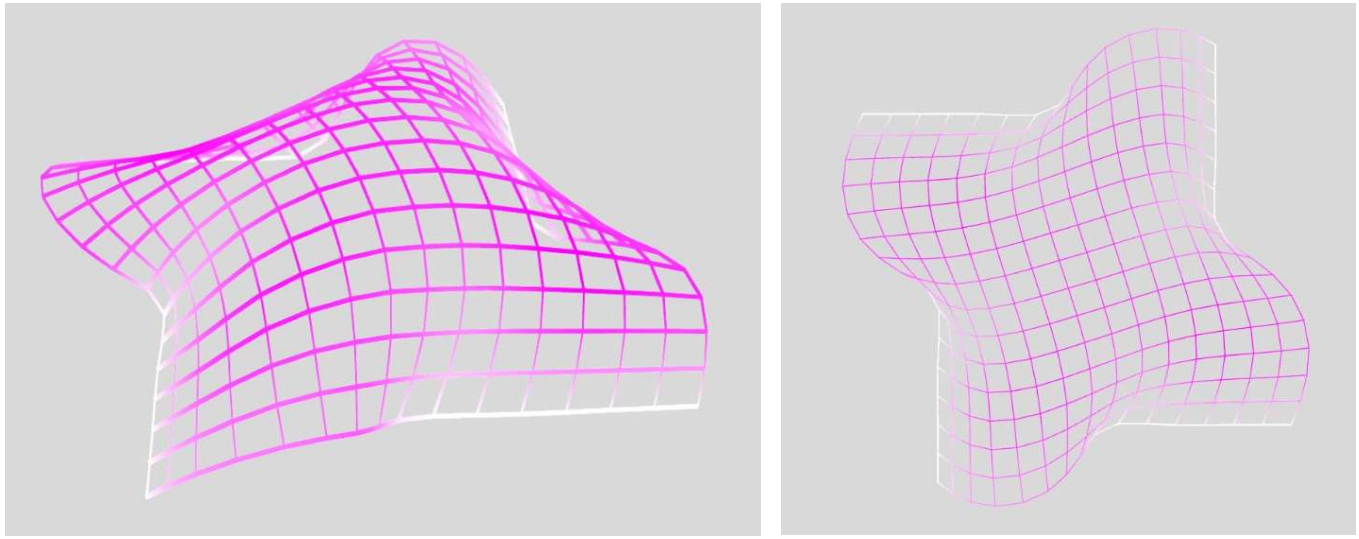


The Supports are defined by a GH Python script

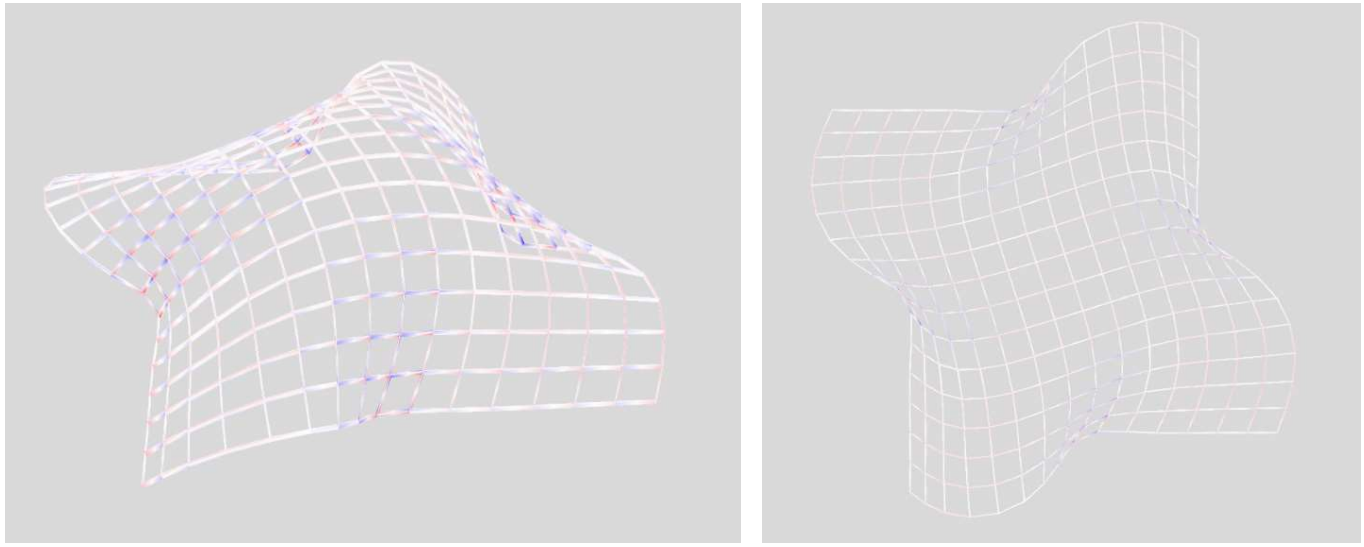




The Elements, Supports and Loads



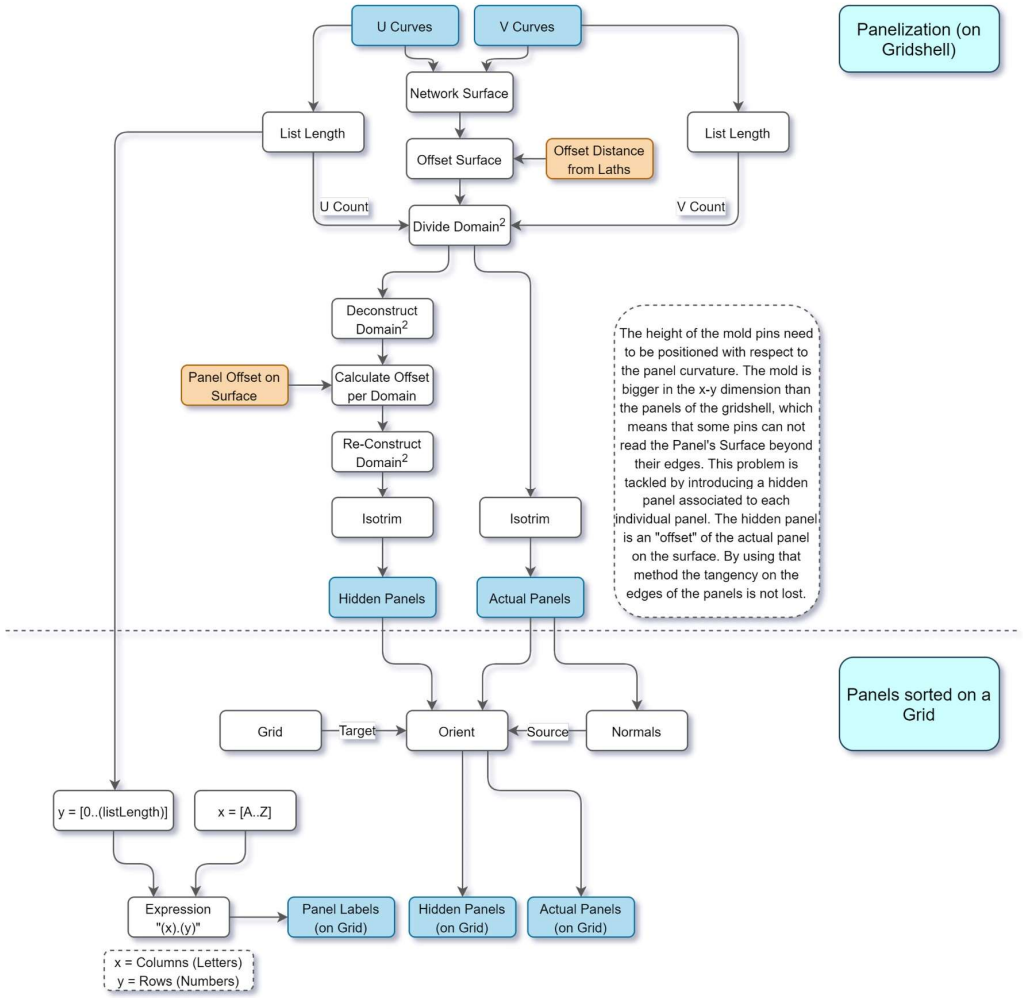
Deformation



Axial Forces

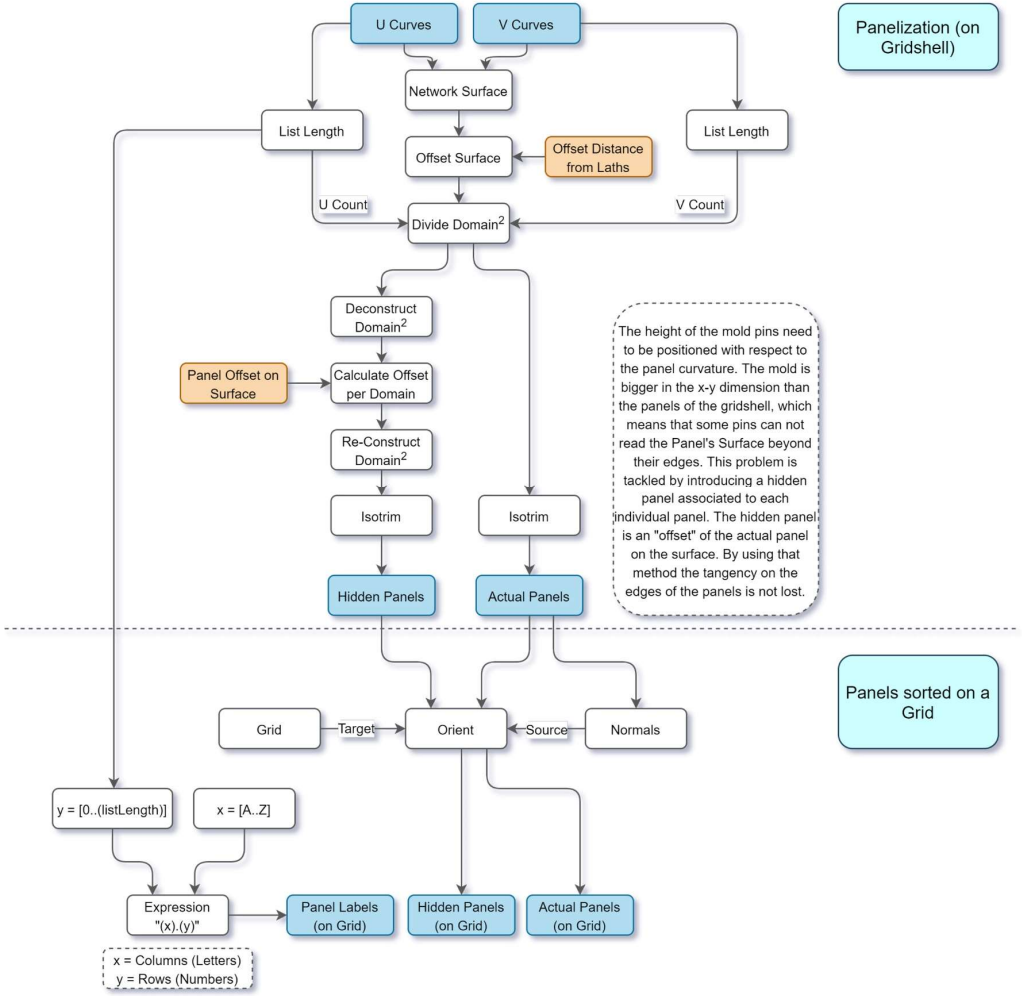
Panelization | Rotational correction

Panelization

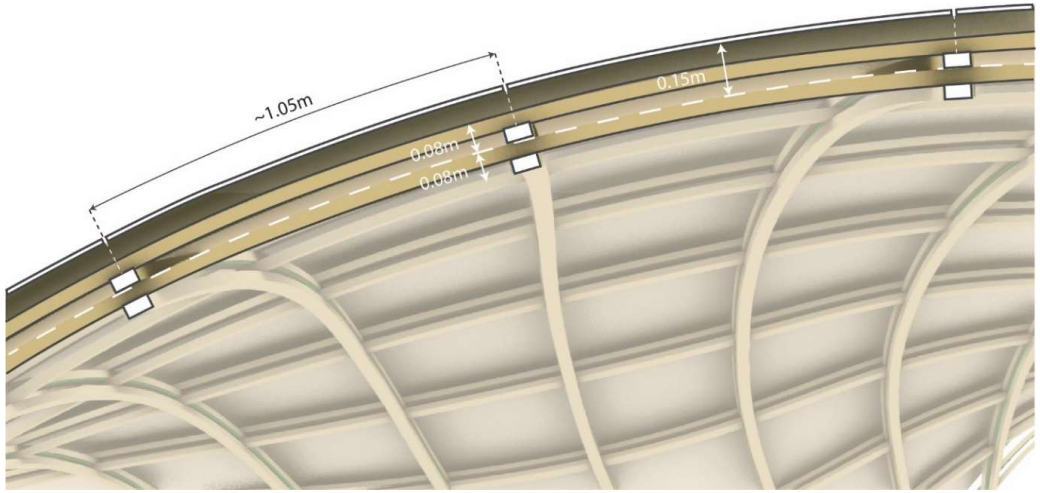


Flowchart

Panelization

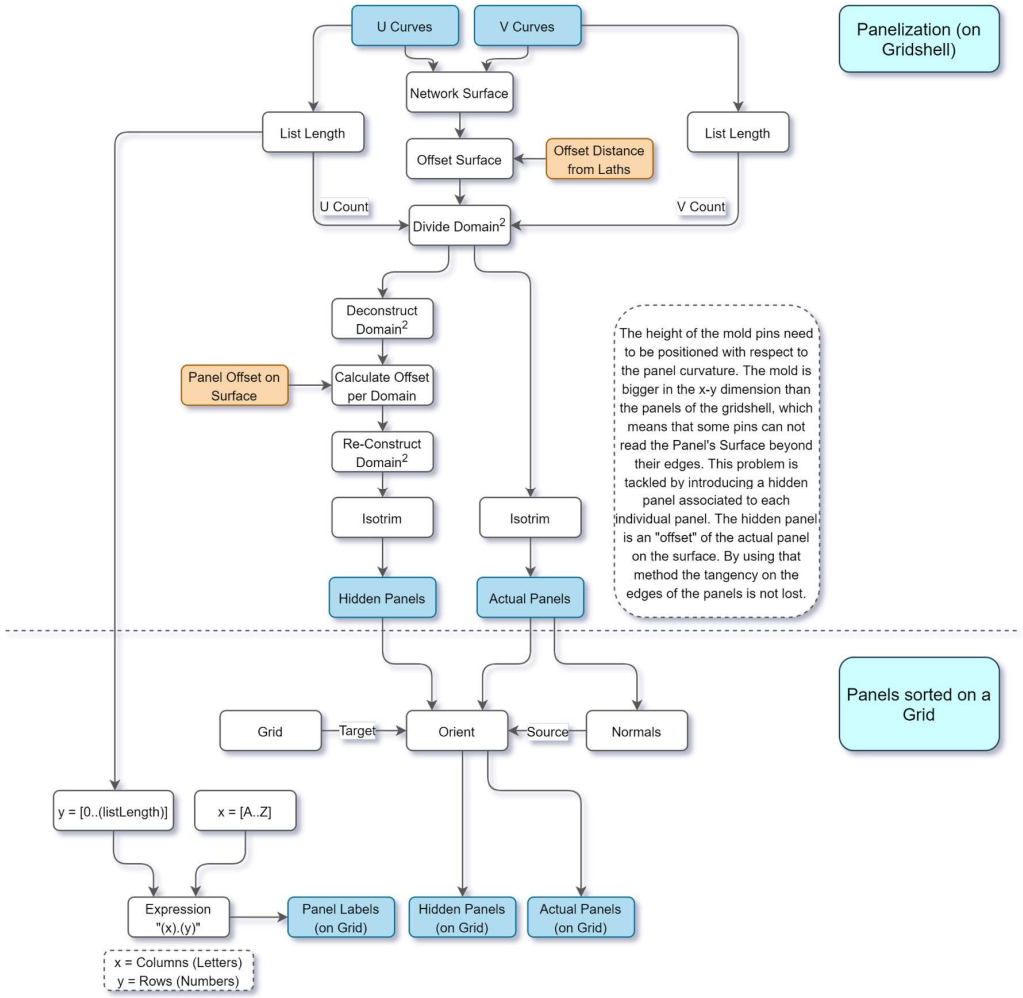


Flowchart

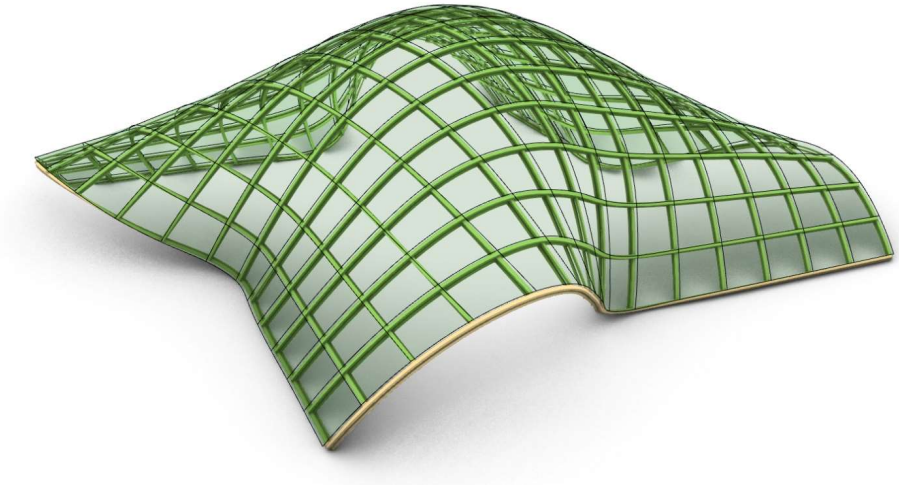


Panelization lines and dimensions

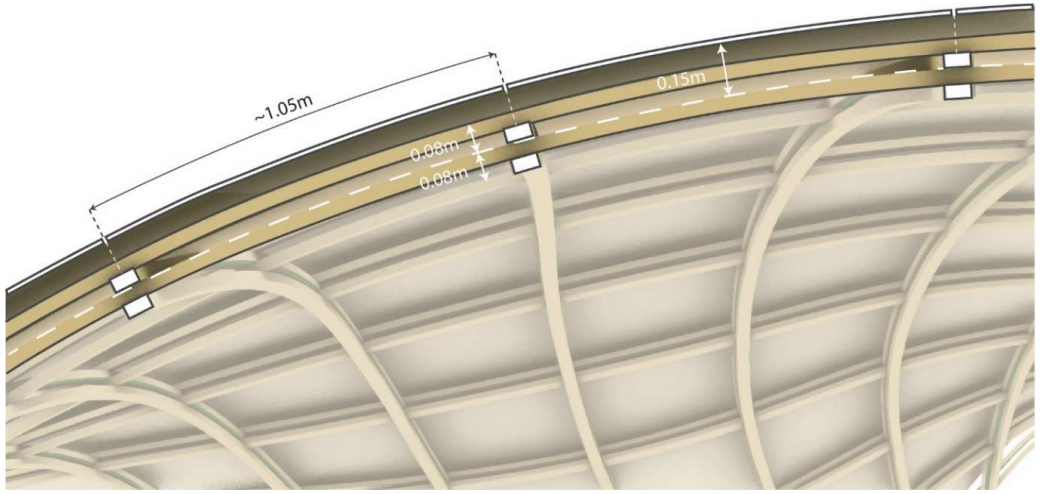
Panelization



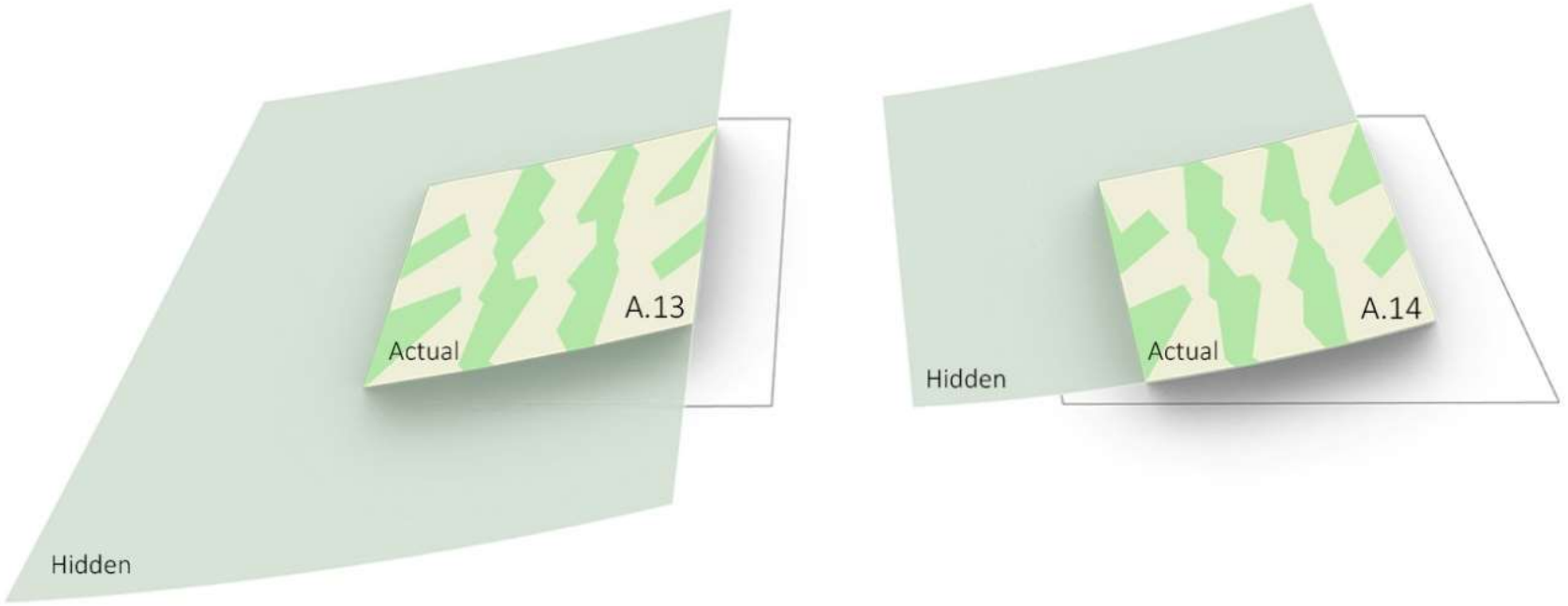
Flowchart



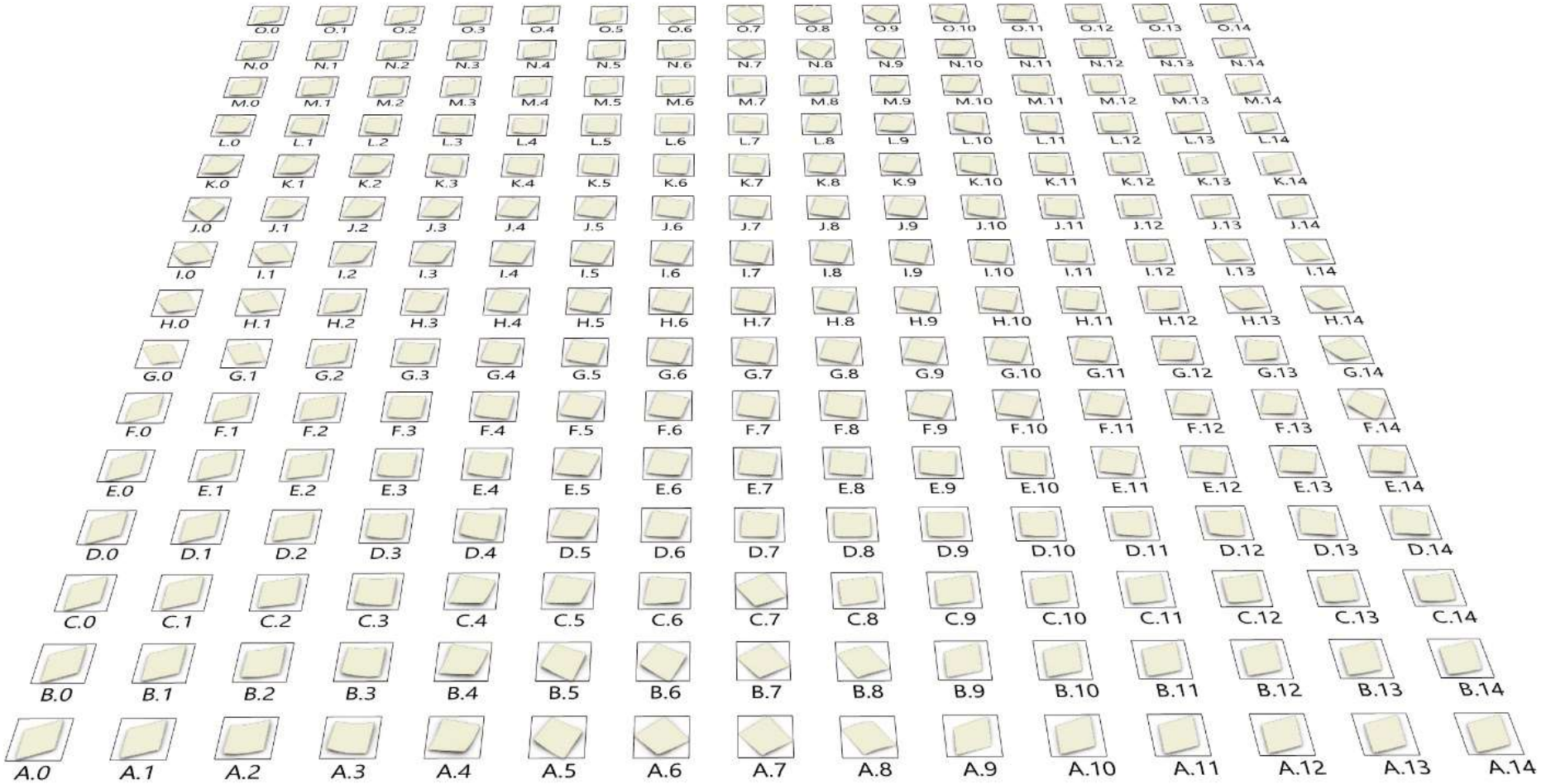
Panel network | Lath network



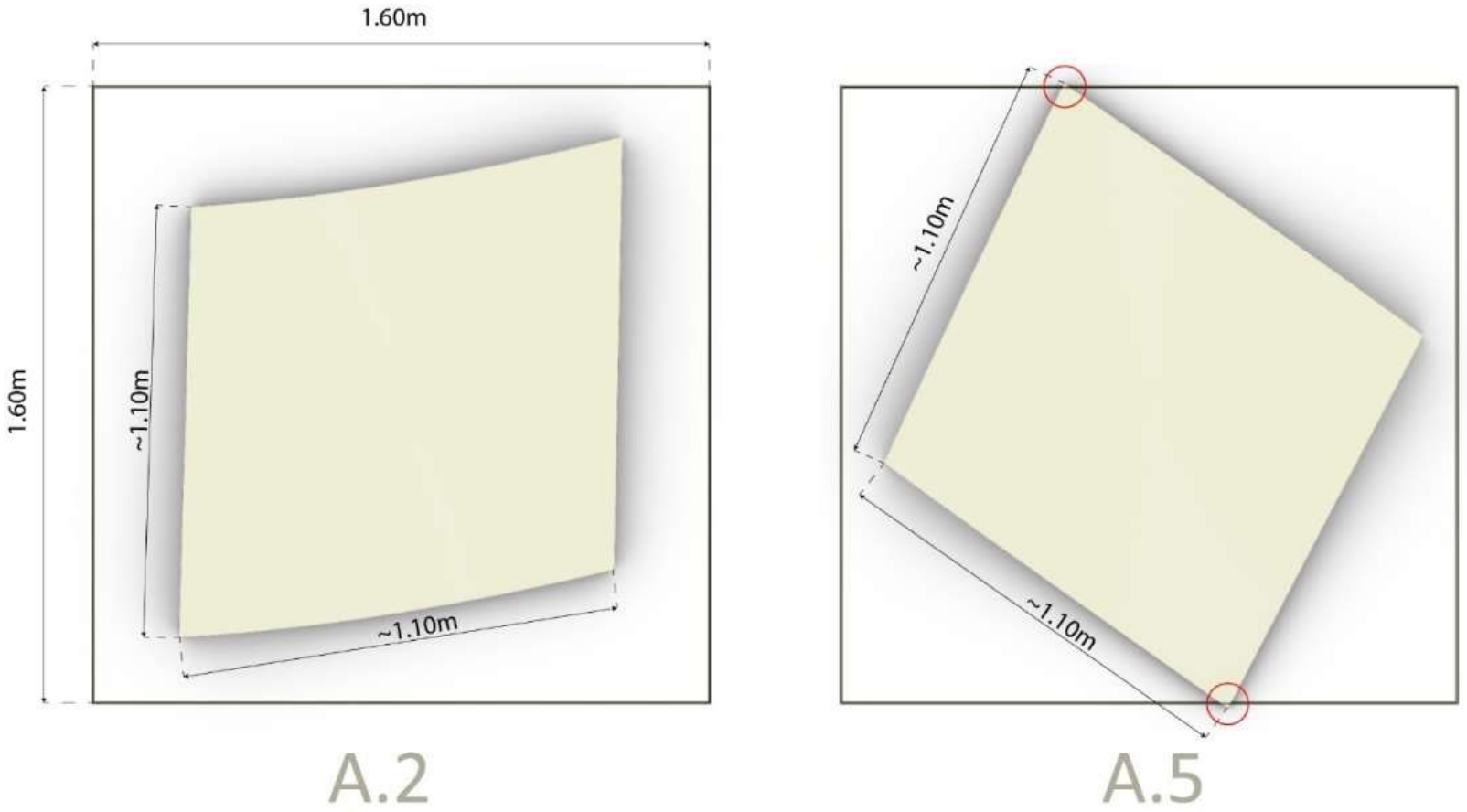
Panelization lines and dimensions



Actual and Hidden Panels



Labelled Panels

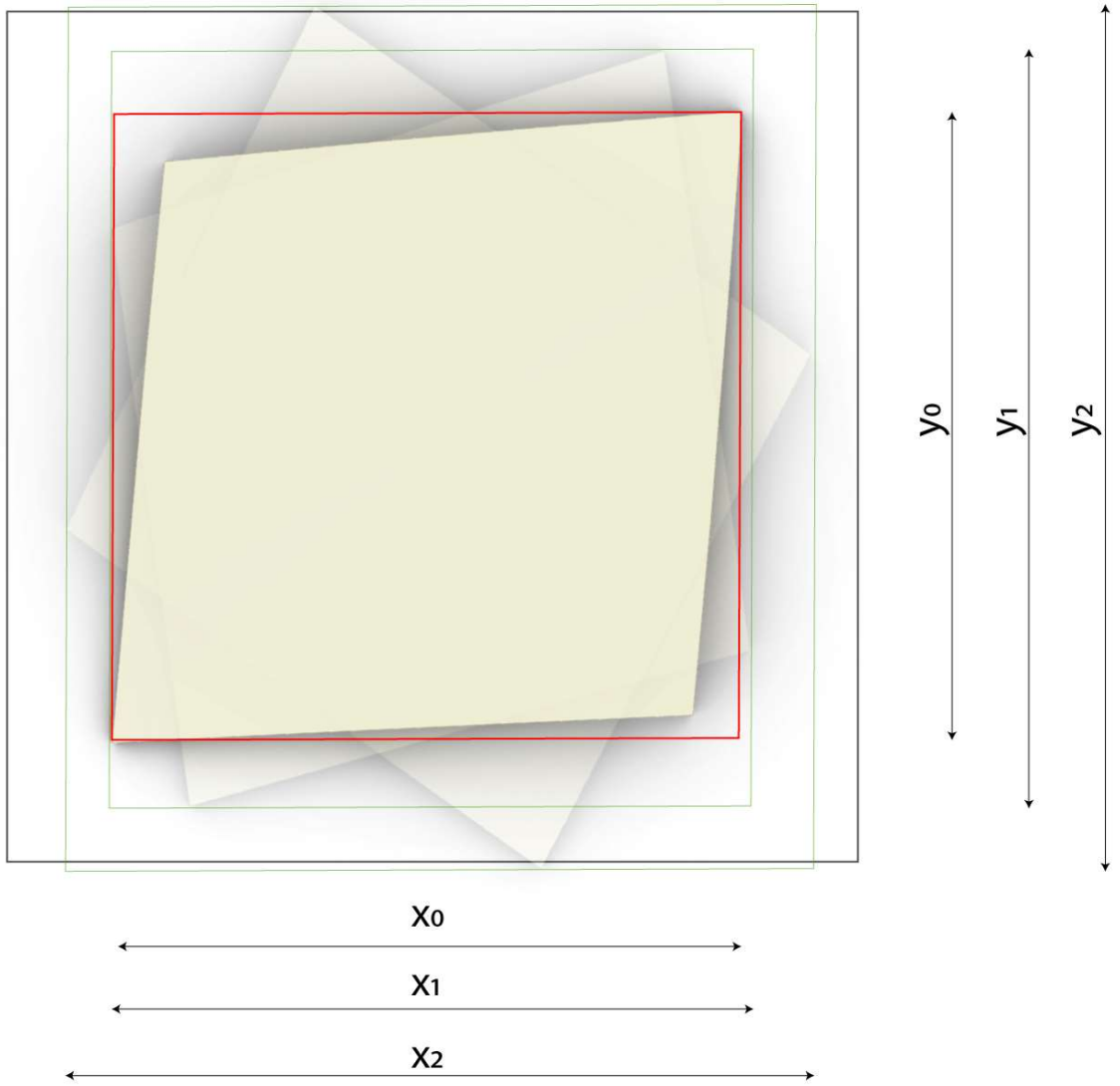


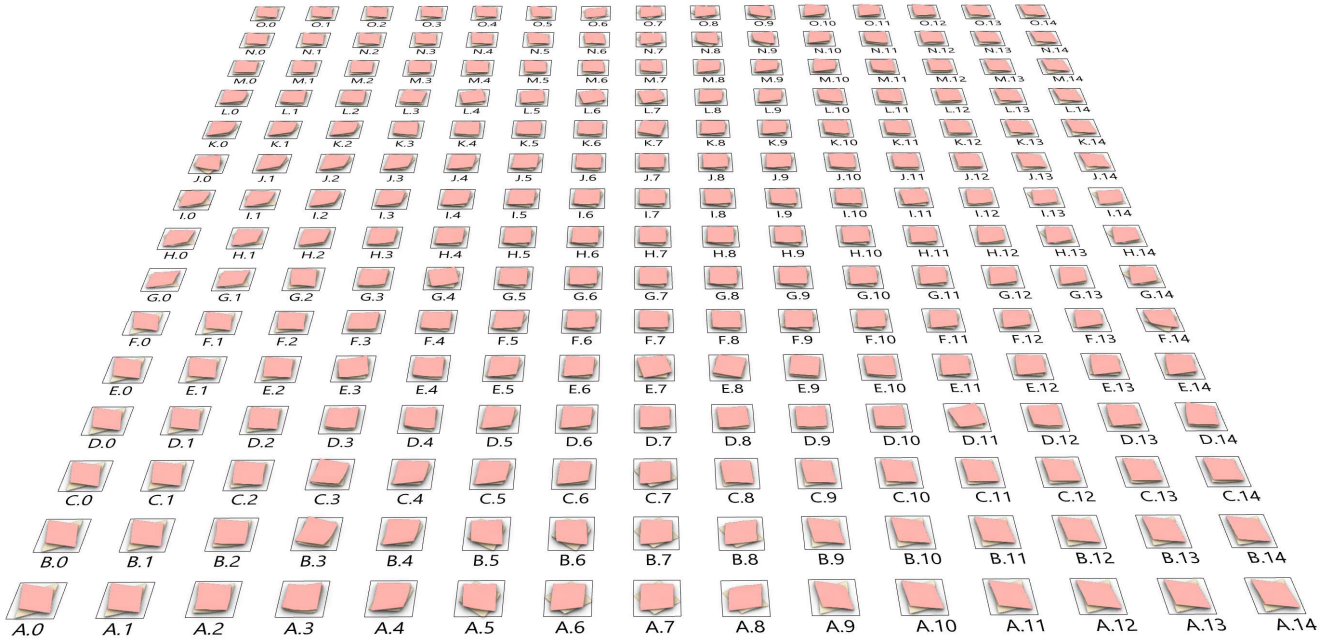
Some Panels require rotational correction

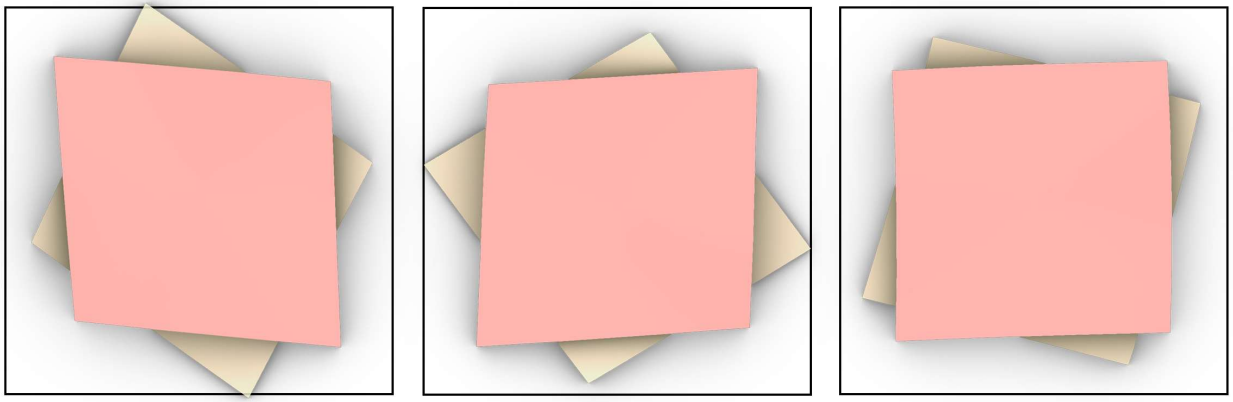
The algorithm corrects the panels in 2 phases:

1. Bounding Box (red line) is square

2. Bounding Box perimeter is smaller than a number



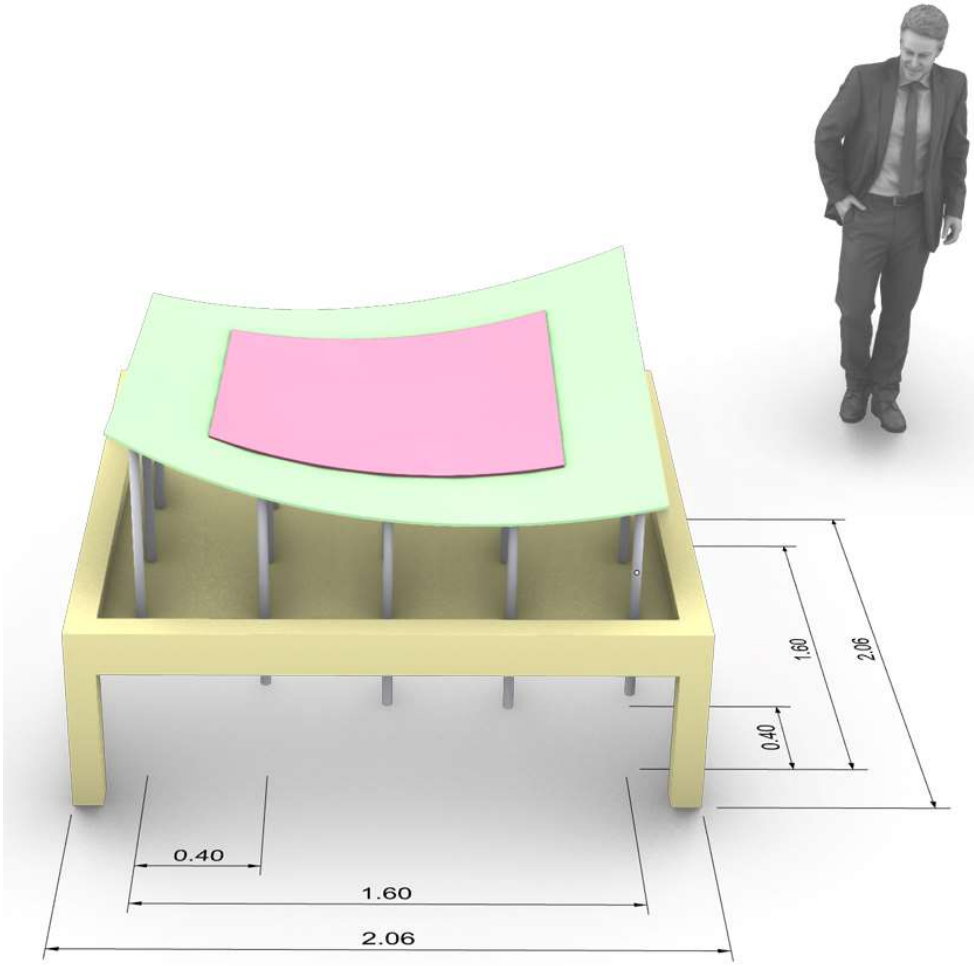




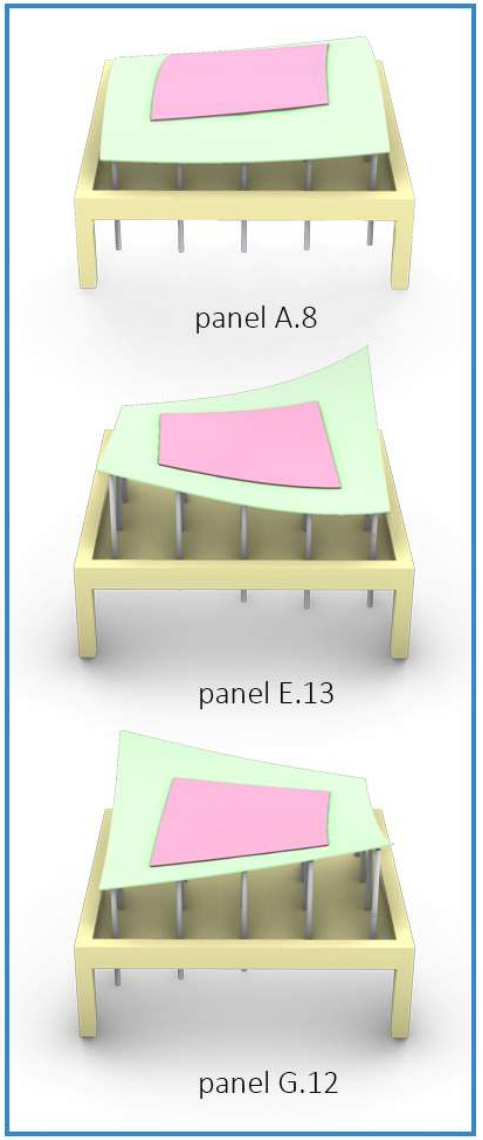
A.5 B.7 J.8

Correctly rotated panels

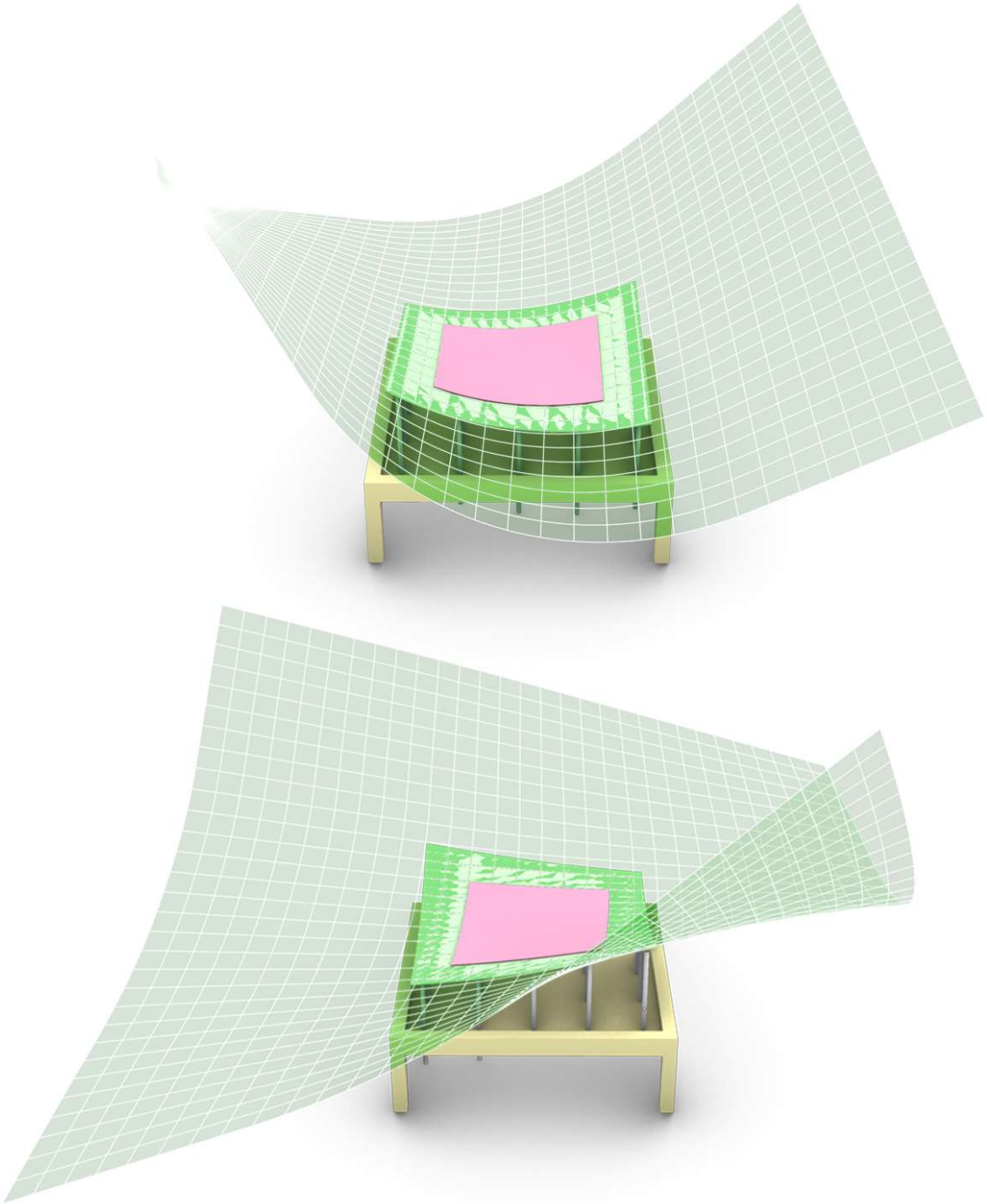
The digital Re-De-Form



panel A.3

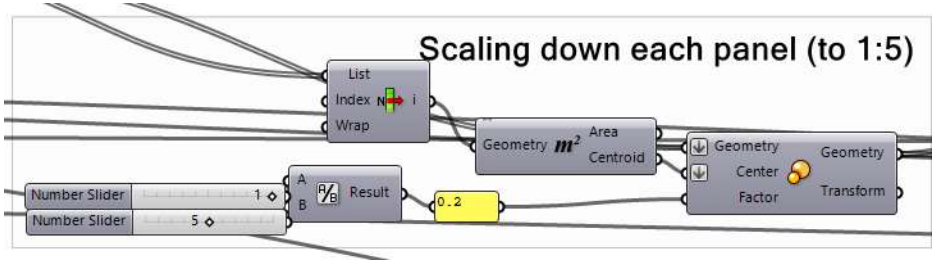


The digital Re-De-Form (5x5pins)

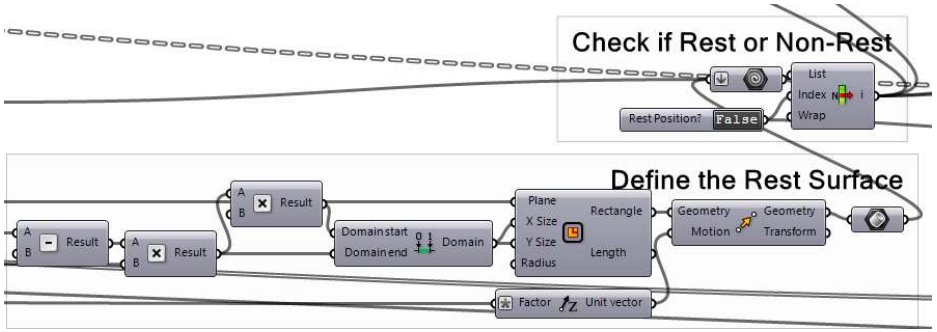


U and V extensions

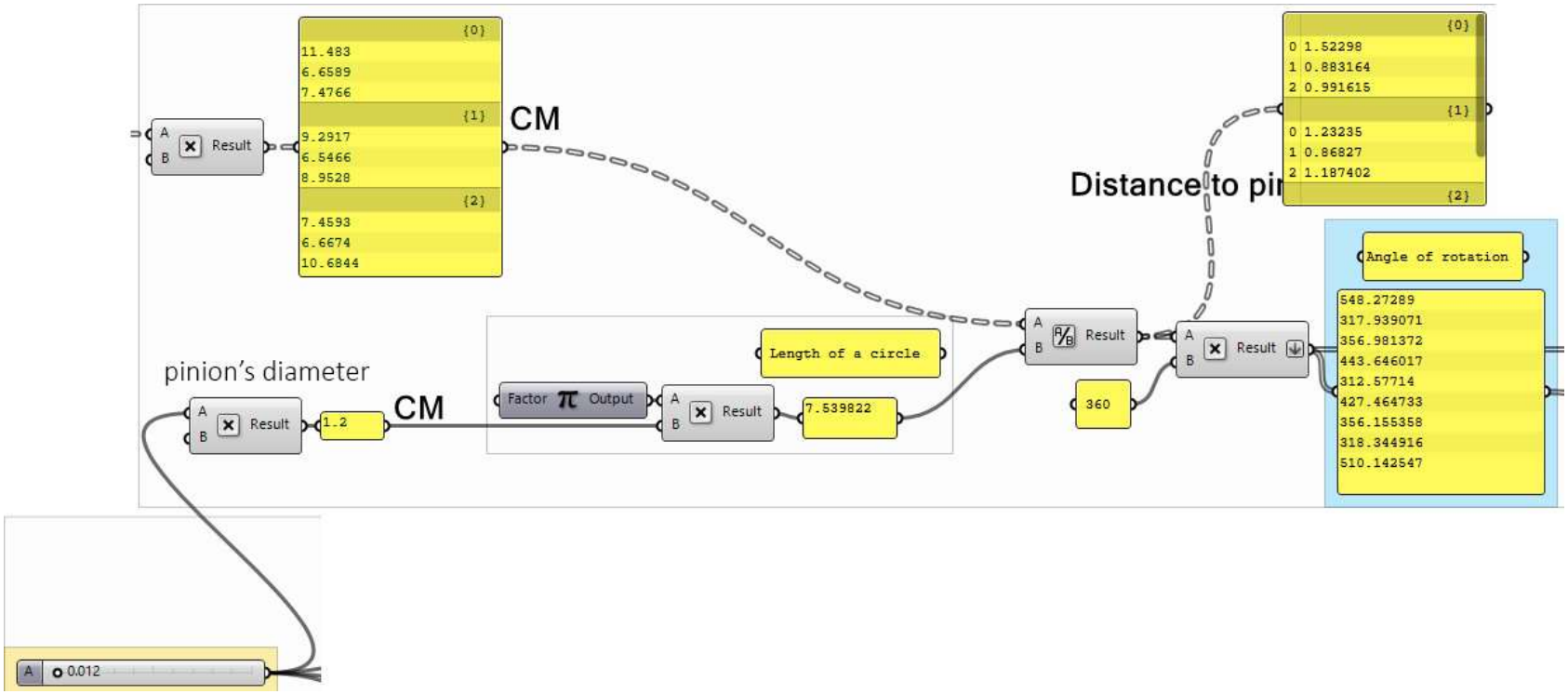
3x3 pin digital Re-De-Form



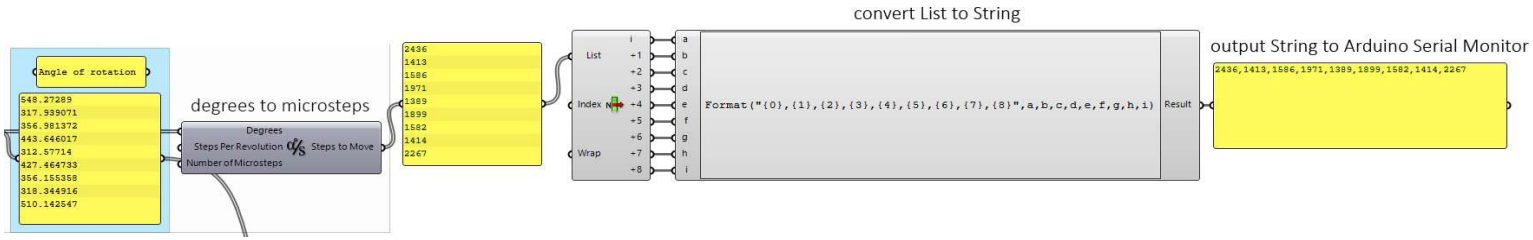
Scale the panels



Home the Pins through Grasshopper

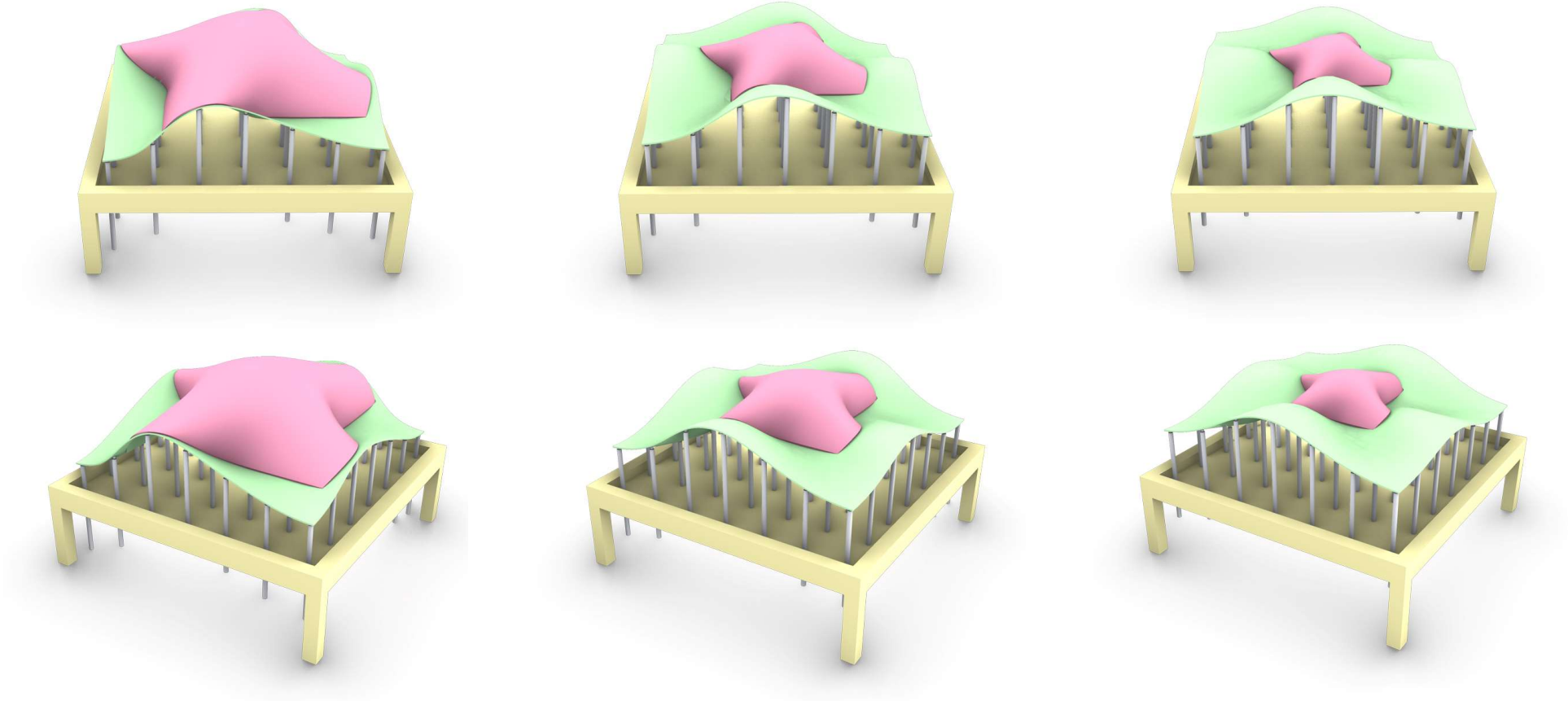


Angles of rotation



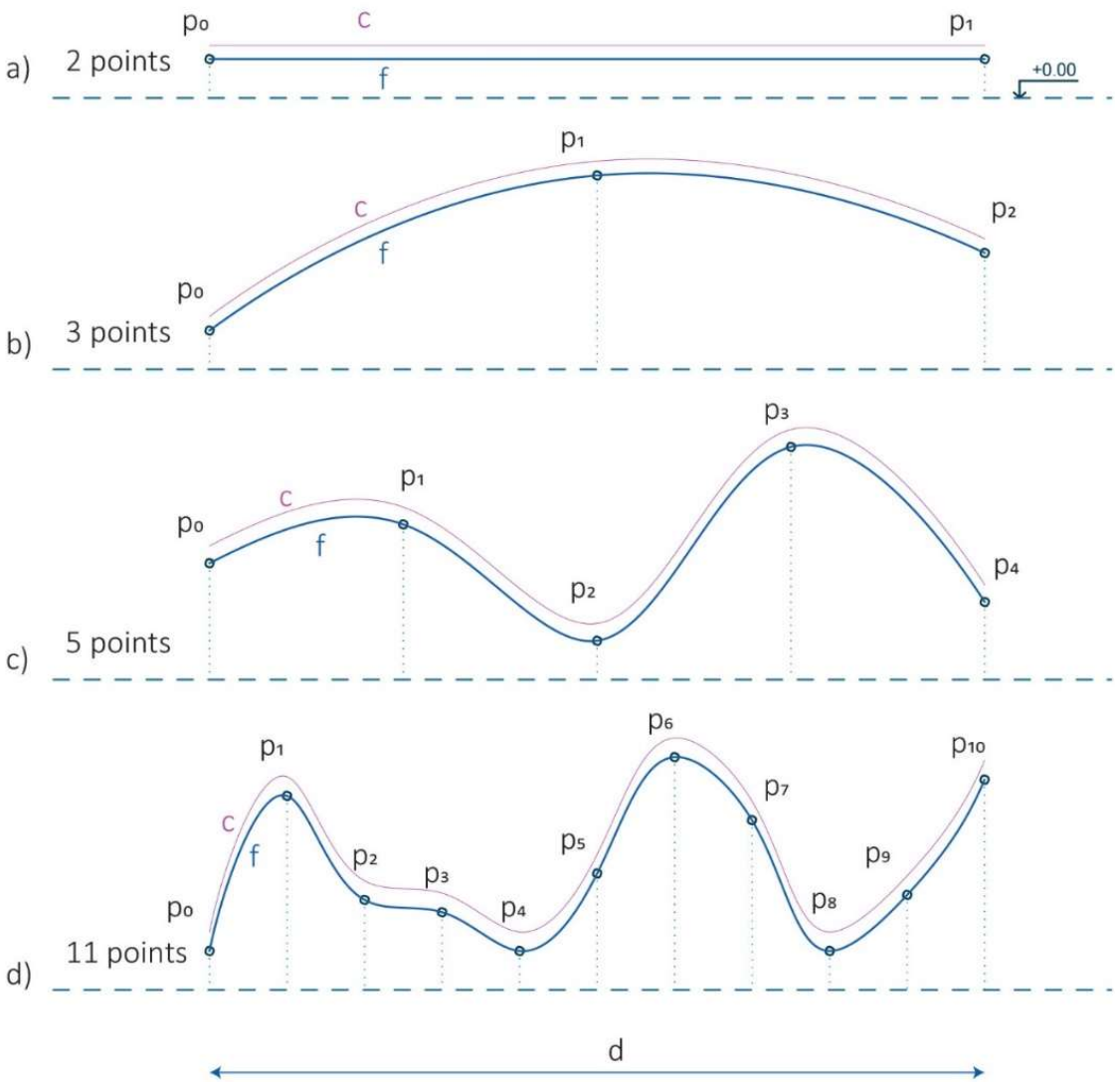
String to Serial Monitor

Physical Modelling

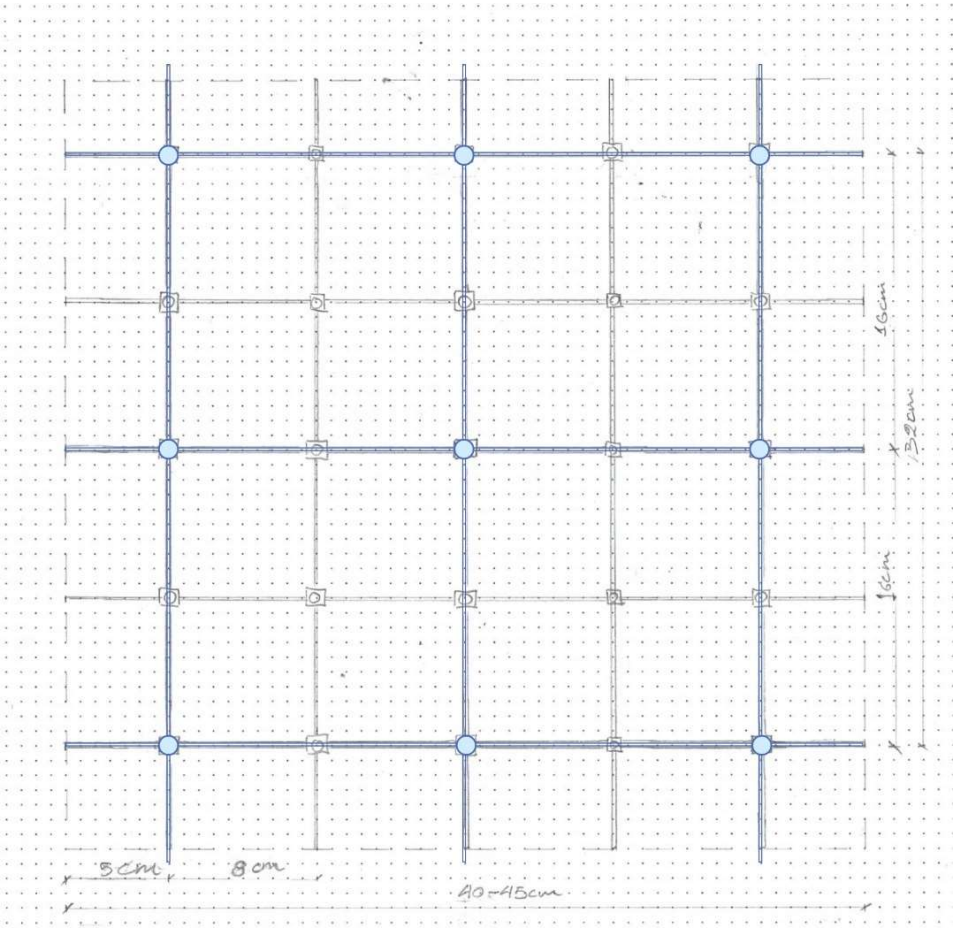


1:10 1:15 1:20

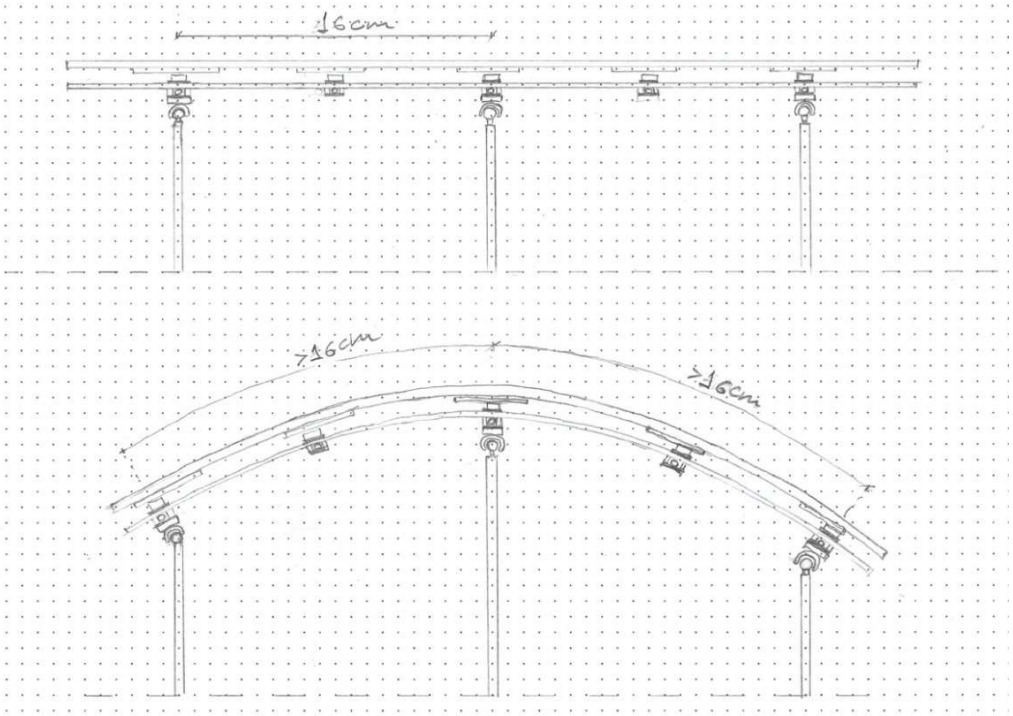
The Re-De-Form prototype



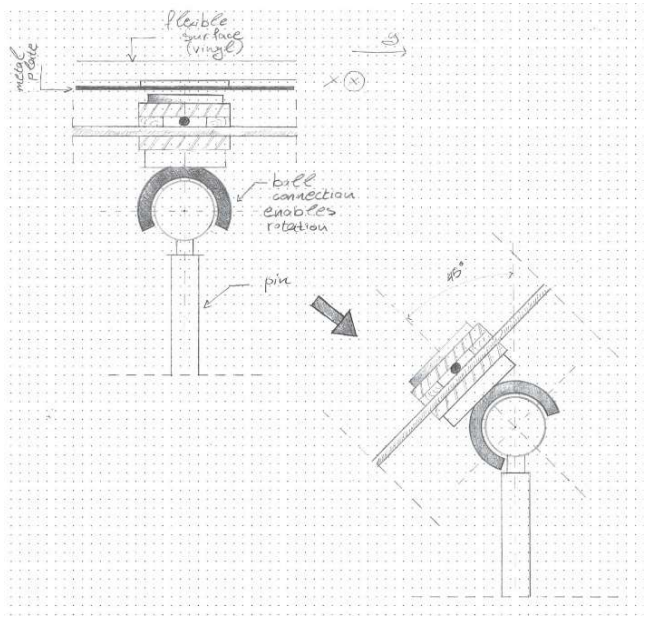
Re-De-Form surface | Freeform surface



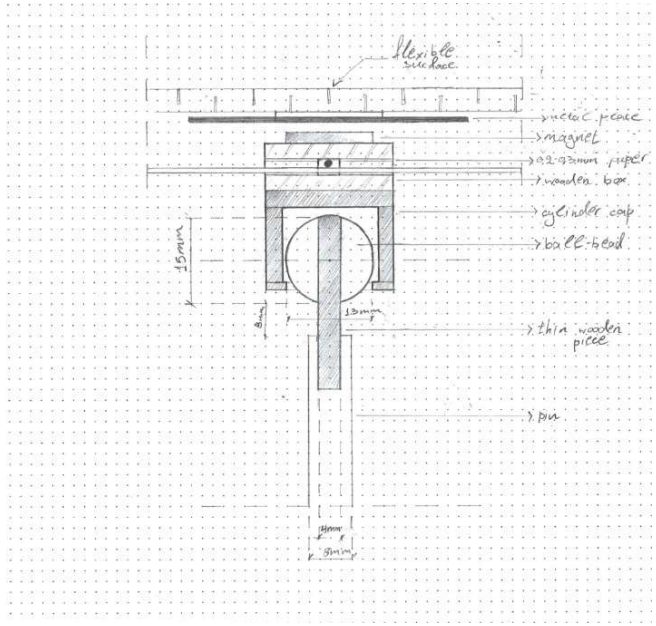
Re-De-Form grid. Top View

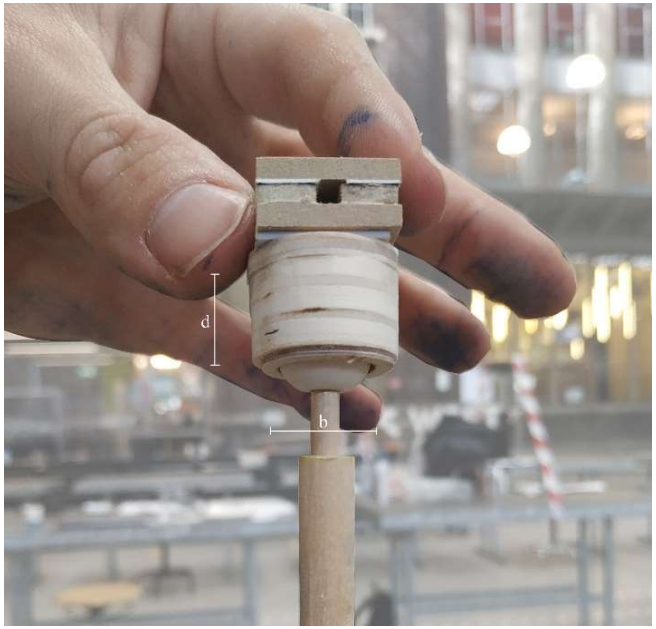


Re-De-Form in Section

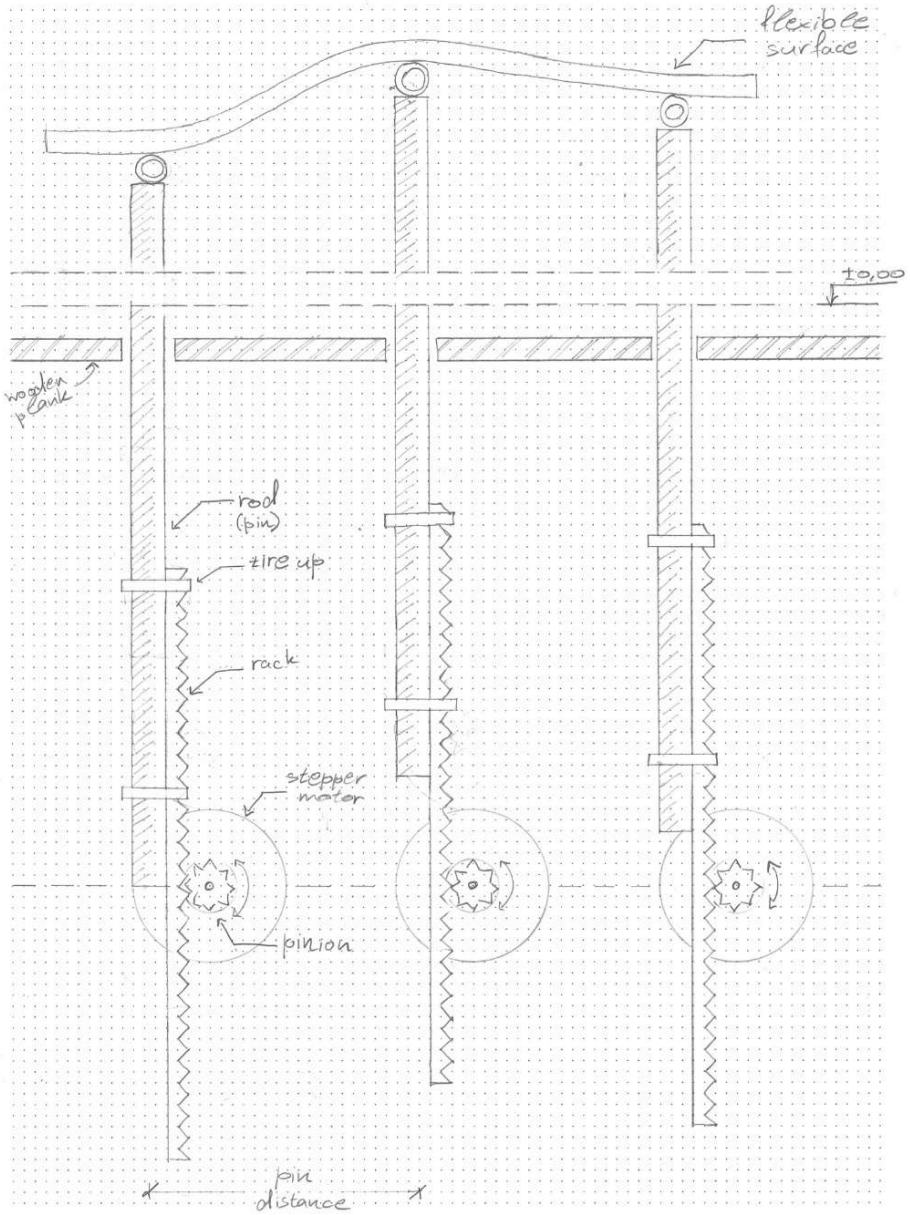


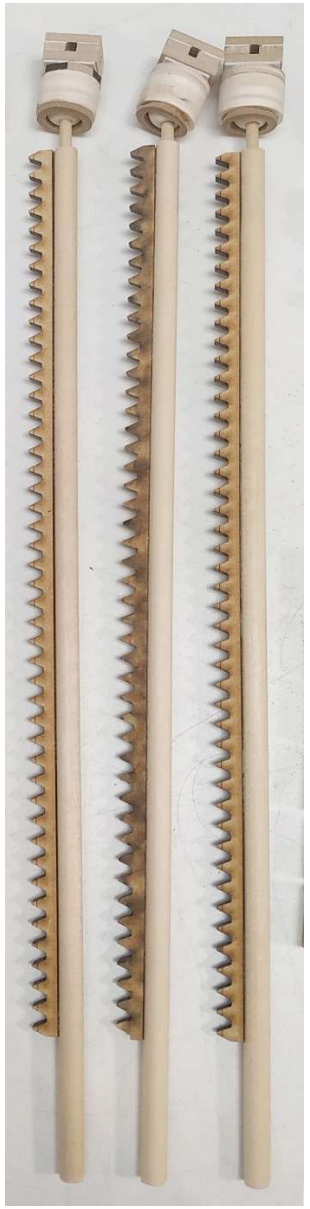
Draft Ball connection





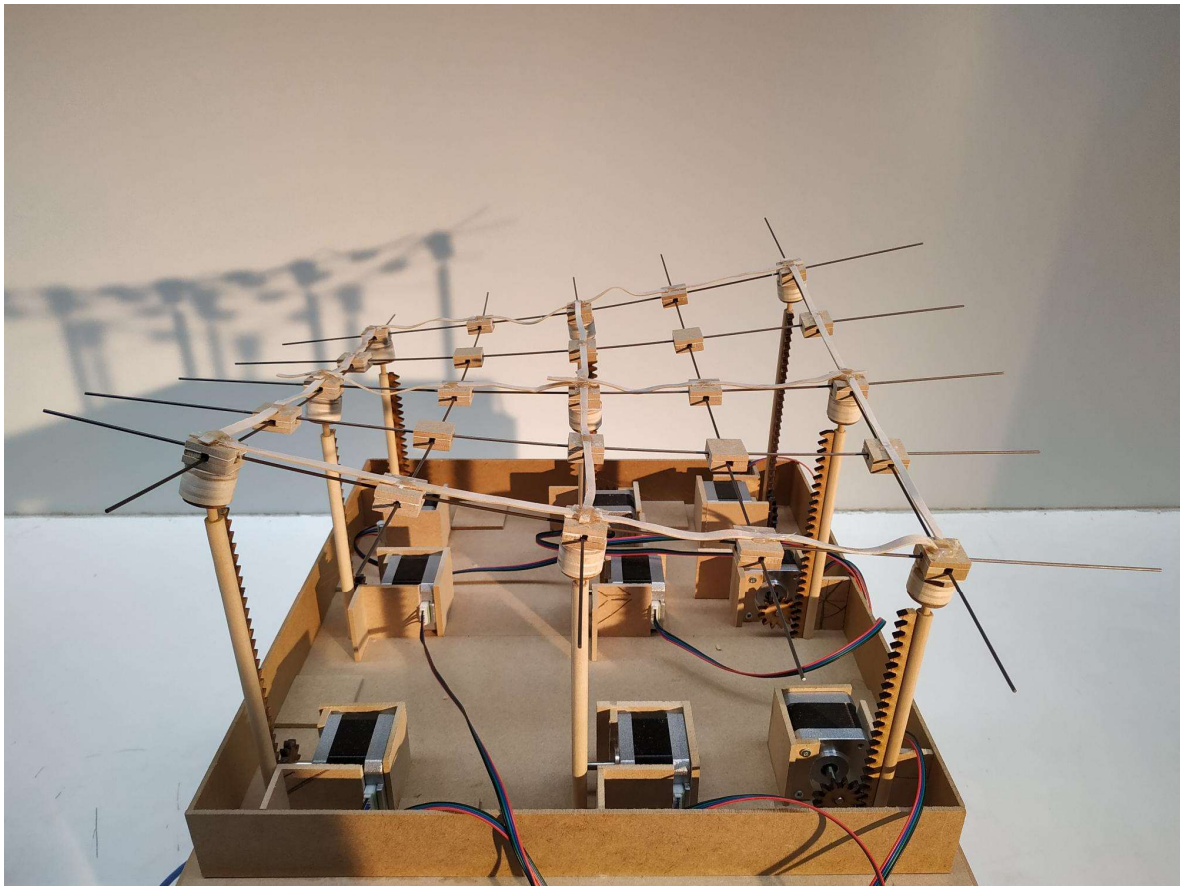
Final Ball connection





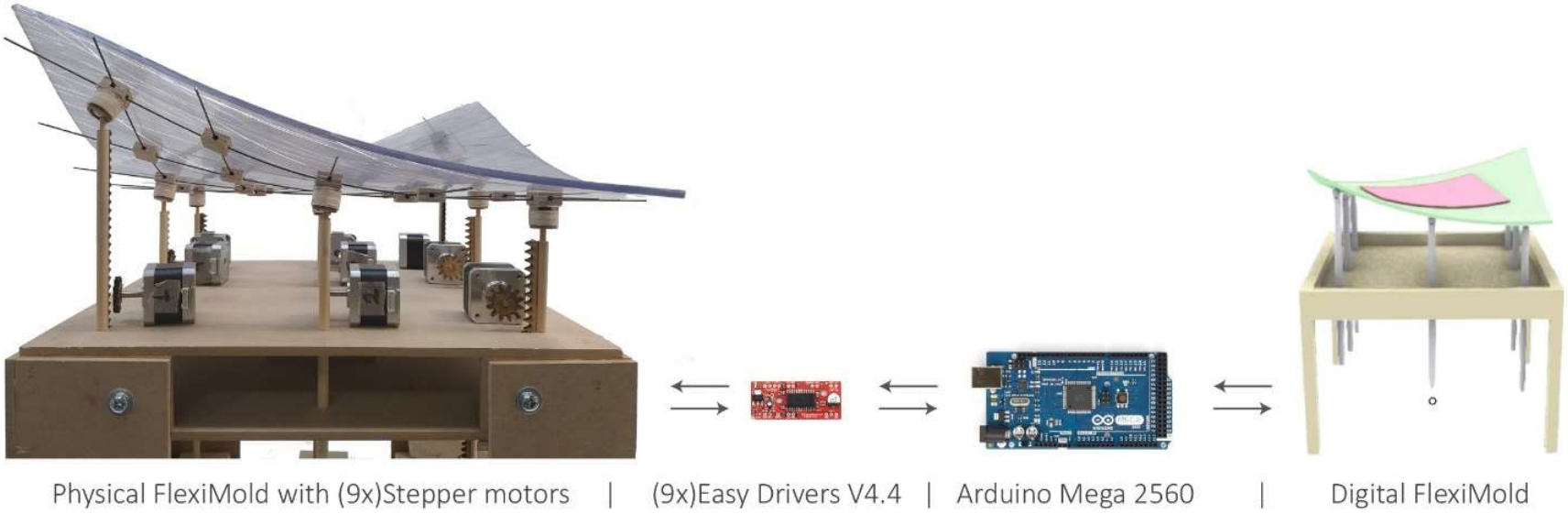
The actuator system

The formwork without rubber bands

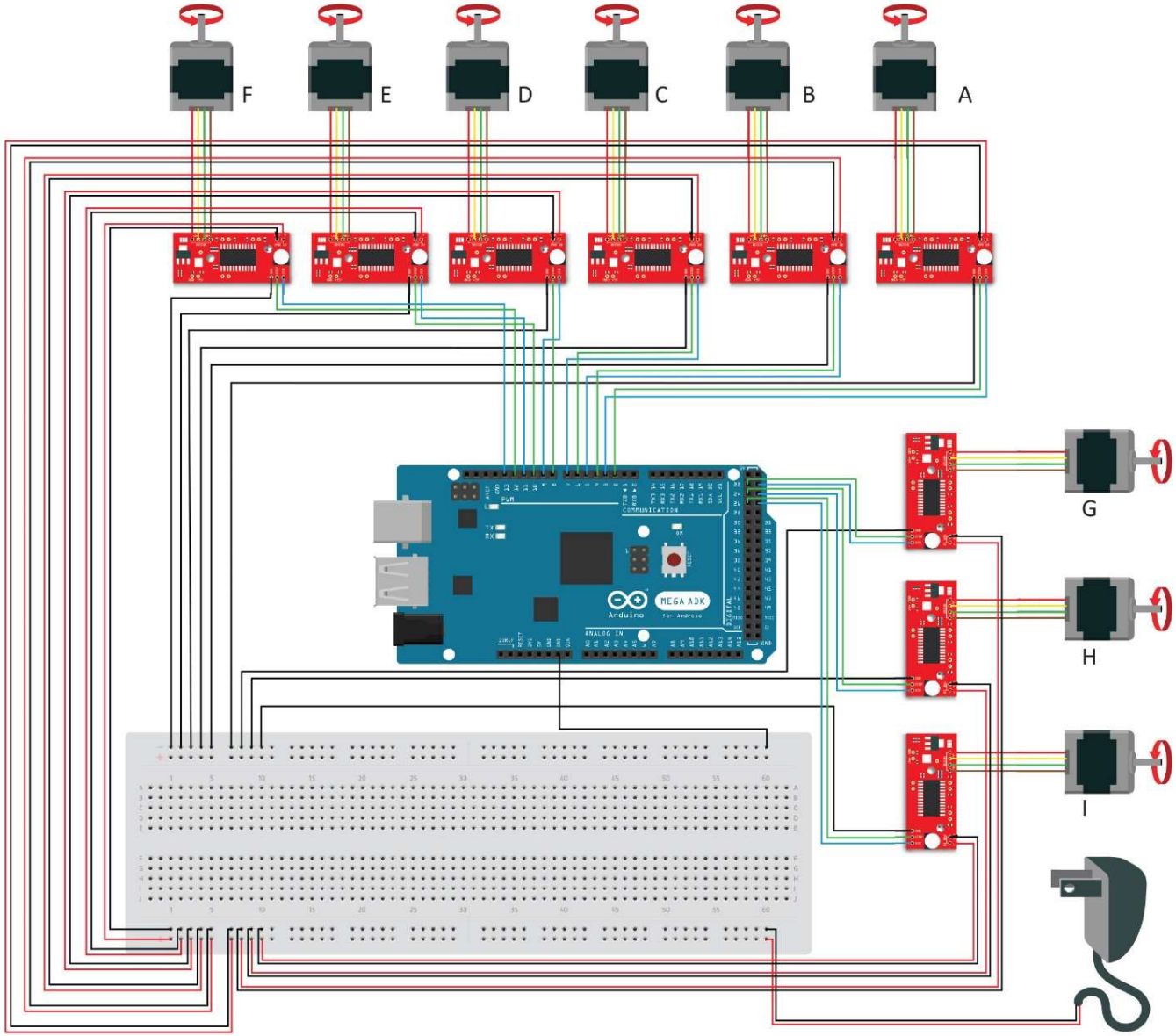


The formwork with rubber bands

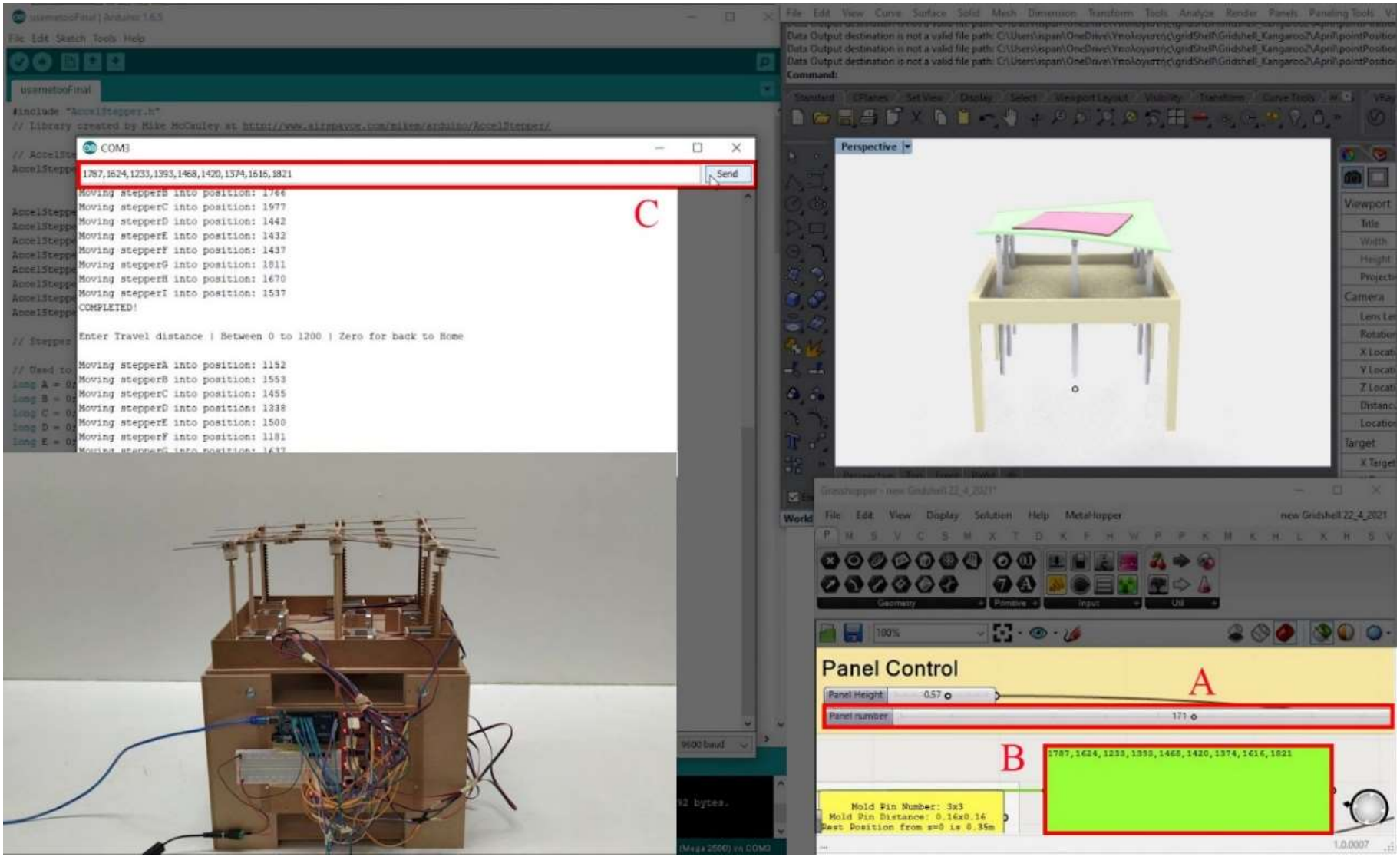
The automation



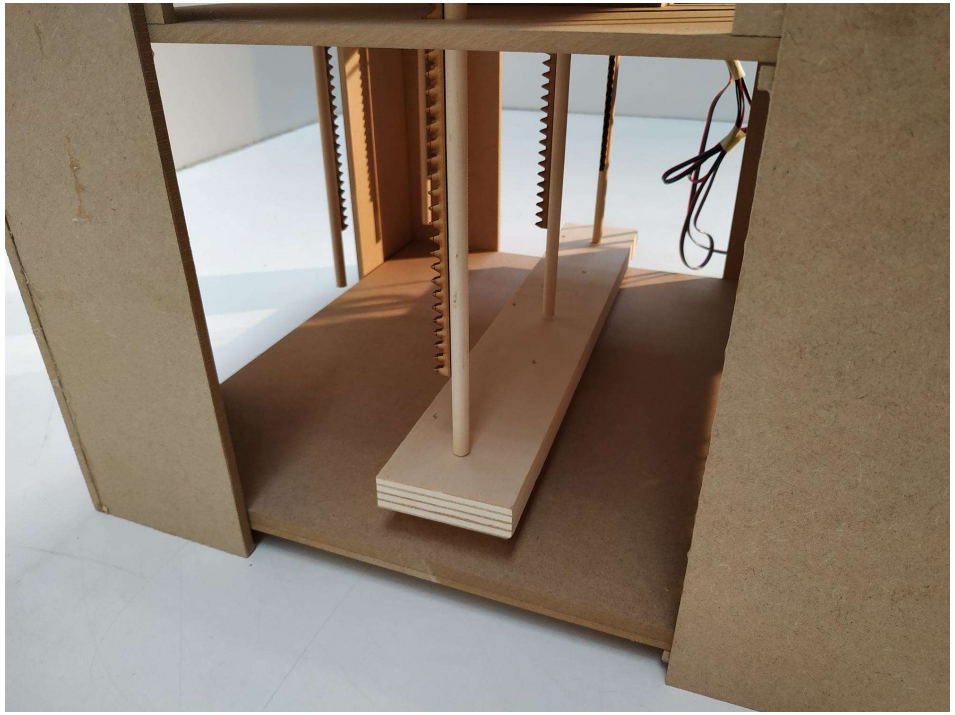
Digital to Physical data transfer



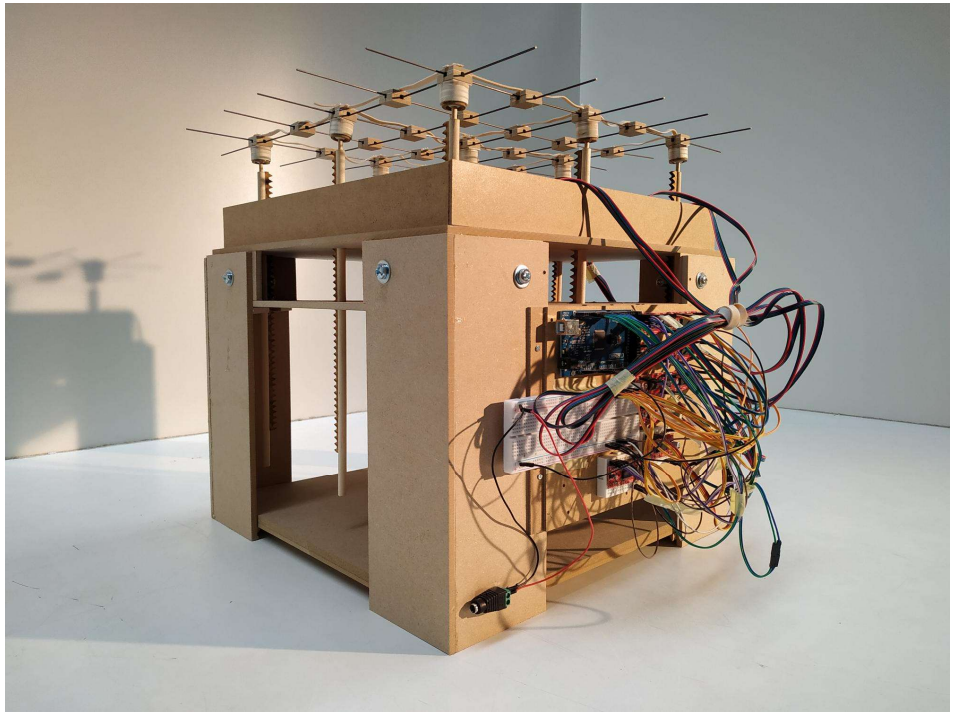
The circuit



The steps to use the prototype



The wooden piece used for Homing



The pins are Homed

	Picture	Number	Cost (Euros)
Arduino Mega 2560		1	15
Male-Female Cable		40-80	4-8
Breadboard		1	5
Stepper Motor		9	54
Motor Driver		9	36
12V Power Adaptor		1	8
DC to terminal block adaptor		1	2
MDF sheets, steel cables, wooden pins, CnC cut		~	25
Total Cost			155

An overview of the components

The Building Weeks

Capabilities

1. Physical modelling mechanism
2. Design in various scales
3. Automation
4. Component Uniqueness
5. Accuracy
6. Calculation Intensity
7. Data communication

Architectural Design

Engineering

Fabrication

Limitation and Future upgrades

1. Magnet application on prototype
2. Surface cutting pattern study
3. Application of more pins
4. The algorithm warns about the consecutive pin's critical height difference
5. Directly connect the positional values to the prototype without the use of Ctrl+C and Ctrl+V

Thank You!