SIMULATING HYGROMORPHIC TIMBER CURVATURE

A Computational Framework for Passive Bilayer Deformation with Reversible Locking Mechanisms

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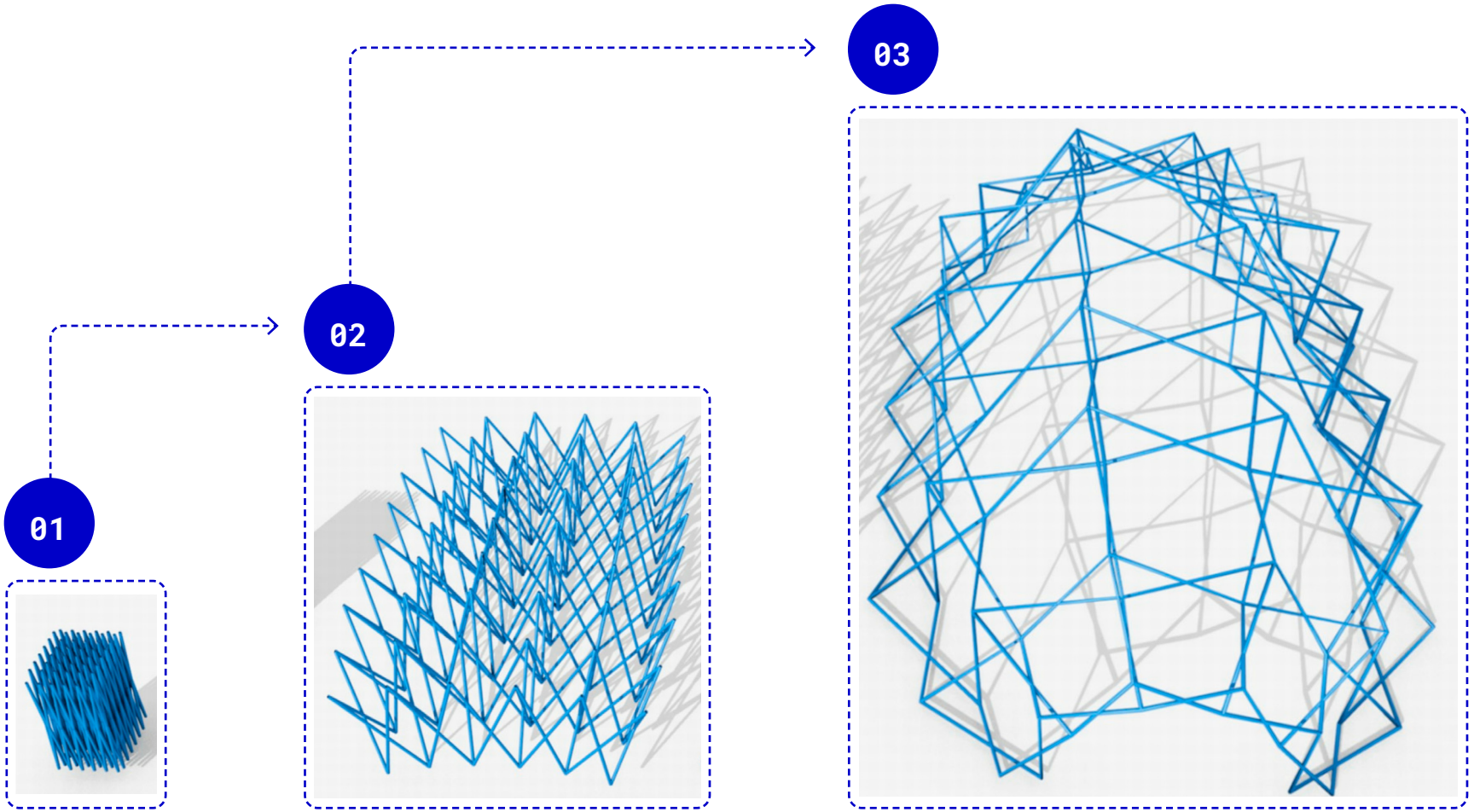
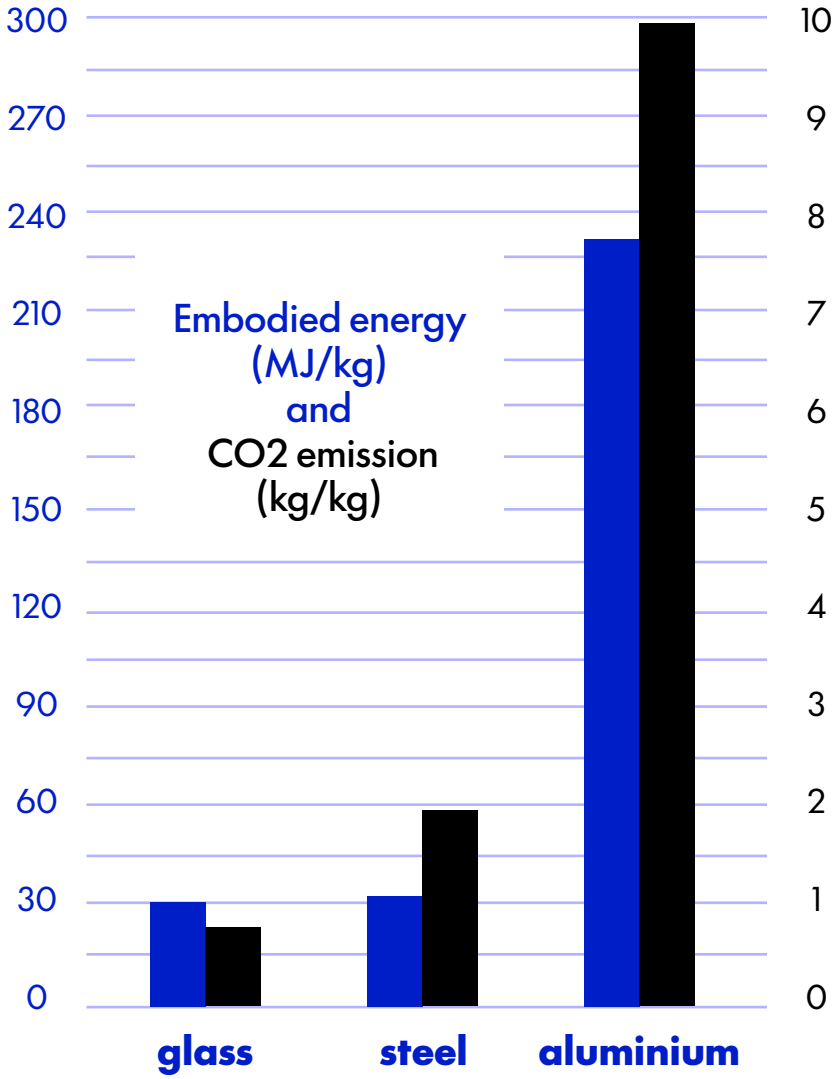
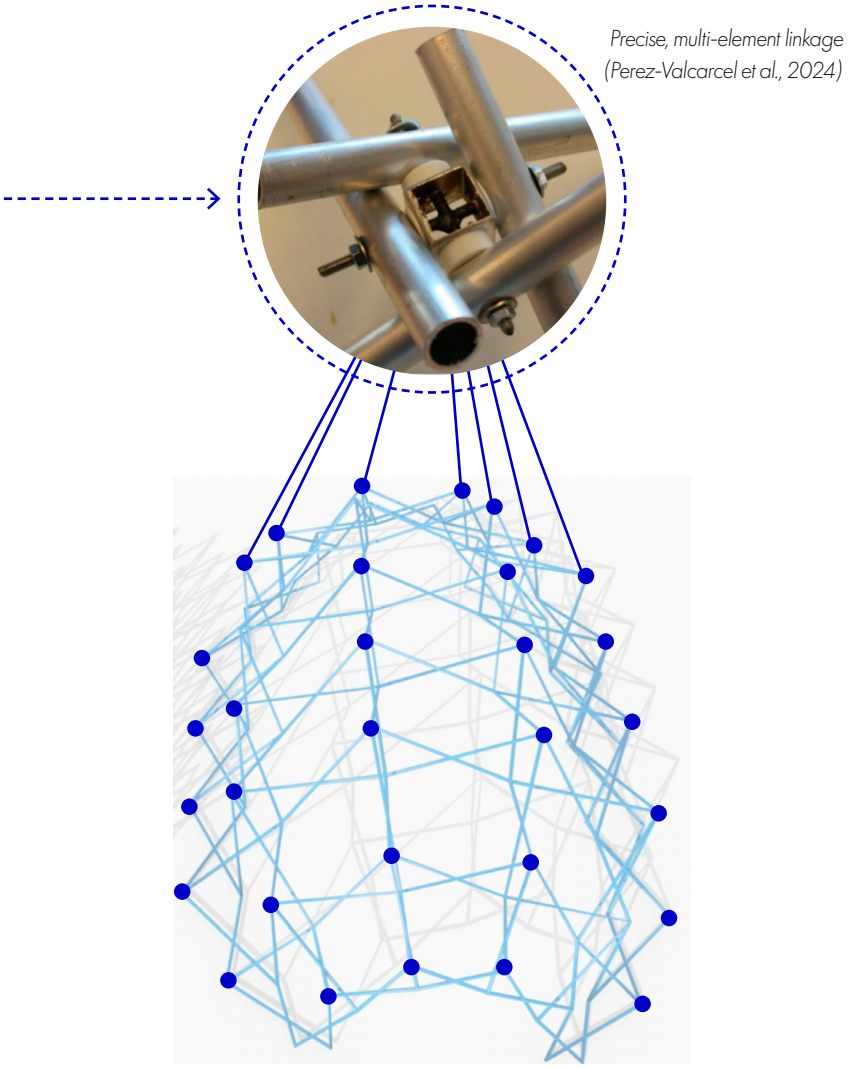


Deployable cylindrical dome
(Perez-Valcarcel et al., 2024)

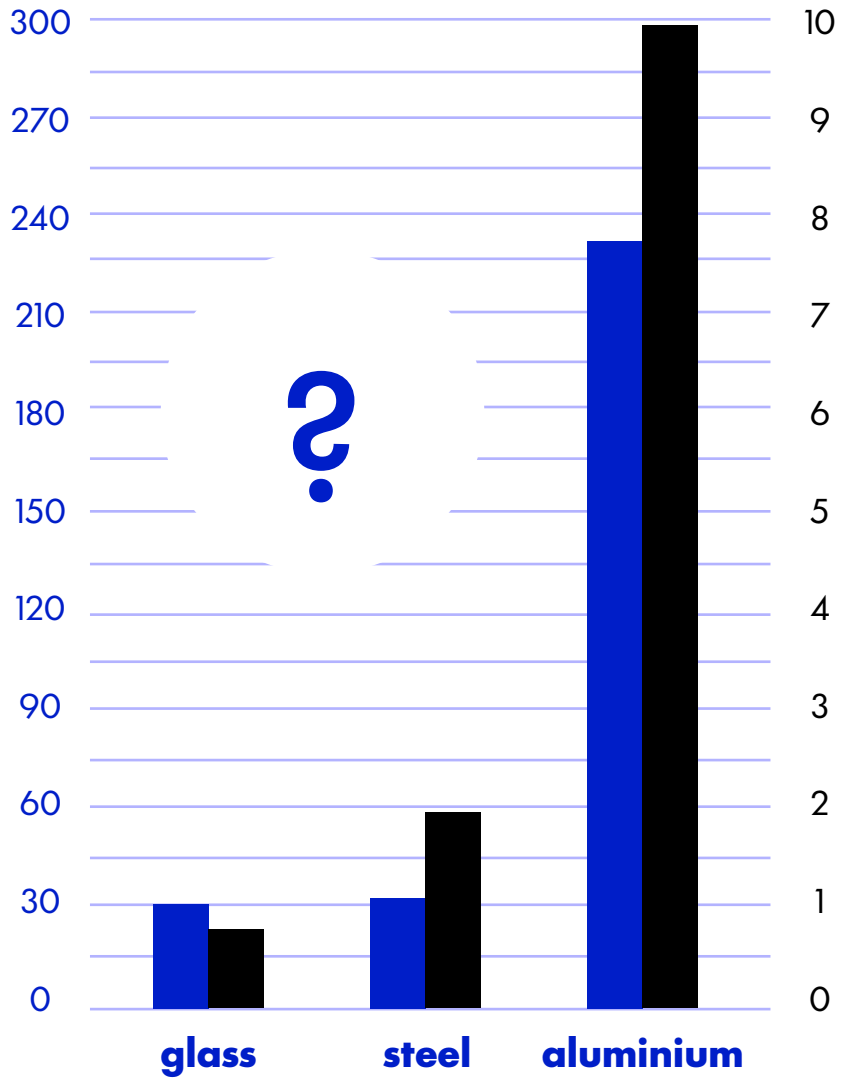




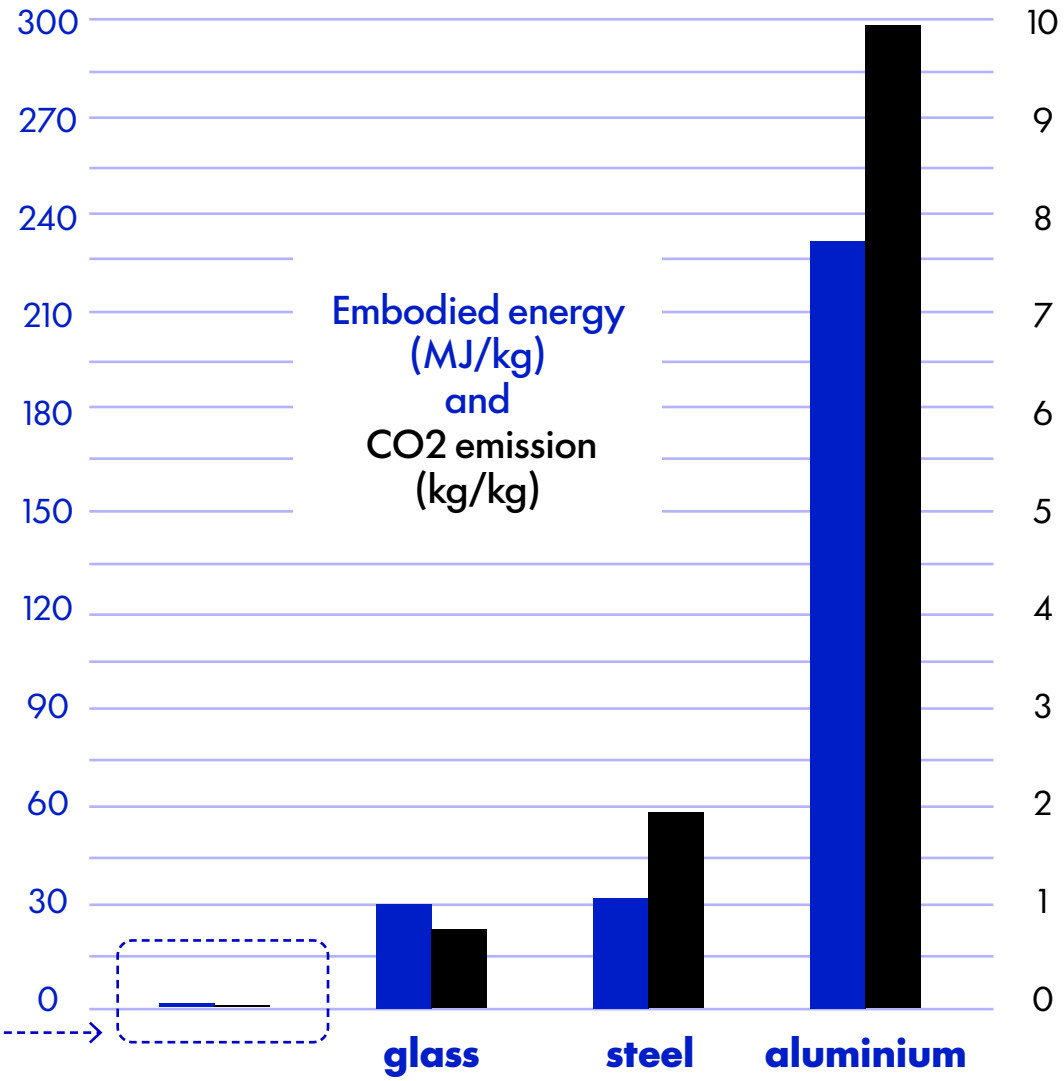
Precise, multi-element linkage
(Perez-Valcarcel et al., 2024)

CORE CHALLENGES:

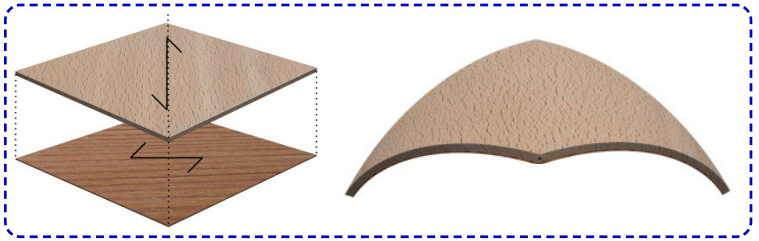
- complexity of modern systems
- unsustainable and energy-intensive material use
- labour-intensive activation process



timber!


300
270
240
210
180
150
120
90
60
30
0
10
9
8
7
6
5
4
3
2
1
0
Embodied energy
(MJ/kg)
and
CO2 emission
(kg/kg)
glass
steel
aluminium

Hygromorphic panel with grain orientation
(Pelliccia et al., 2020)



Urbach Tower
(University of Stuttgart, 2019)

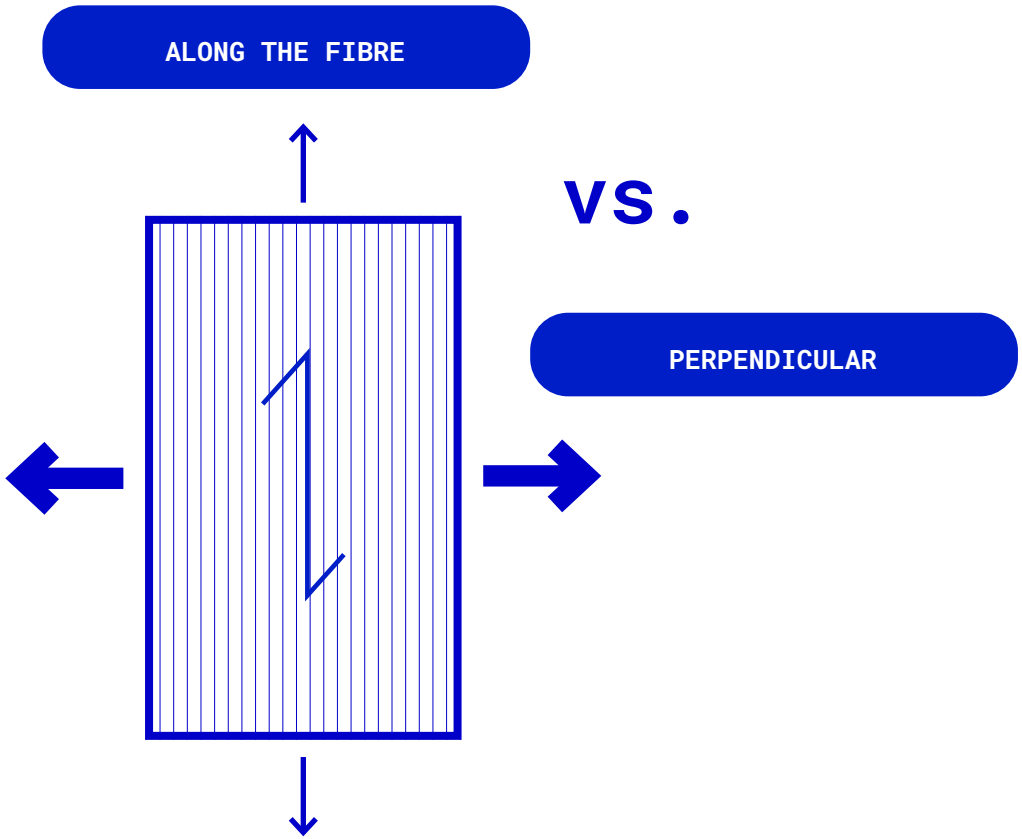
WHAT is the hygromorphic timber bilayer?

WHY it effective for deployable structures?

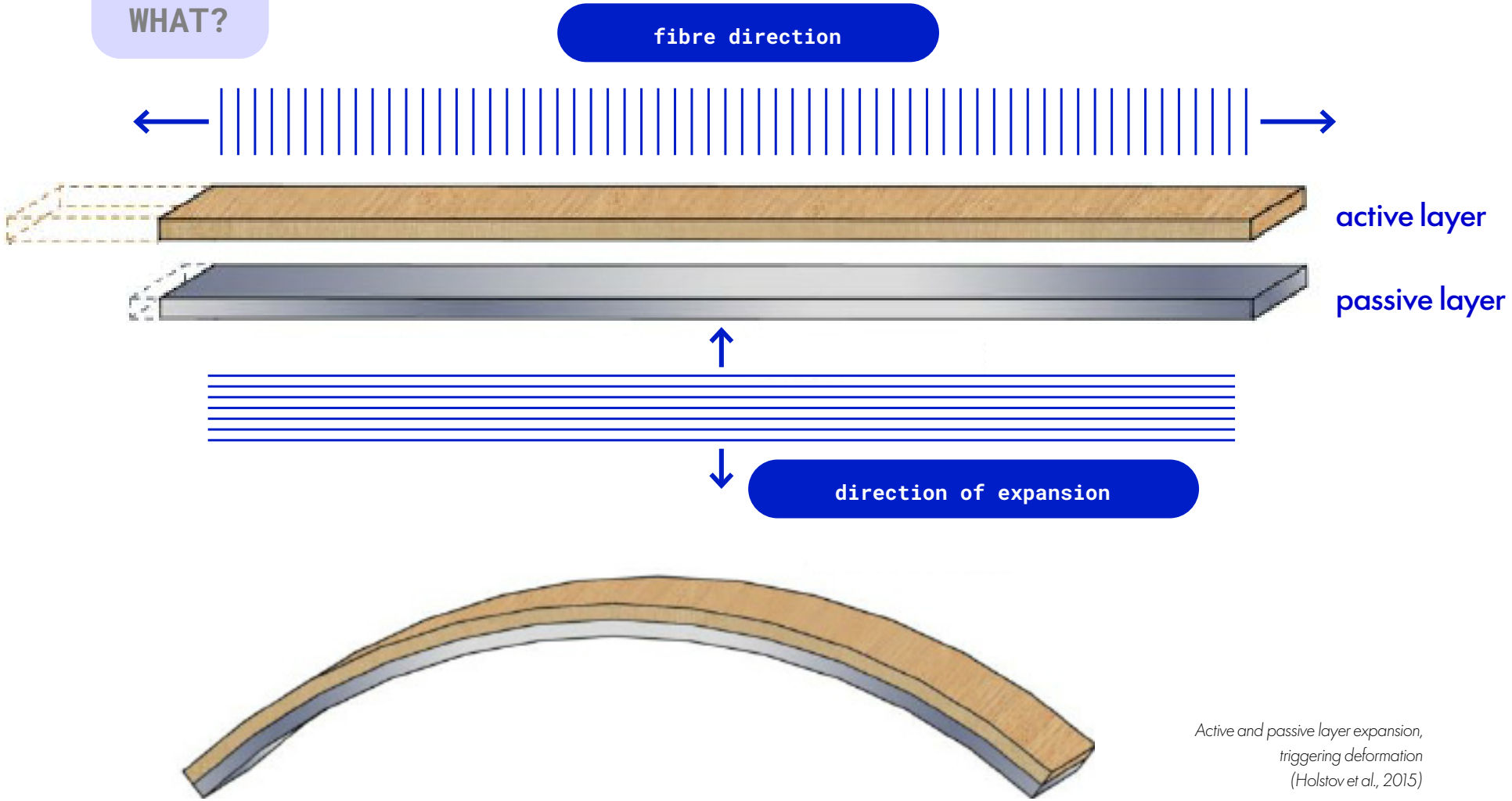
HOW does it simplify the activation system?

WHAT?

ANISOTROPIC MATERIAL



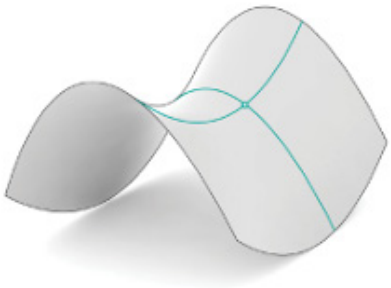
WHAT?



Active and passive layer expansion, triggering deformation (Holstov et al., 2015)

WHY?

ANTICLASTIC



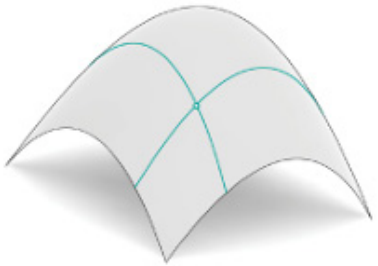
Anticlastic
K < 0

MONOCLASTIC



Monoclastic
K = 0

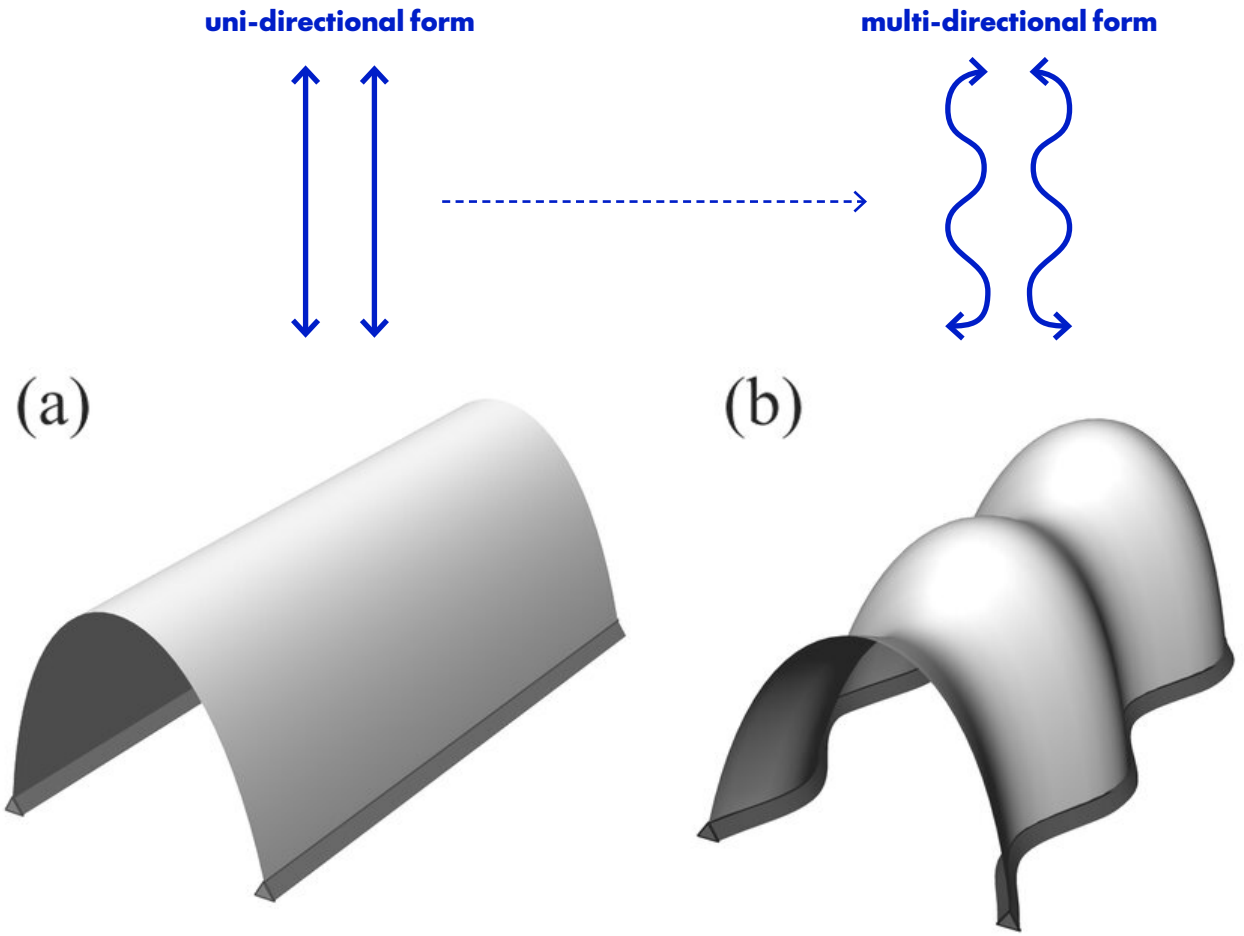
SYNCLASTIC



Synclastic
K > 0

Anticlastic, monoclastic, and synclastic curvature (Roberto et al., 2018)

WHY?

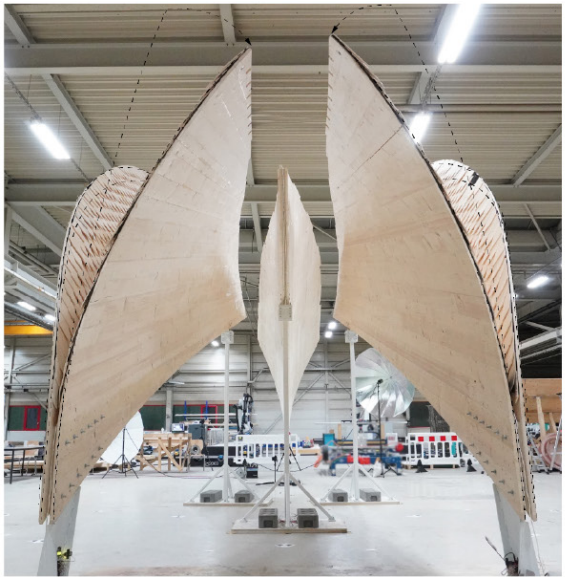


Monoclastic curvature to free-form shell
(D'Amico, 2015)

HOW?



time = 0h
WMC = 19%

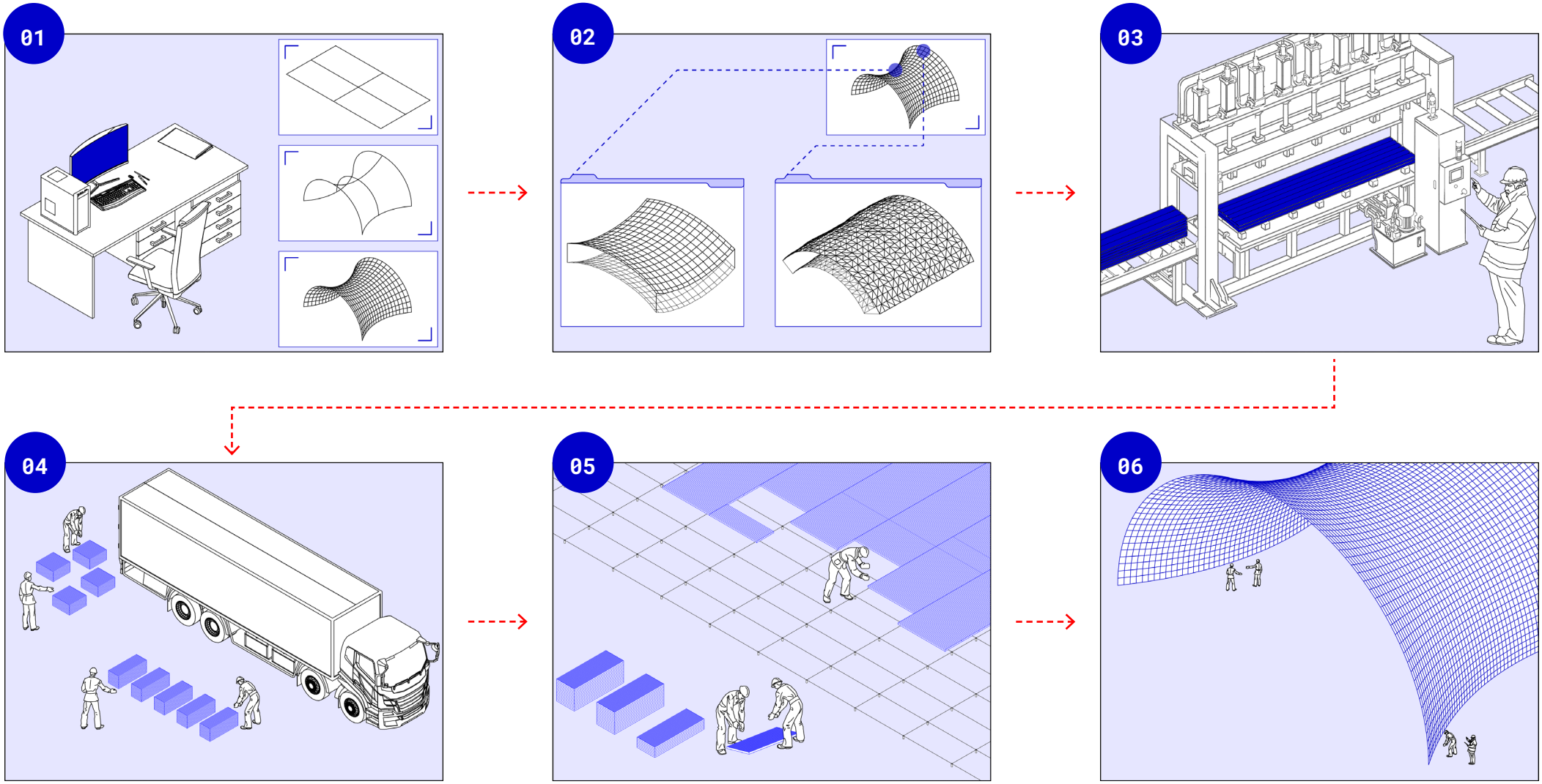


time = 48h
WMC = 15%

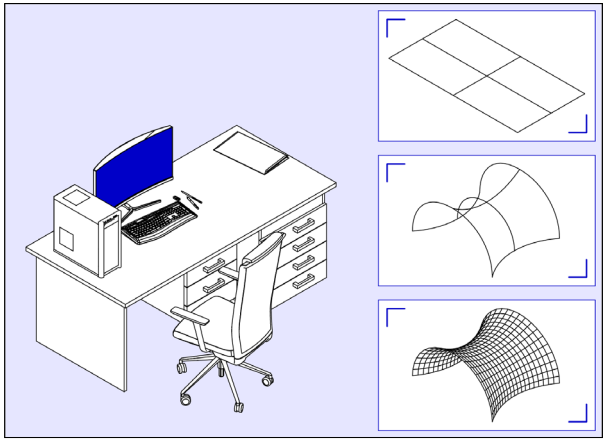


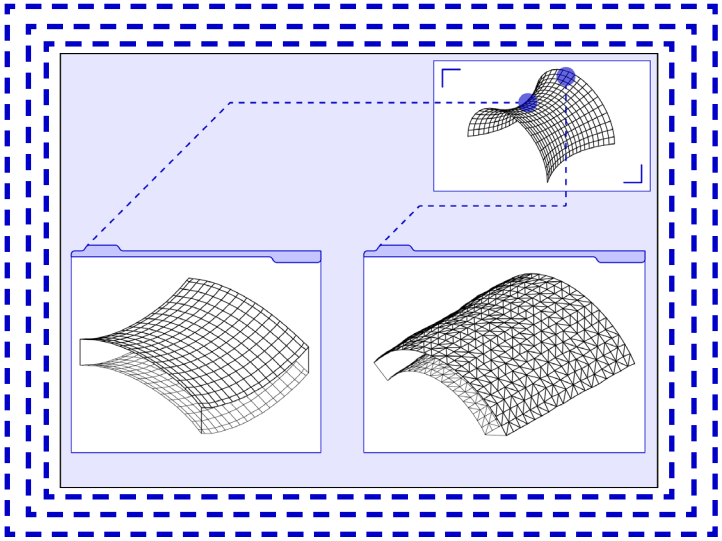
time = 96h
WMC = 11%

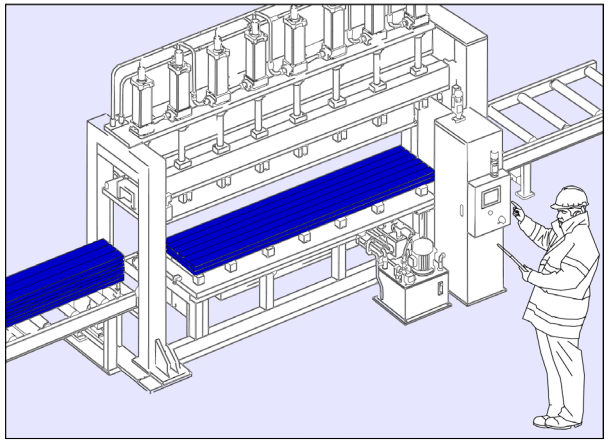
HygroShell
(Menges et al., 2023)

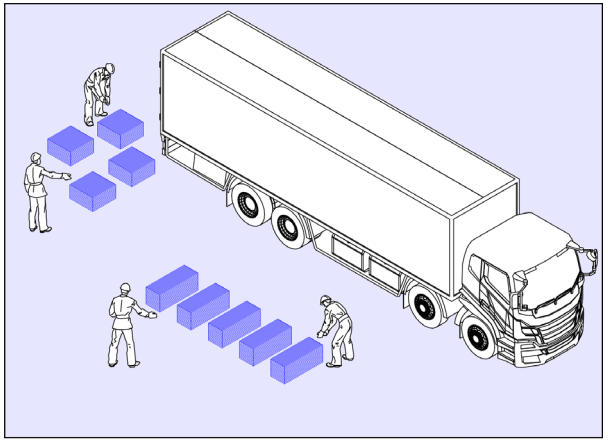

01
02
03
04
05
06

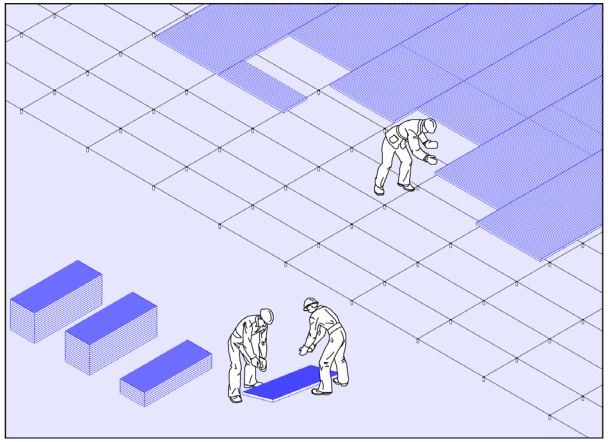
critical limitation

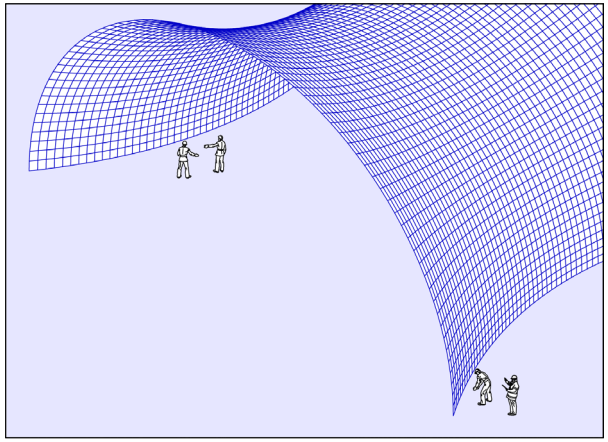






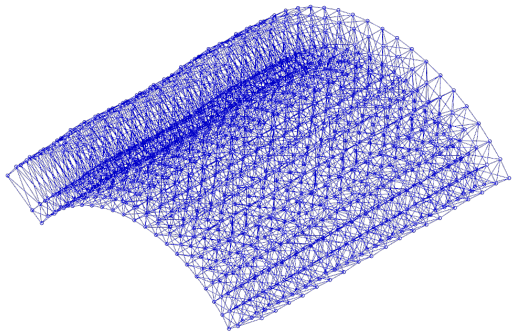




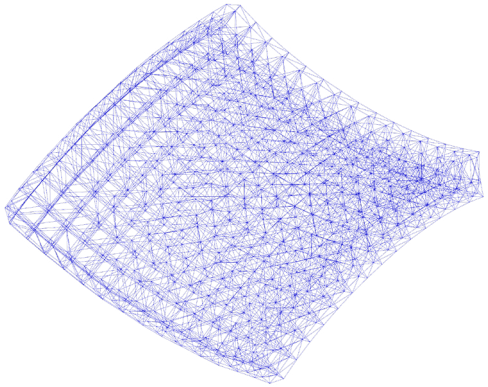


How can a computational design workflow be developed for simulating hygromorphic bilayer deformation to support the design of deployable free-form structures?

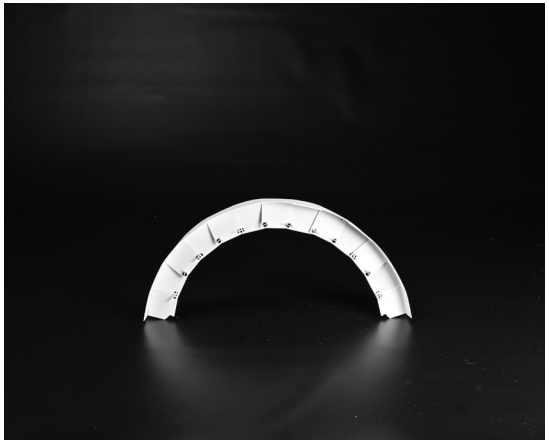
01 Monoclastic simulative tool



02 Anticlastic simulative tool

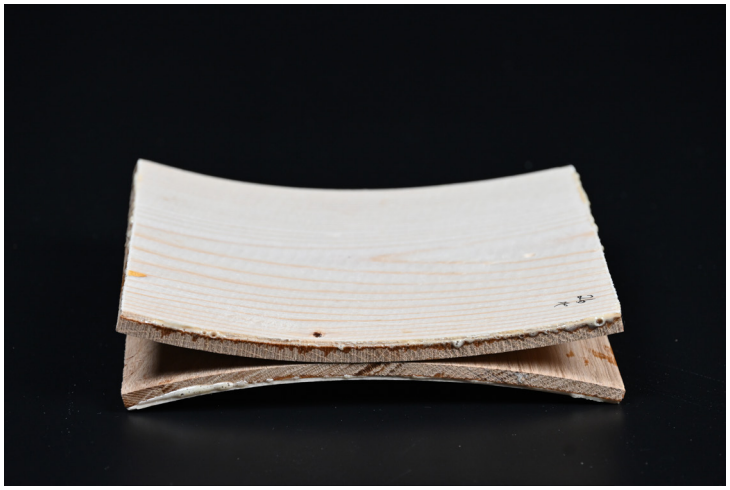


03 Reversible locking system



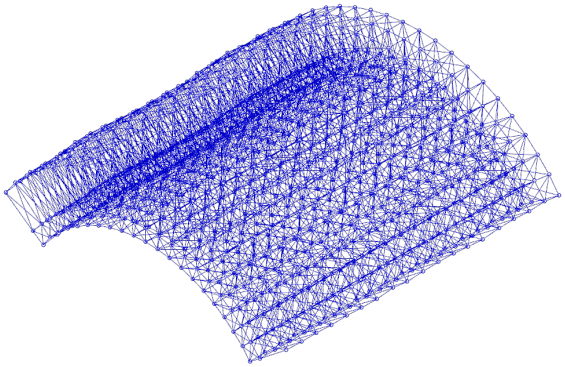
STAGE 001

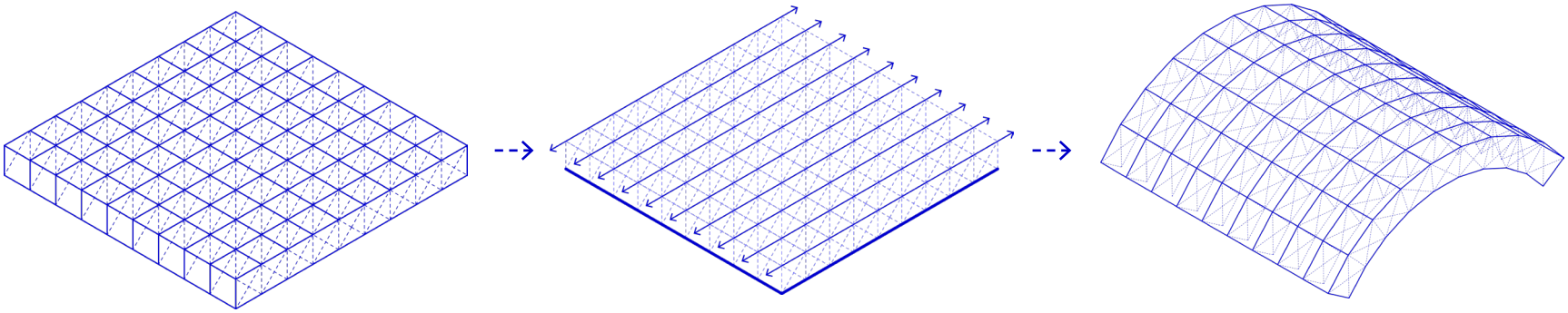
real-world behaviour



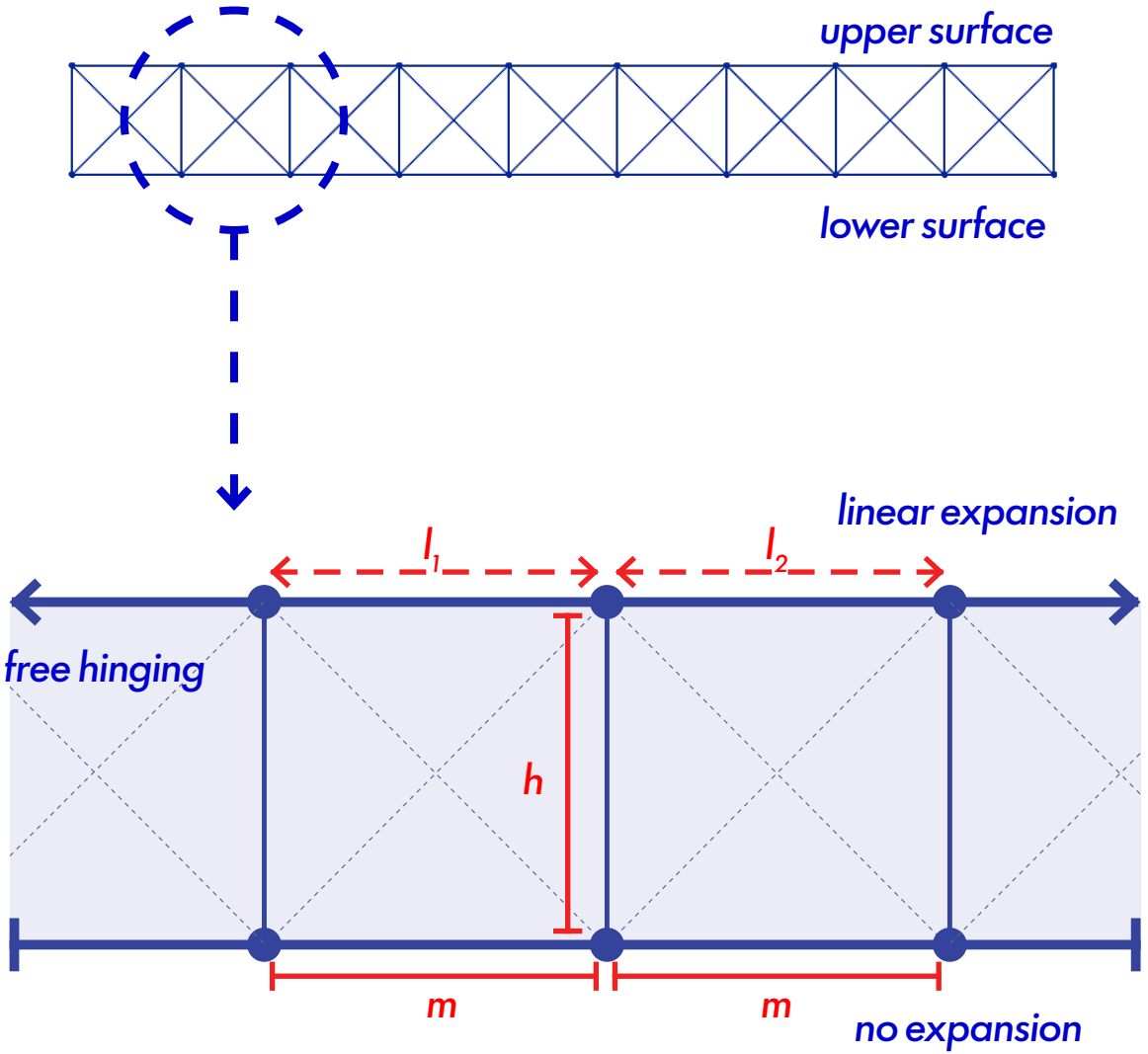
TO

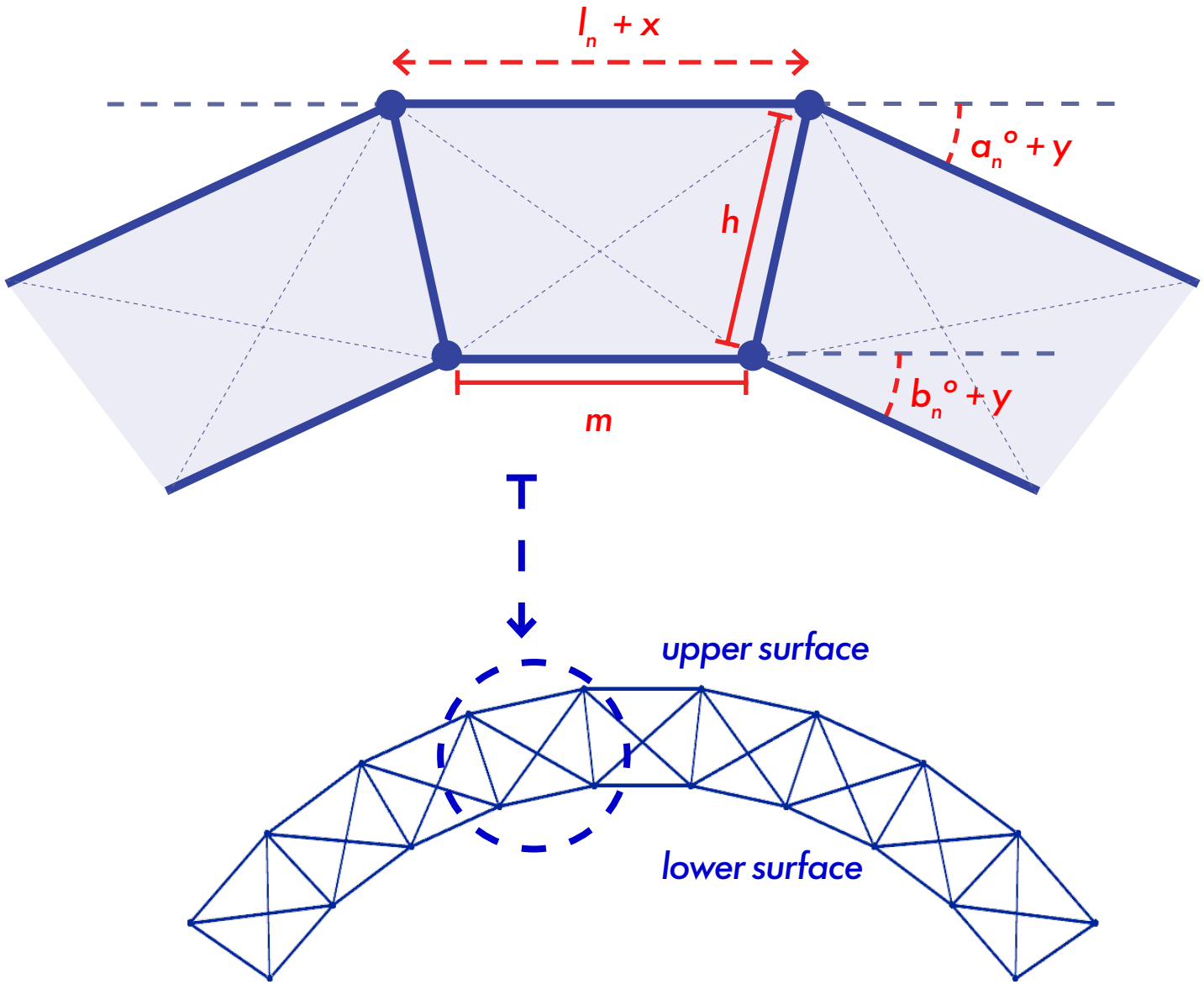
digital simulation





original contribution


upper surface
lower surface
linear expansion
l_1
l_2
free hinging
h
m
m
no expansion


$l_n + x$
$a_n° + y$
h
$b_n° + y$
m
upper surface
lower surface

FINAL CURVATURE

$$\frac{1}{\rho} = \frac{6(1+m)^2}{\left(3(1+m)^2 + (1+mn)\left(m^2 + \frac{1}{mn}\right)\right)} \frac{(\alpha_2 - \alpha_1)(c - c_0)}{h}$$

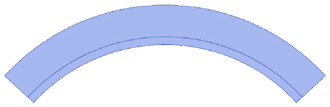
$$= k\frac{\Delta\alpha\Delta c}{h}, \quad m = \frac{h_1}{h_2}, \quad n = \frac{E_1}{E_2}$$

[accuracy]

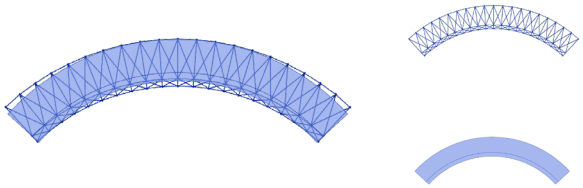
~90%



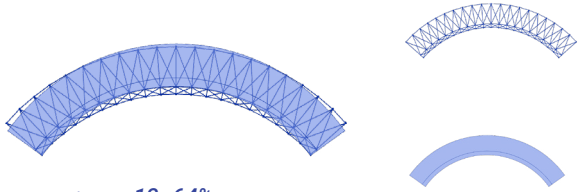
space frame curvature



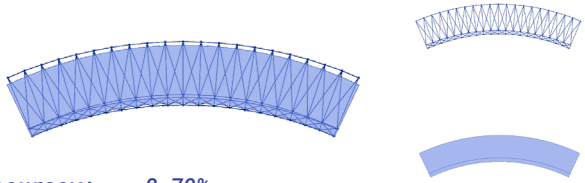
mathematical curvature



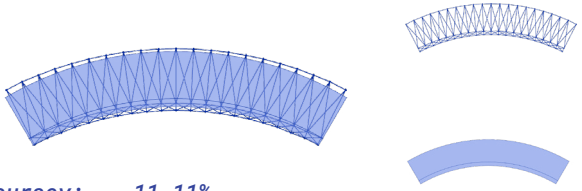
inaccuracy: 10.62%
active: 2mm passive: 0.5mm



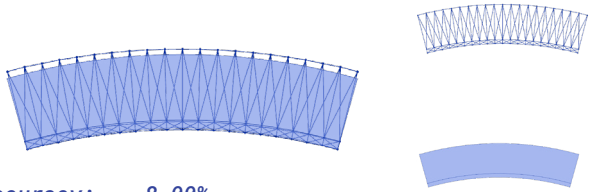
inaccuracy: 12.64%
active: 2mm passive: 0.5mm



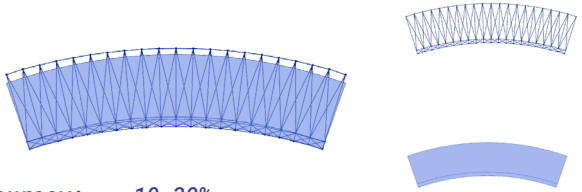
inaccuracy: 8.79%
active: 3mm passive: 0.5mm



inaccuracy: 11.11%
active: 3mm passive: 0.5mm



inaccuracy: 8.00%
active: 4mm passive: 0.5mm



inaccuracy: 10.30%
active: 4mm passive: 0.5mm

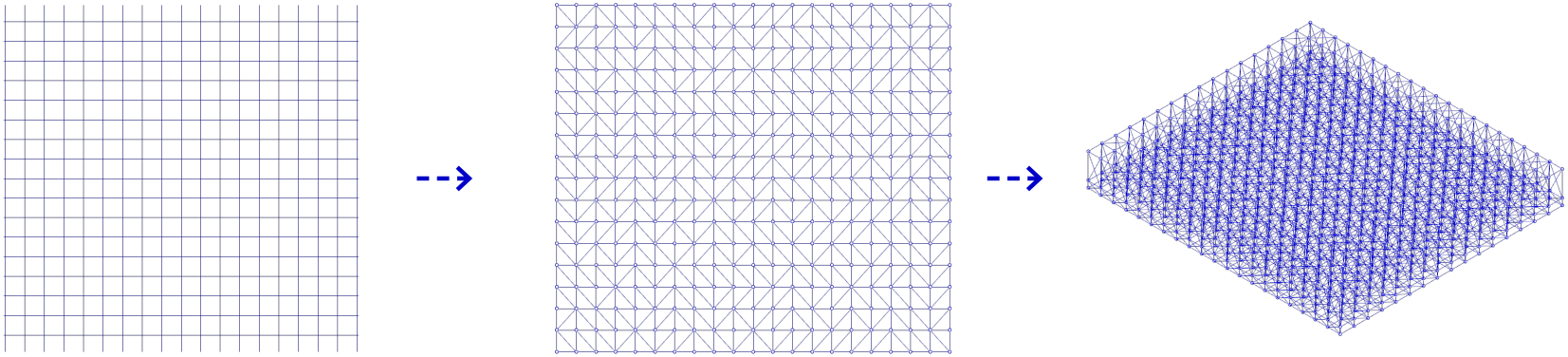
multi-directional form

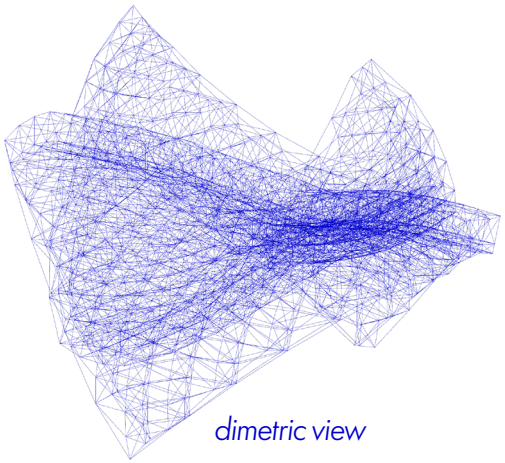


Monoclastic curvature to free-form shell
(D'Amico, 2015)

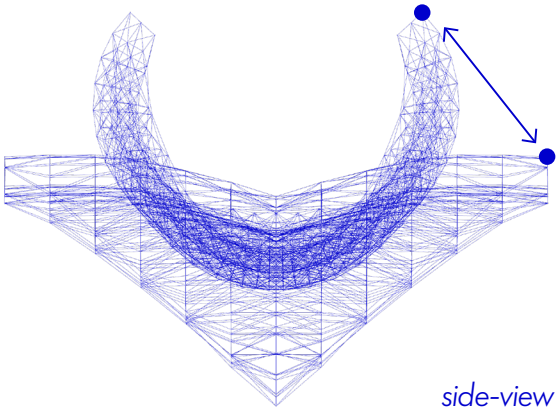
STAGE 002

LINES ..... TO ..... STRUCTURE



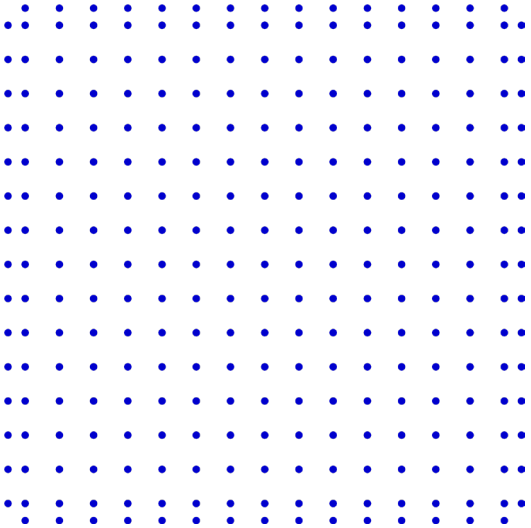


dimetric view

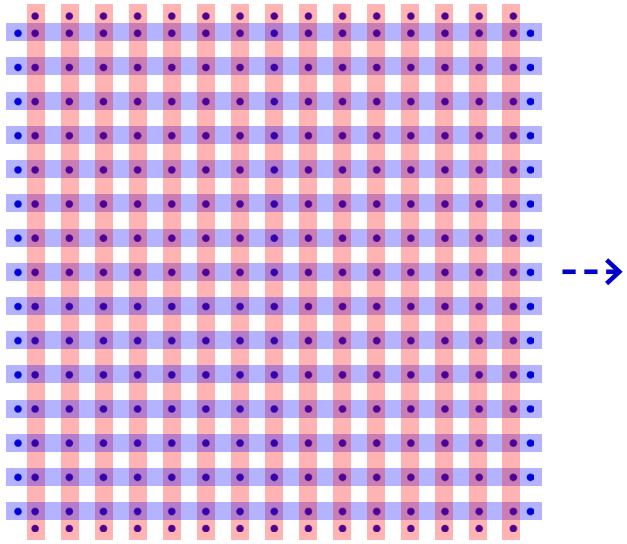


side-view

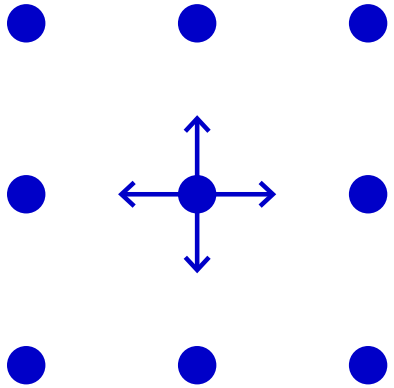
point grid



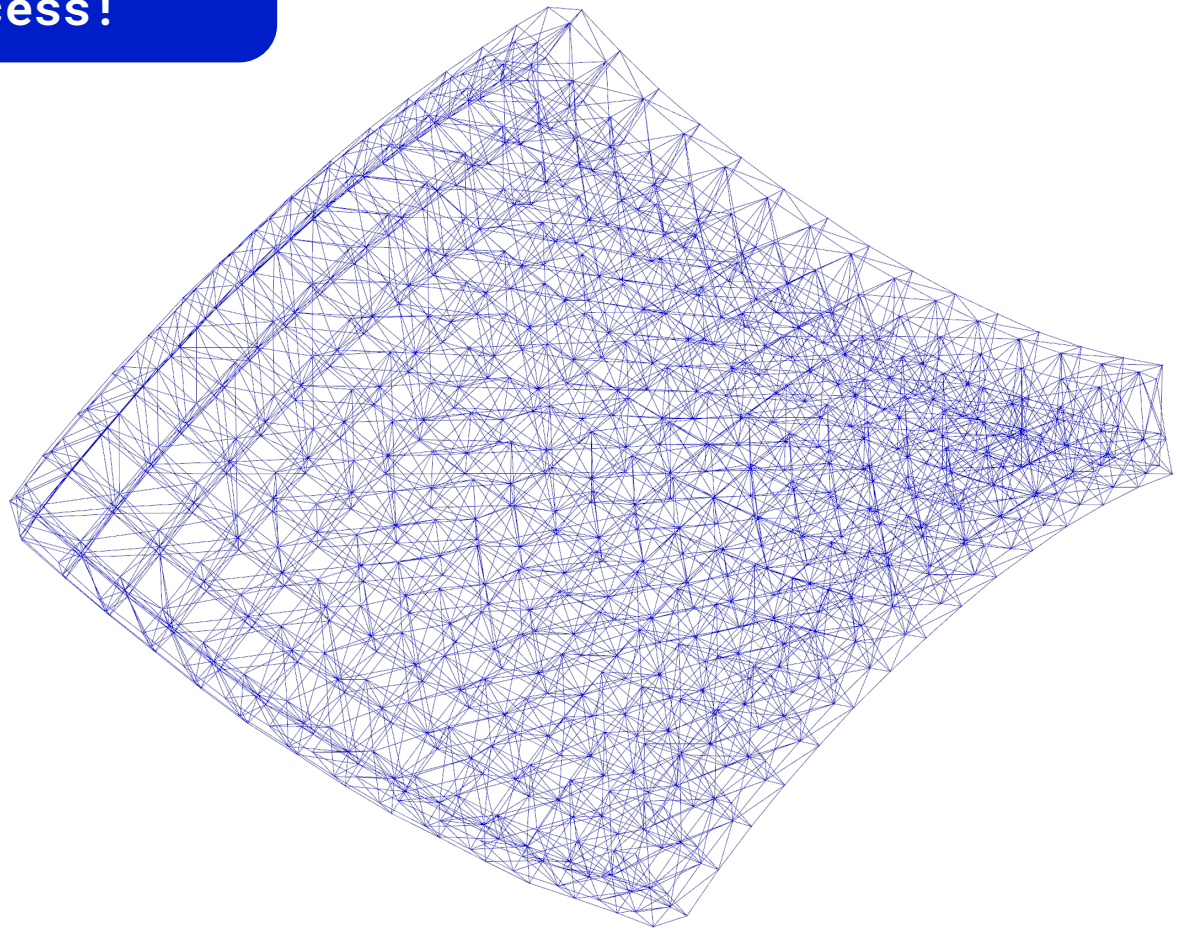
axes of expansion



multi-directional influence

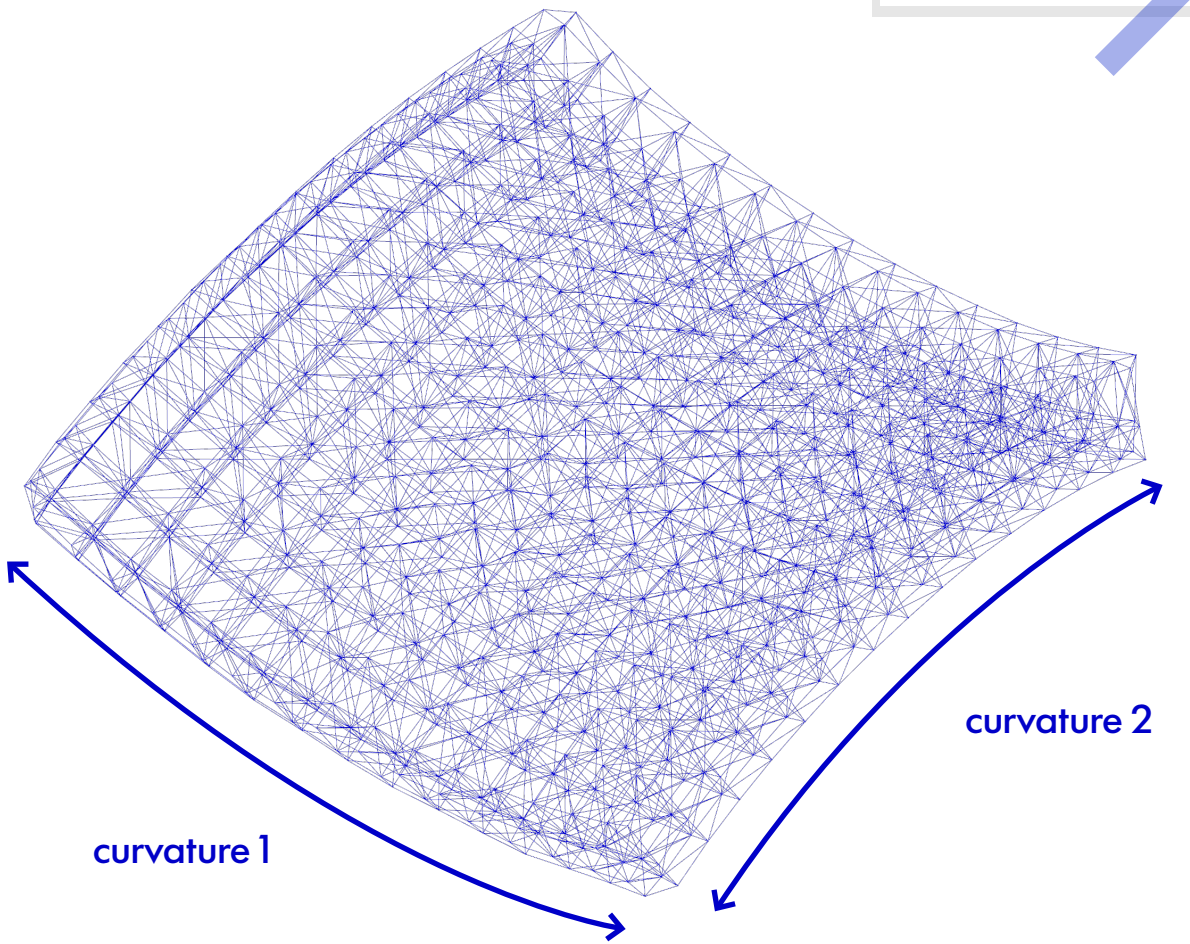


success!



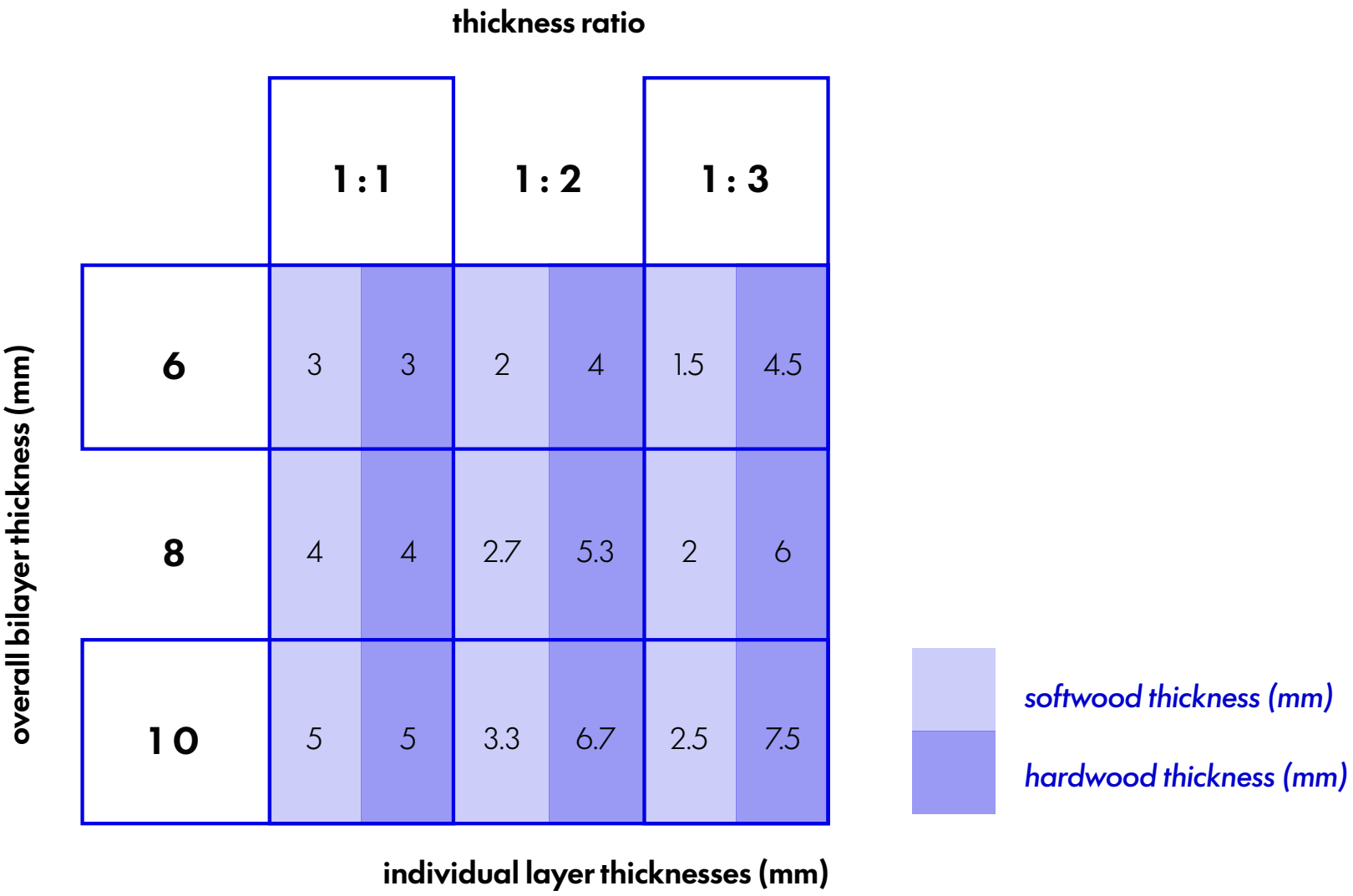
$$\frac{1}{\rho} = \frac{6(1+m)^2}{\left(3(1+m)^2 + (1+mn)\left(m^2 + \frac{1}{mn}\right)\right)} \frac{(\alpha_2 - \alpha_1)(c - c_0)}{h}$$
$$= k\frac{\Delta\alpha\Delta c}{h}, \quad m = \frac{h_1}{h_2}, \quad n = \frac{E_1}{E_2}$$

only 1 curvature!



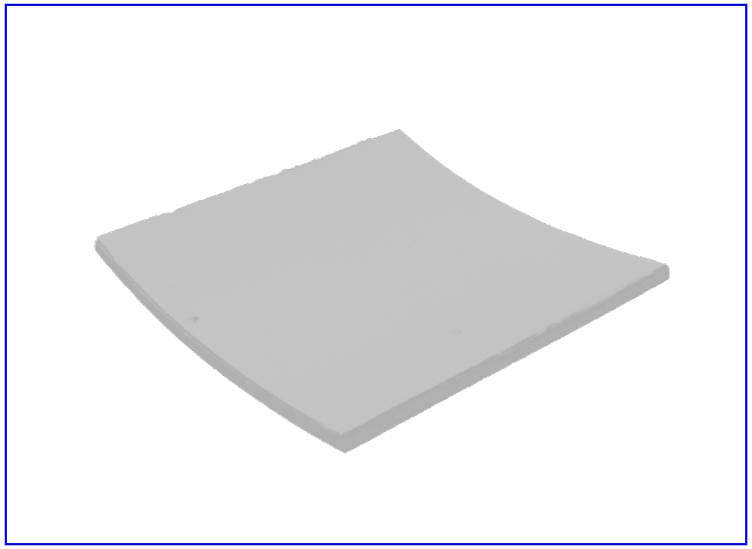


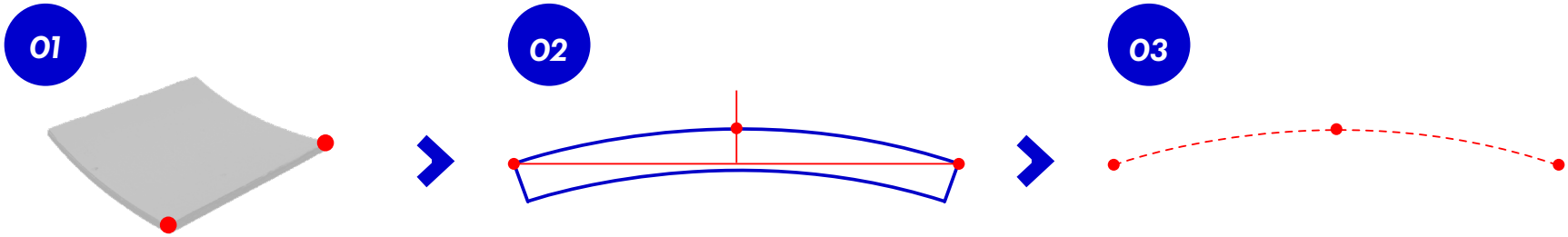
STAGE 003


thickness ratio
1 : 1
1 : 2
1 : 3
6
3
3
2
4
1.5
4.5
8
4
4
2.7
5.3
2
6
10
5
5
3.3
6.7
2.5
7.5
overall bilayer thickness (mm)
individual layer thicknesses (mm)
softwood thickness (mm)
hardwood thickness (mm)

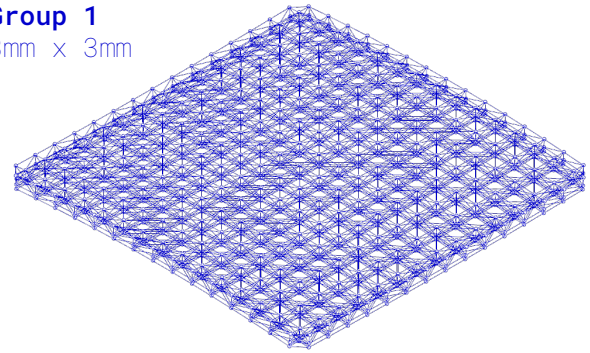


digital 3D scan

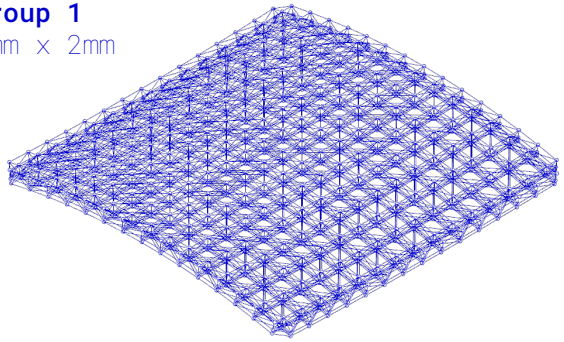




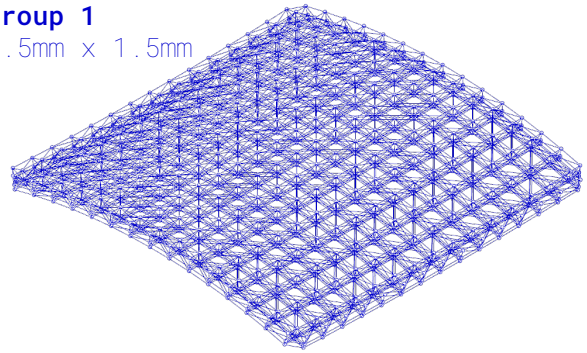
Group 1
3mm x 3mm



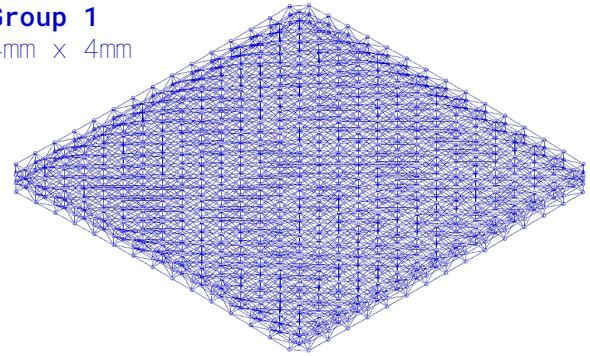
Group 1
4mm x 2mm



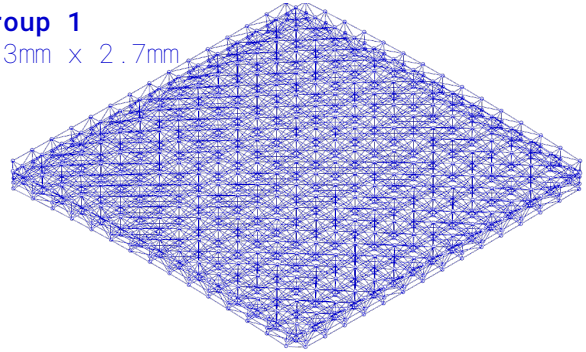
Group 1
4.5mm x 1.5mm



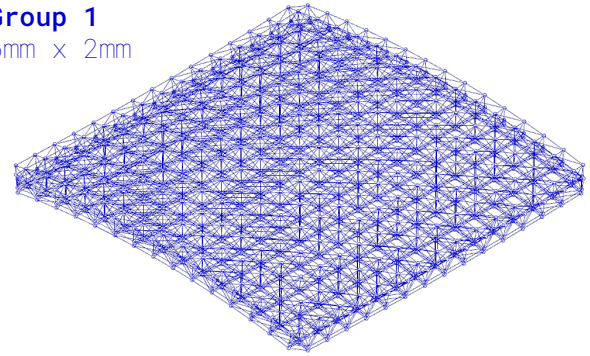
Group 1
4mm x 4mm



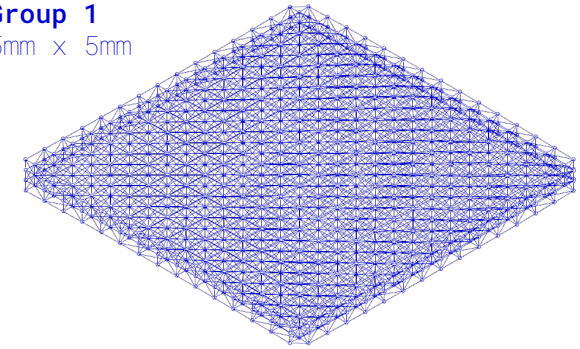
Group 1
5.3mm x 2.7mm



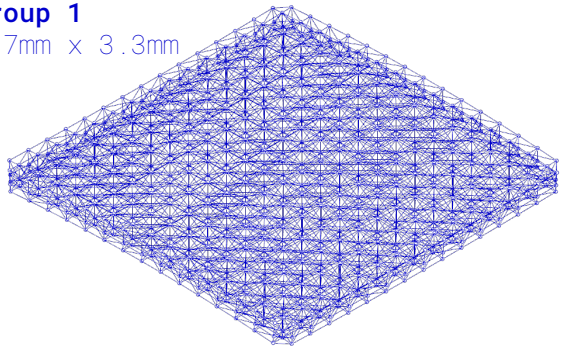
Group 1
6mm x 2mm



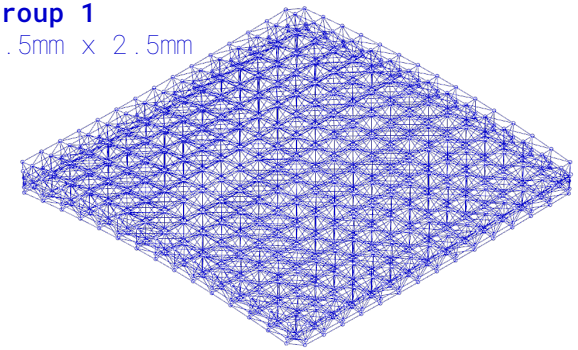
Group 1
5mm x 5mm



Group 1
6.7mm x 3.3mm

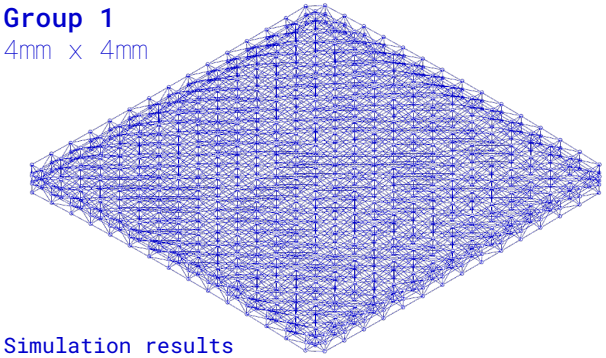


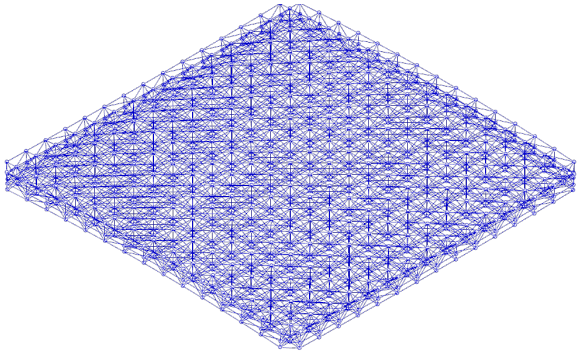
Group 1
7.5mm x 2.5mm

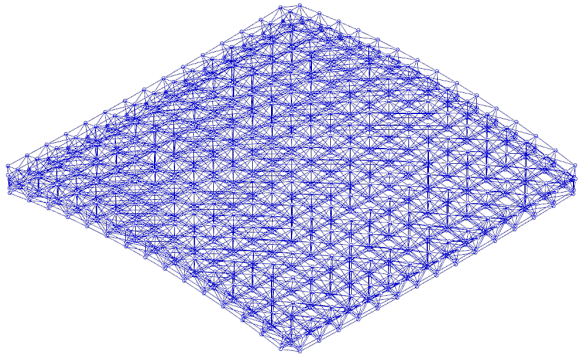


Group 1

4mm x 4mm



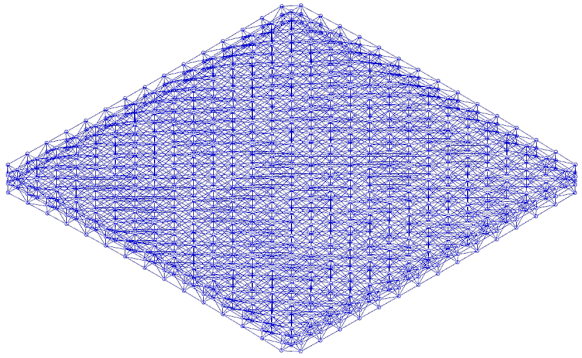




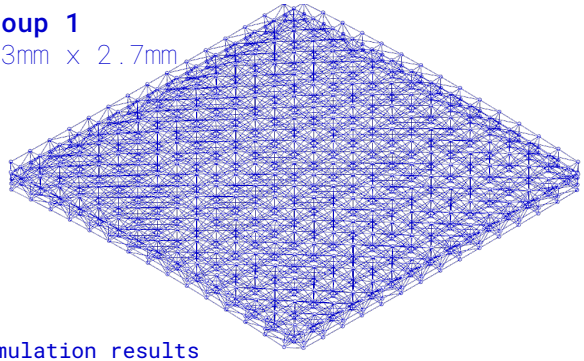
Simulation results

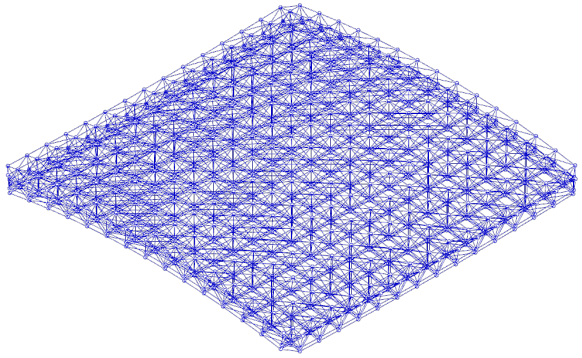
hardwood curvature: 0.00064 [accuracy; 98%]

softwood curvature: 0.00027 [accuracy; 55%]



Group 1
5.3mm x 2.7mm

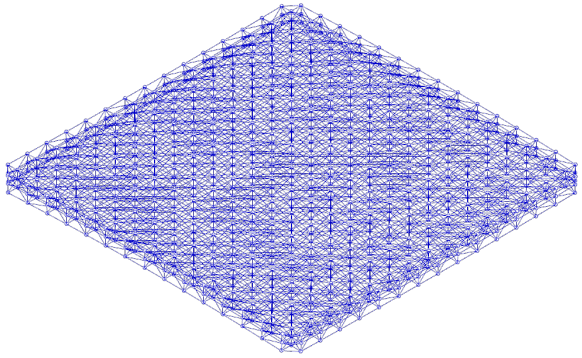


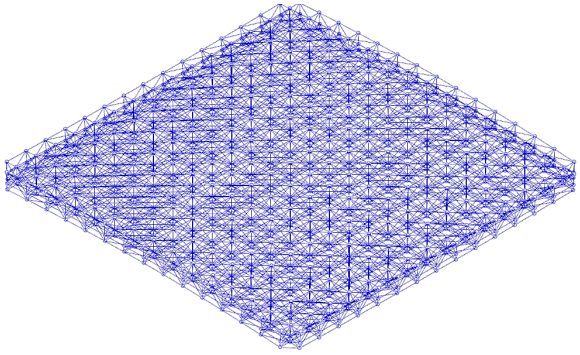


Simulation results

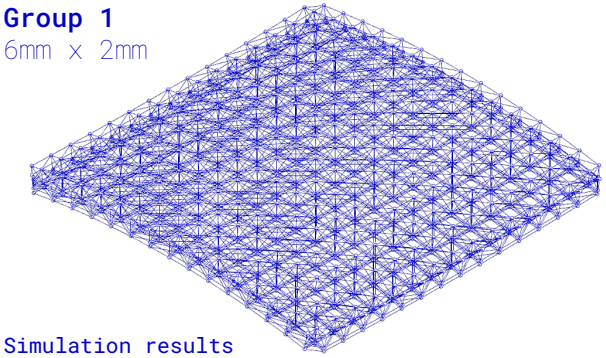
hardwood curvature: 0.00092 [accuracy; 99%]

softwood curvature: 0.00027 [accuracy; 36%]





Group 1
6mm x 2mm

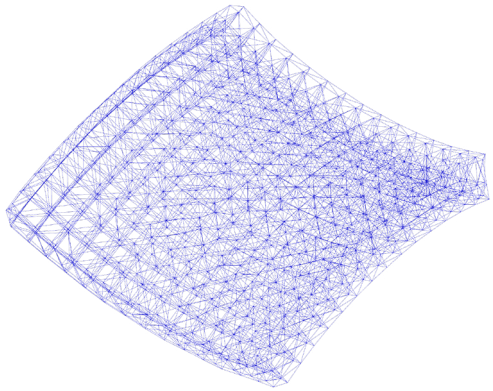


Simulation results

hardwood curvature: 0.00229 [accuracy; 95%]

softwood curvature: 0.00049 [accuracy; 12%]

magnitude of curvature
+
curvature sensitivity

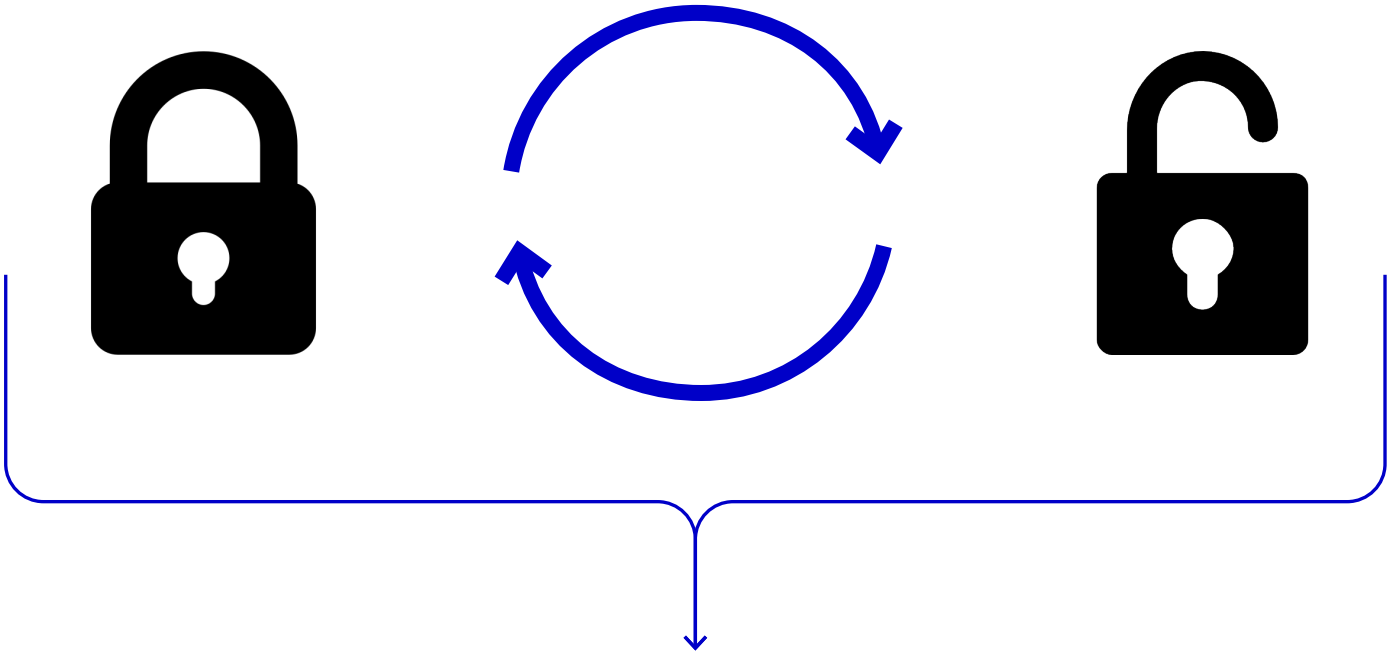


=

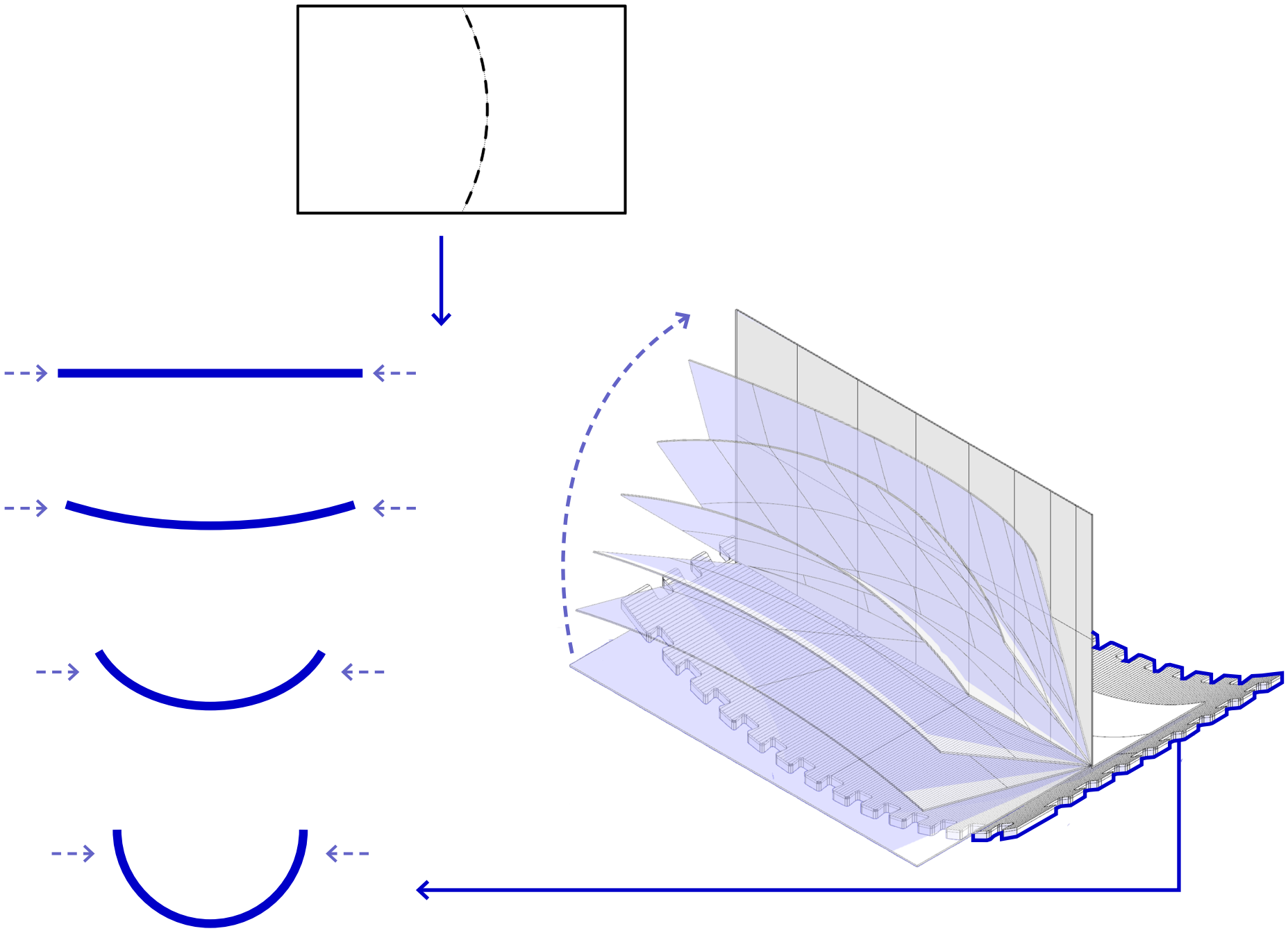
tolerance

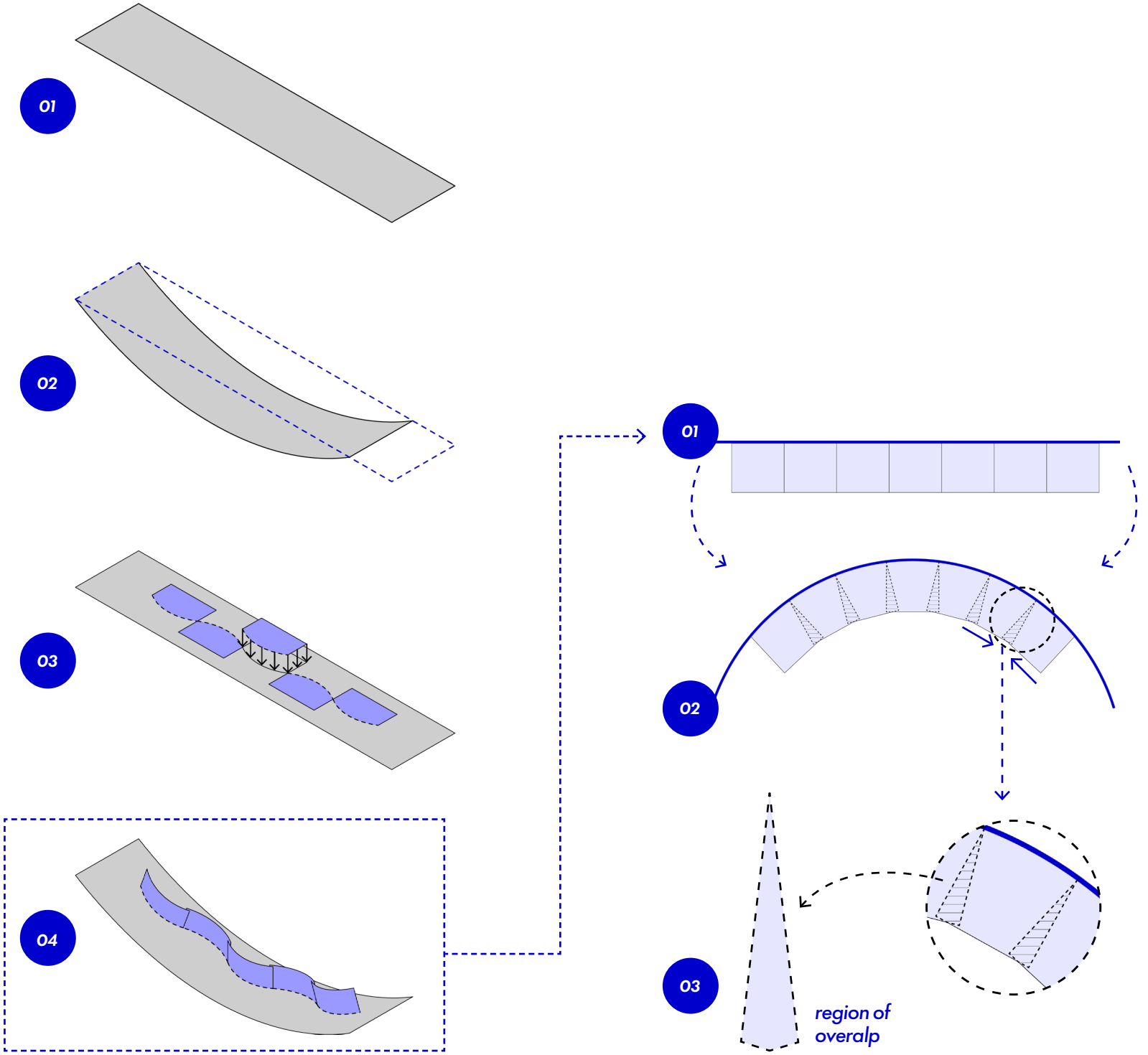
+/- 1mm

STAGE 004

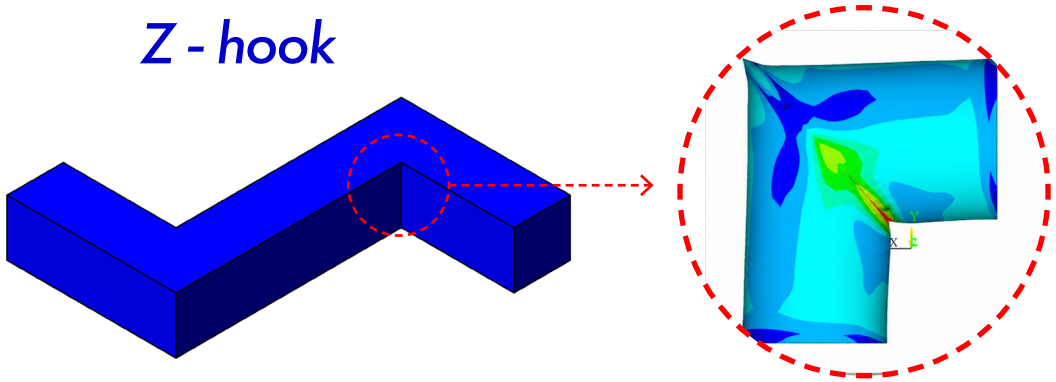


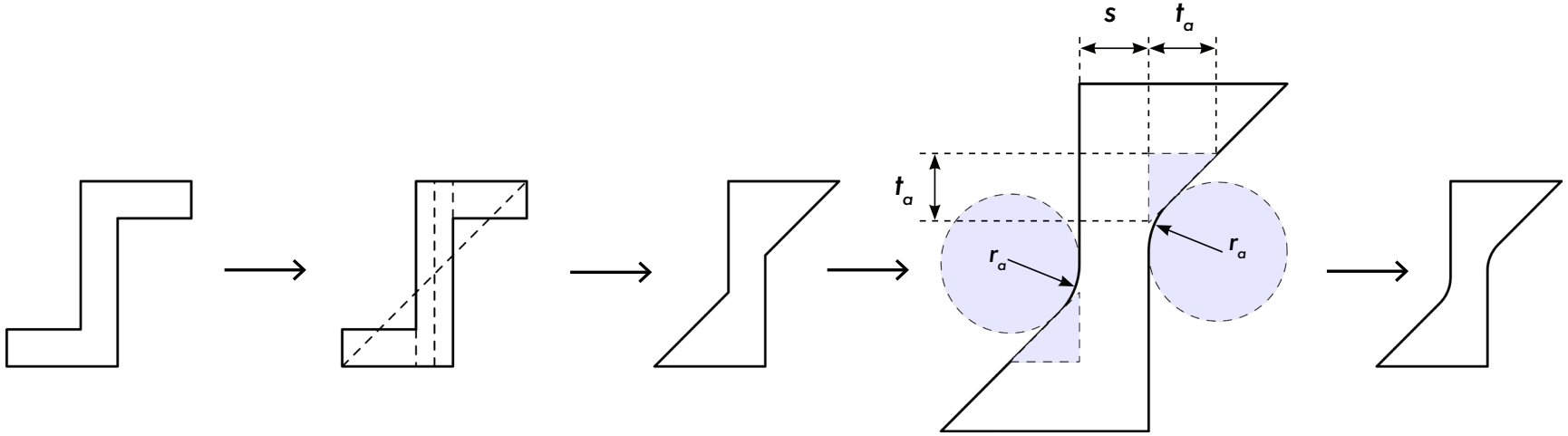
CURVE-LINE ACTIVATION

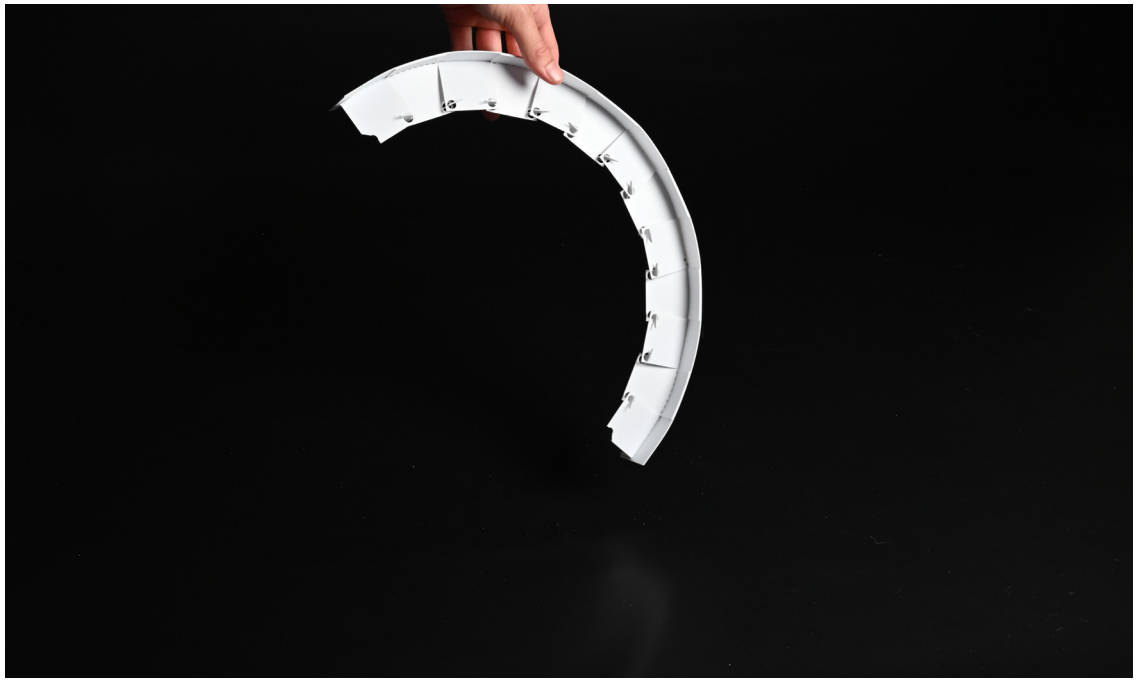



01
02
03
04
01
02
03
region of
overalp

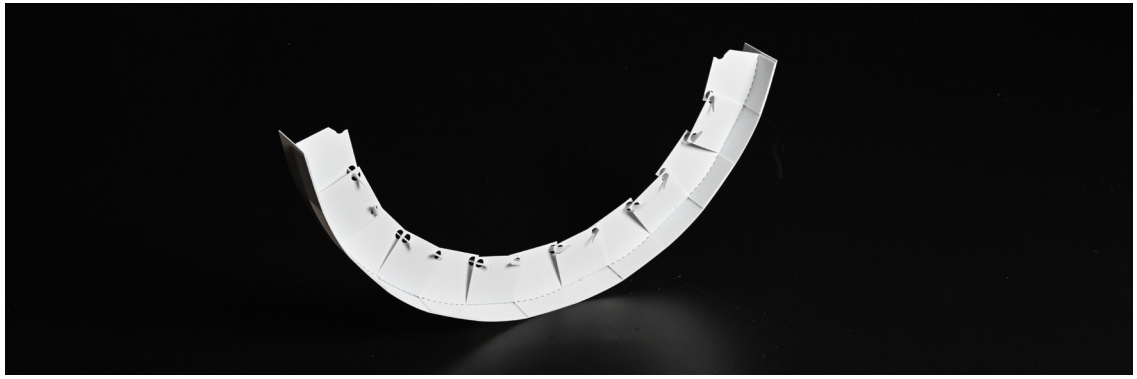
Z - hook







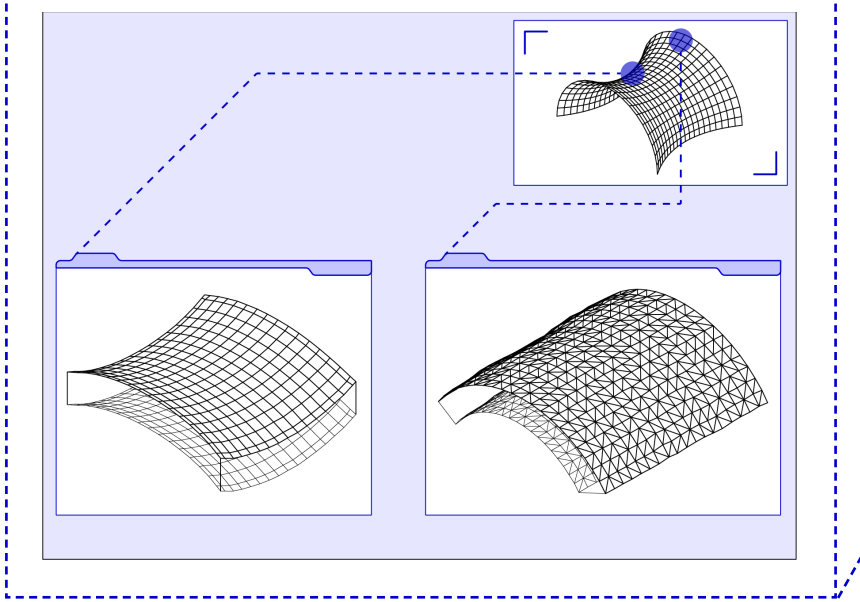


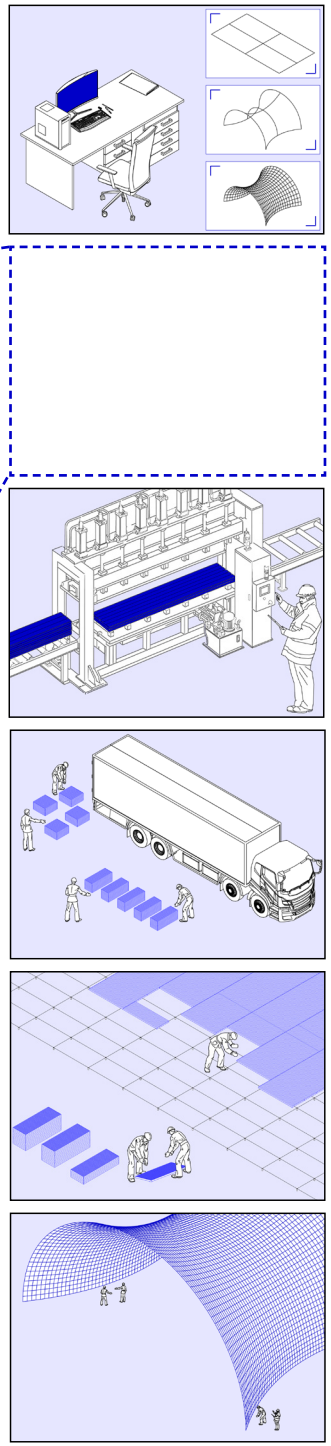




CONCLUSIONS

How can a computational design workflow be developed for simulating hygromorphic bilayer deformation to support the design of deployable free-form structures?

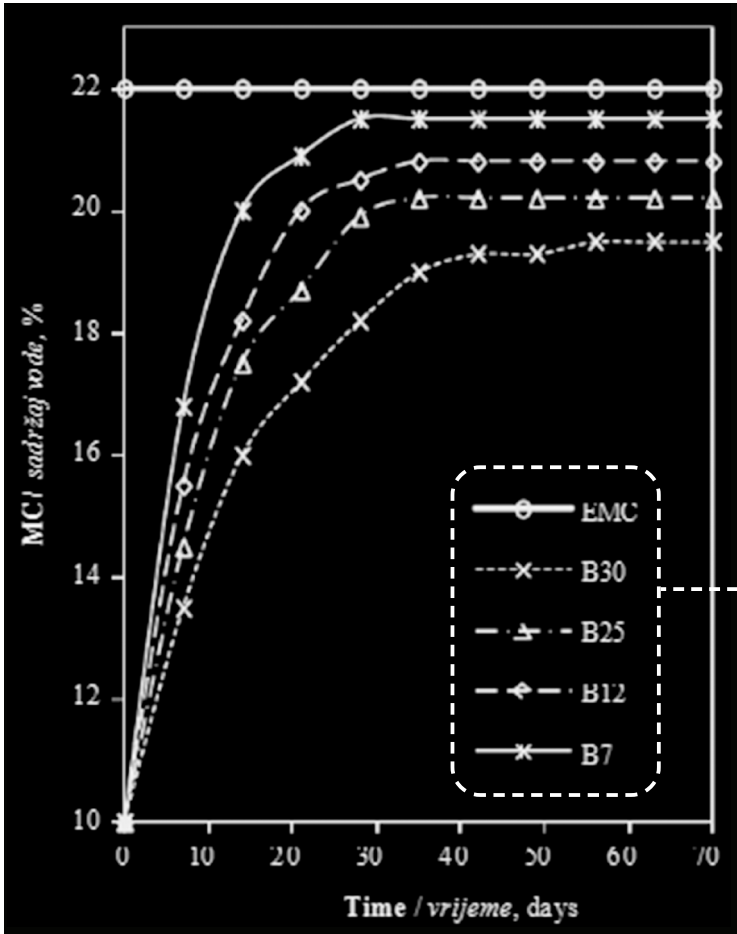


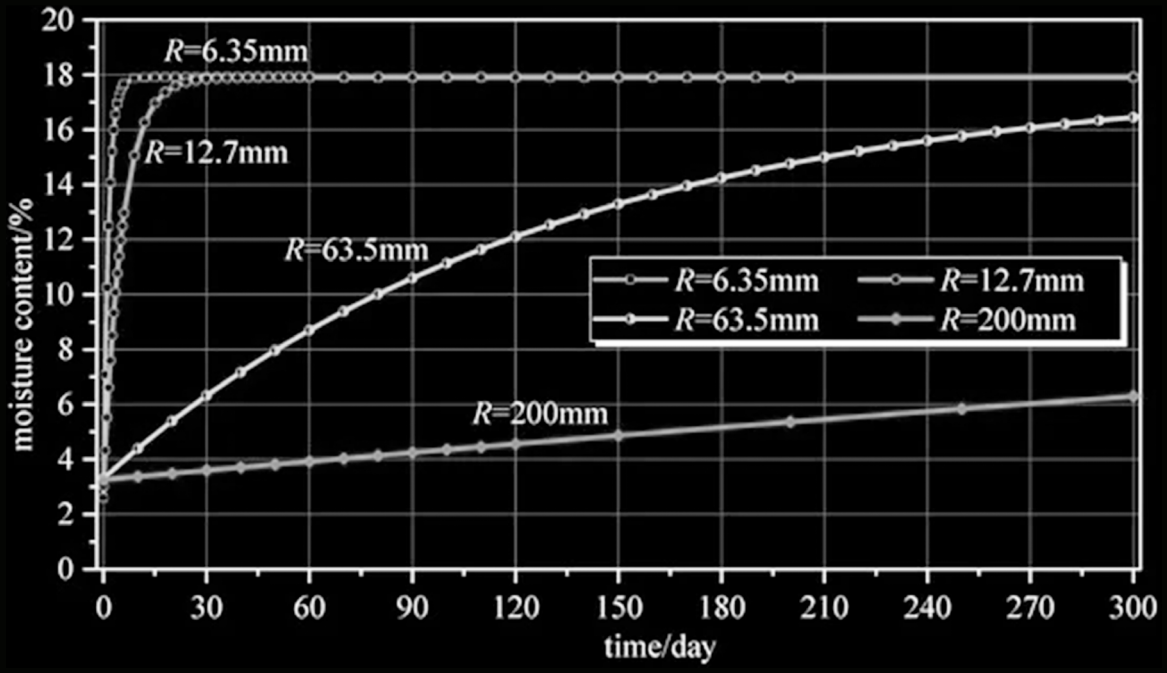


Simulating bilayer deformation

thank you

W A T E R ABSORPTION





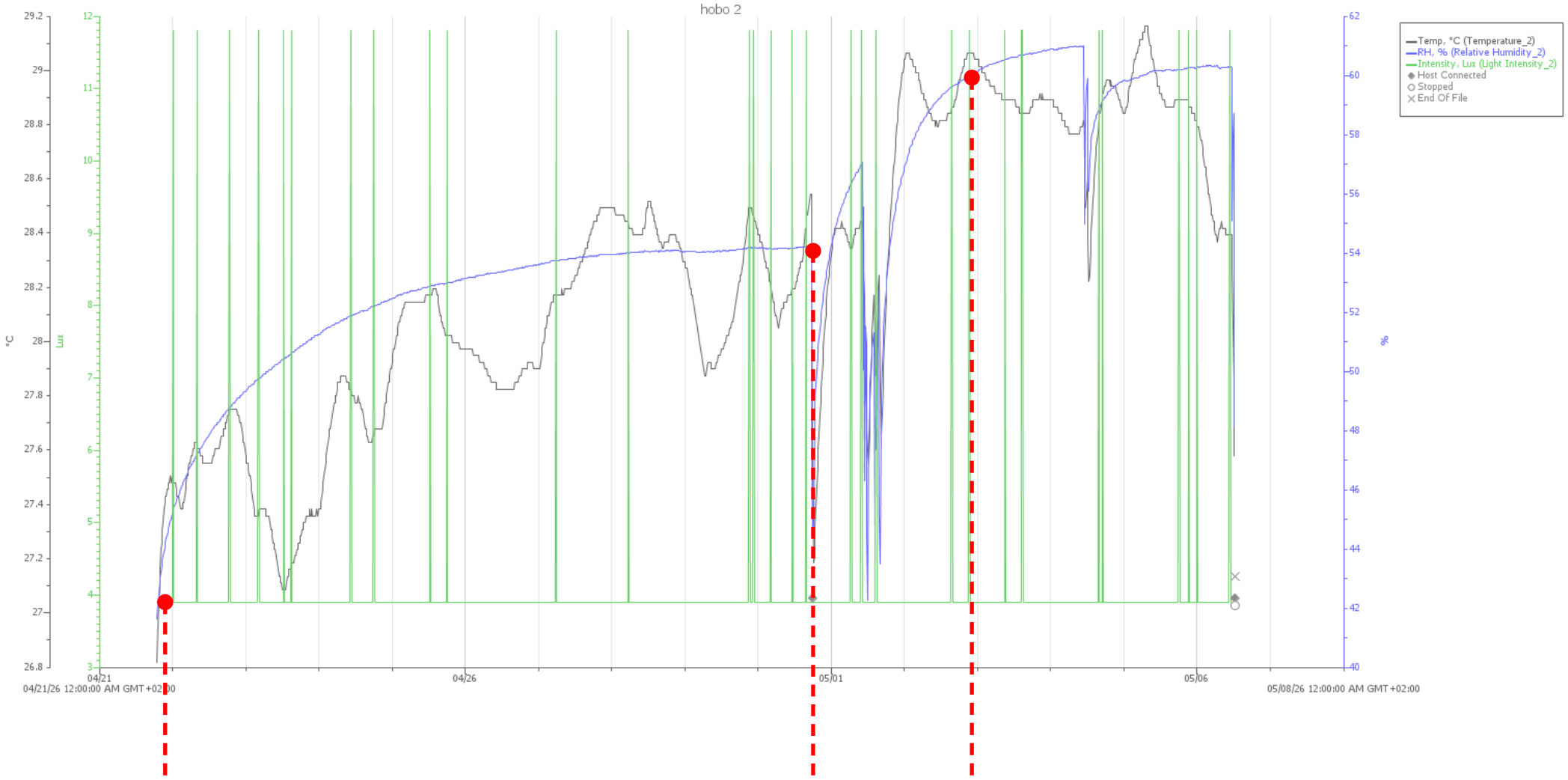
Beech samples with varied thickness;

B30 = 30mm
B25 = 25mm
B12 = 12mm
B7 = 7mm

FINAL CONCLUSIONS:

for 7.5mm thickness,
85% moisture equilibrium
within 14 days.

CONDITIONING PROCESS



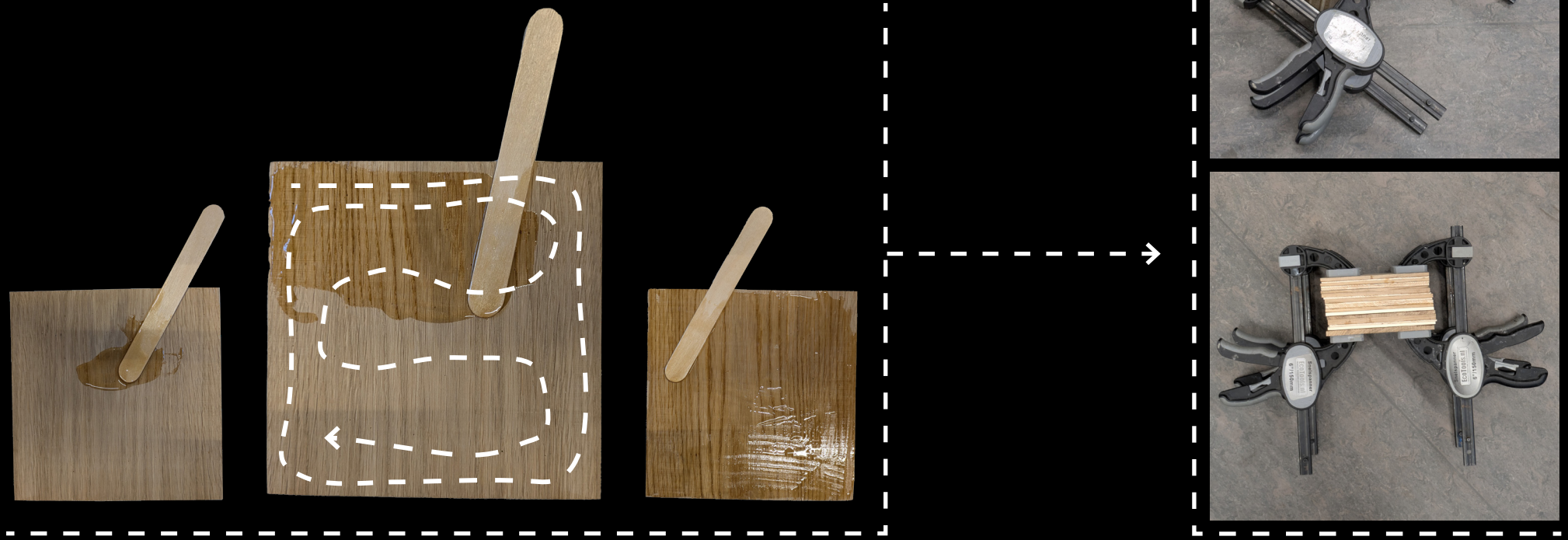
samples placed in refrigerator

more water added

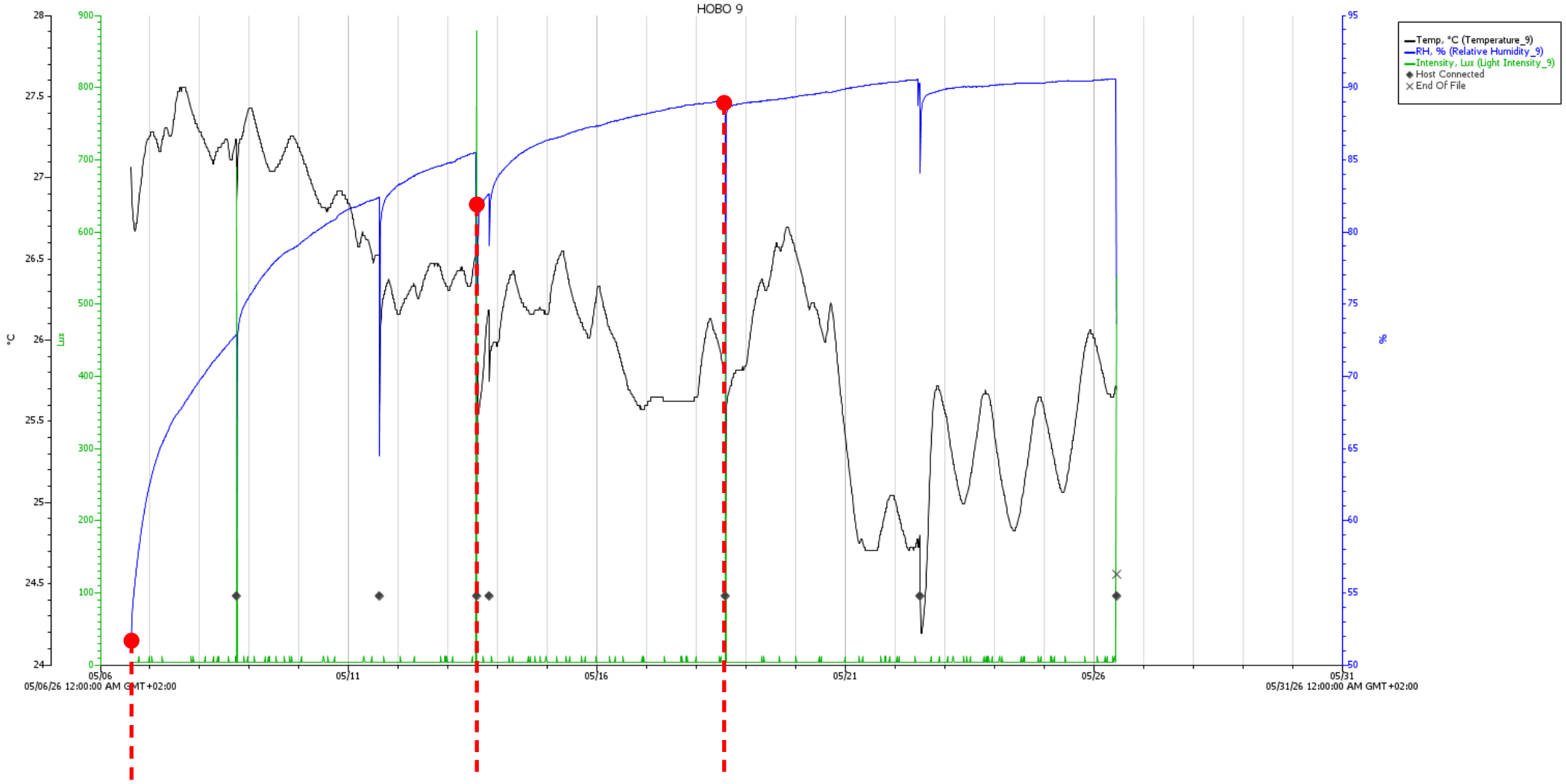
late stabilisation

LAMINATING BILAYERS

Gluing process



HUMIDIFICATION PROCESS

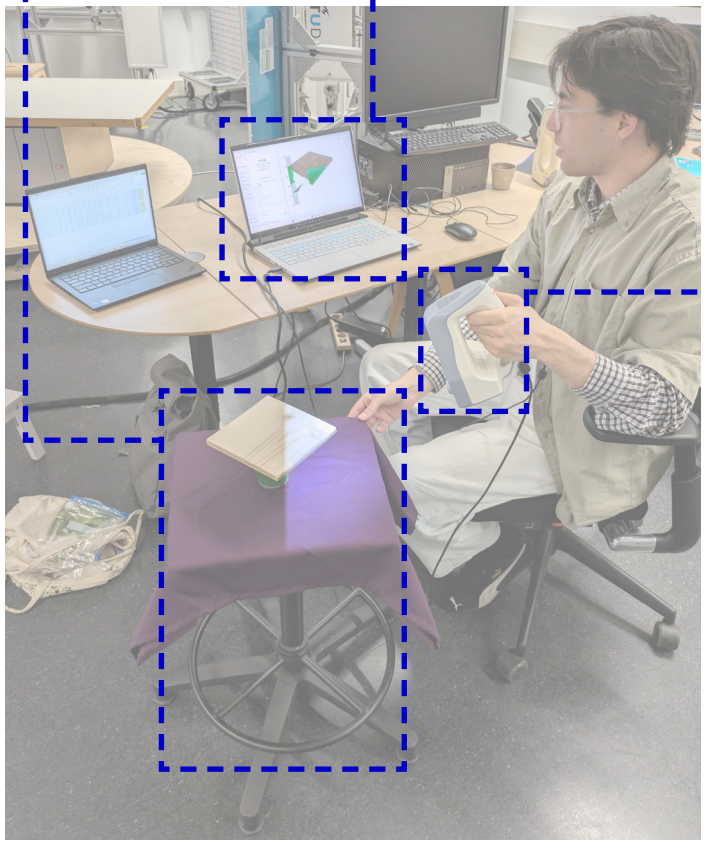


ASSESSING CURVATURE

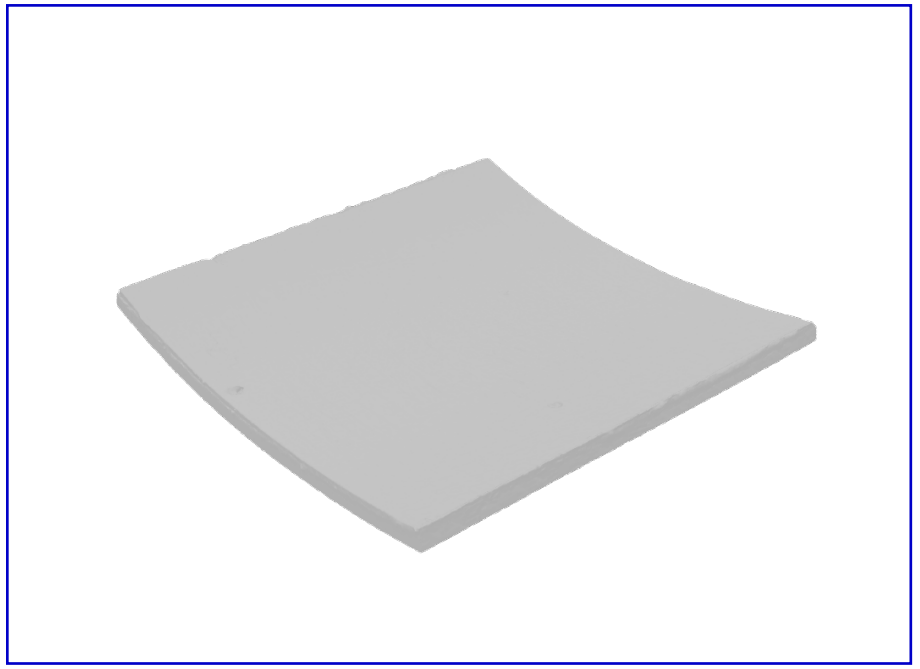
scan setup with rotating stool and cup

Artec Studio software

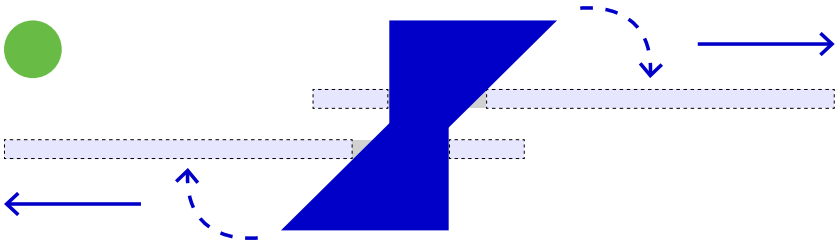
Artec Spider II

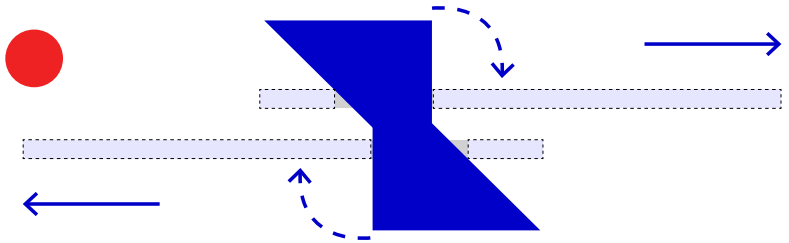


digital 3D scan



REVERSIBILITY





curve-line element

Z-lock

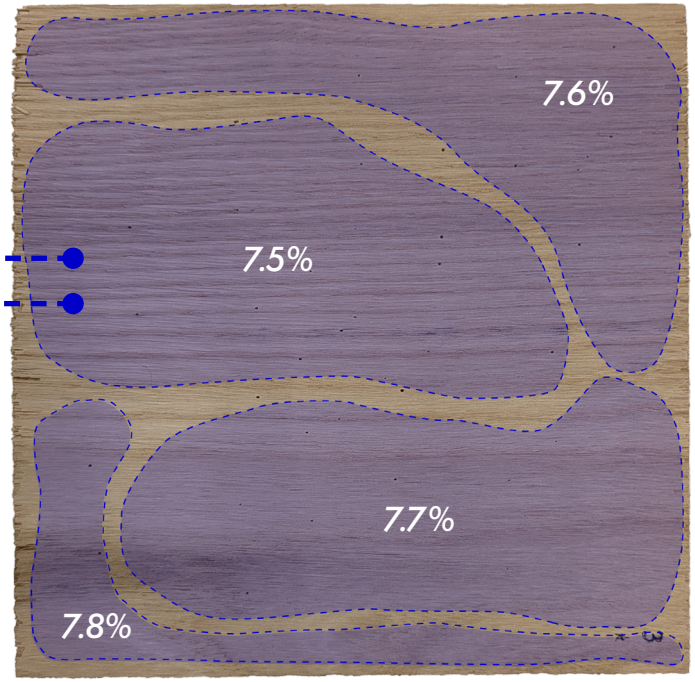
movement of curve-line elements

rotation of Z-lock

ASSESSING MOISTURE CONTENT

slight variation in results





Universal Humid Moisture Meter
from BOSCH

(BOSCH, 2026)
https://www.bosch-diy.com/sa/en/p/universalhumid-0603688001

ASSESSING MOISTURE CONTENT

wood moisture content



vs.

> 1%

L I M I T E D S P A C E



95% RH



limited refrigerator space

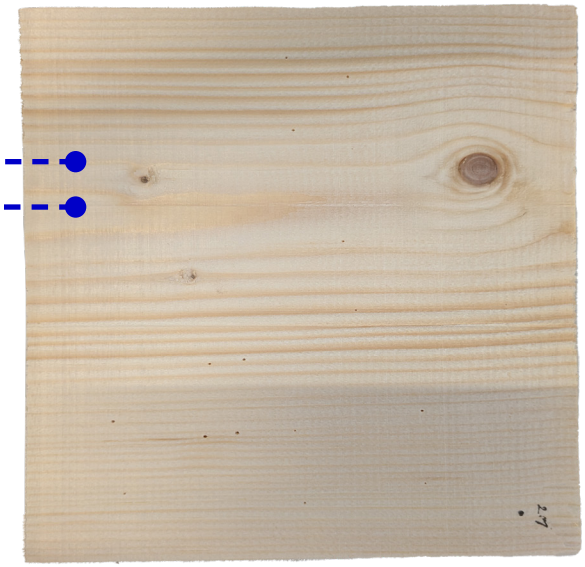
RE-ASSESSING MOISTURE CONTENT



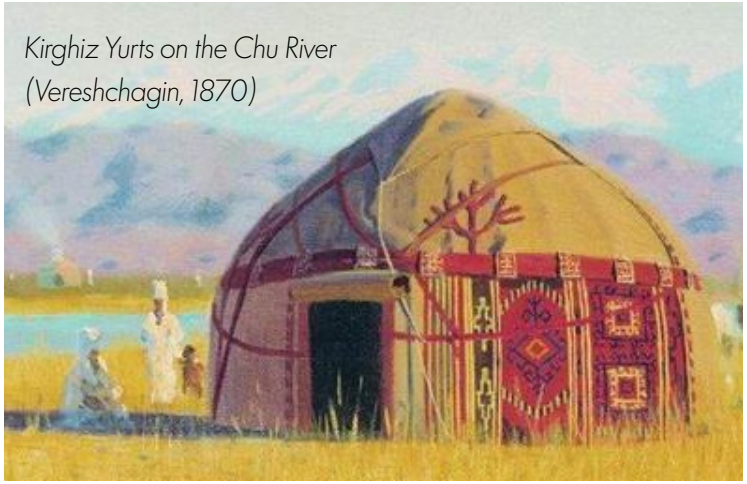
Universal Humid Moisture Meter
from BOSCH

(BOSCH, 2026)
https://www.bosch-diy.com/sa/en/p/universalhumid-0603688001

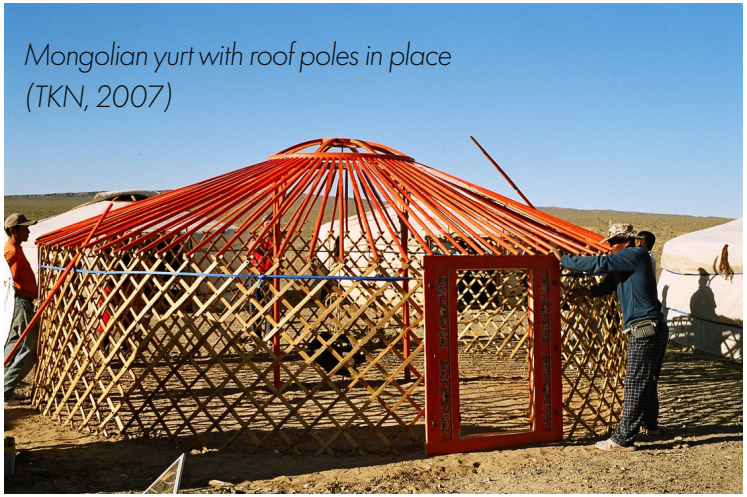




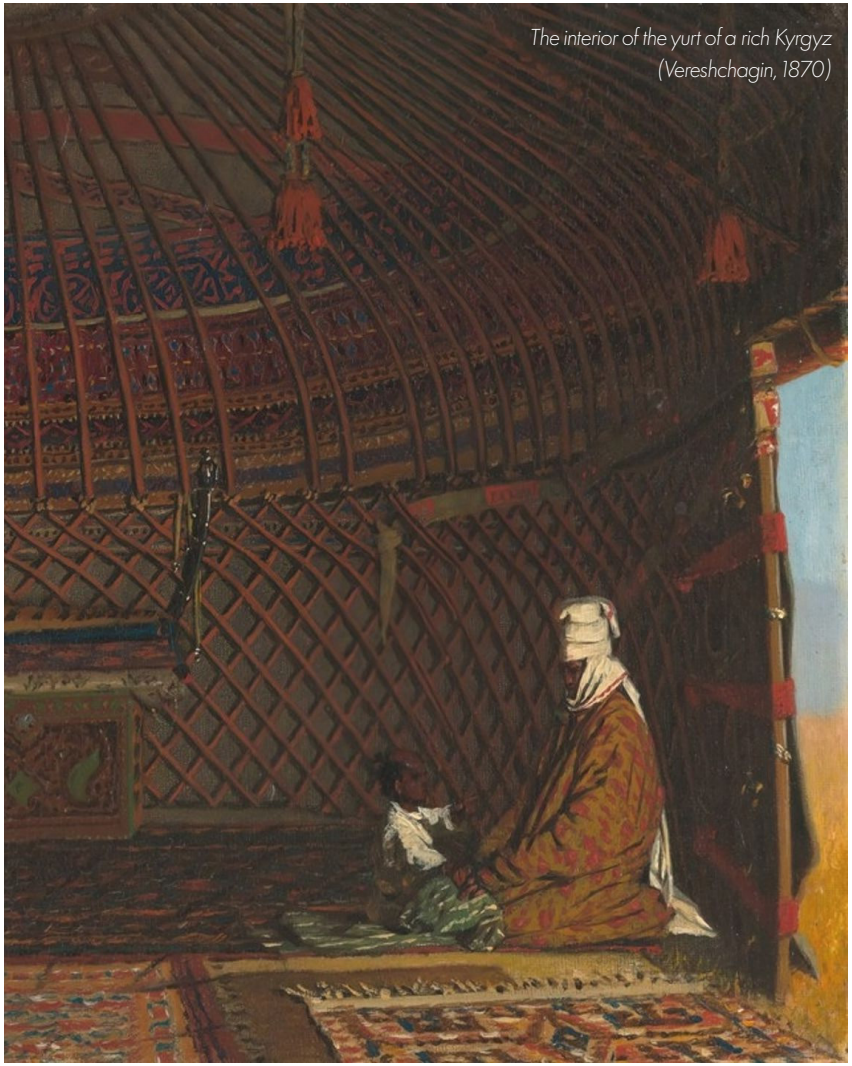
> 1.5%



Kirghiz Yurts on the Chu River
(Vereshchagin, 1870)

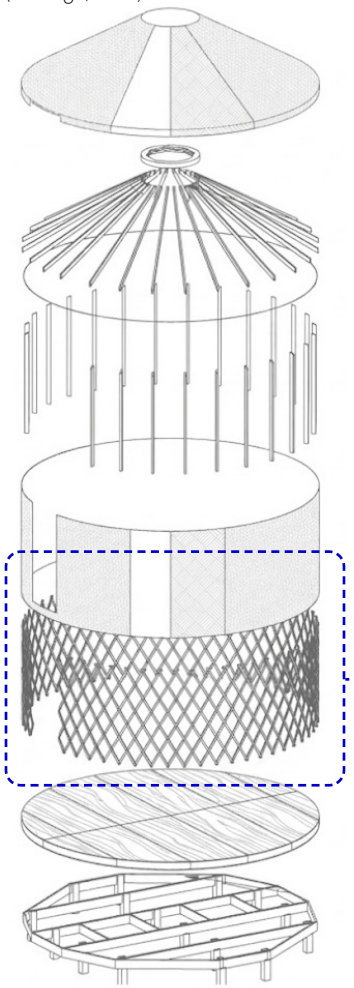


Mongolian yurt with roof poles in place
(TKN, 2007)



The interior of the yurt of a rich Kyrgyz
(Vereshchagin, 1870)

Exploded yurt axonometric
(Santiago, 2013)



LATTICE FRAME

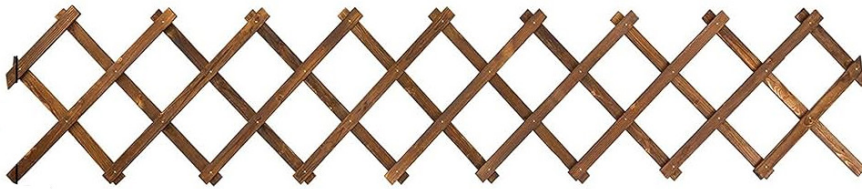
01



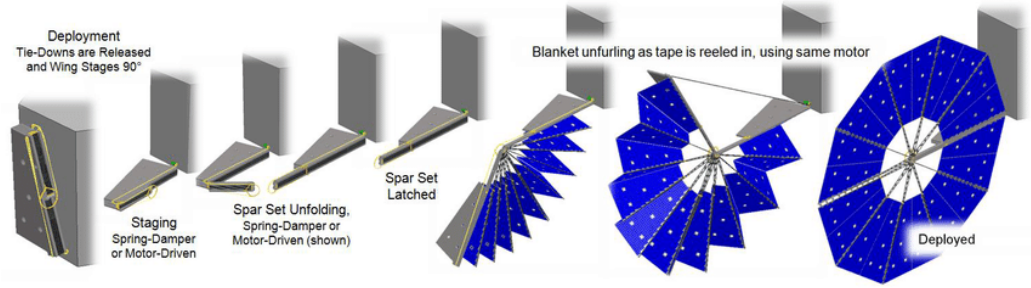
02

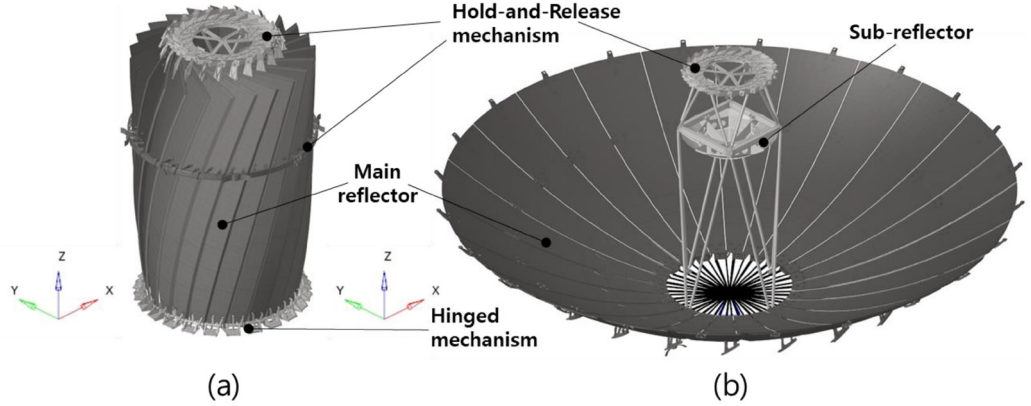


03



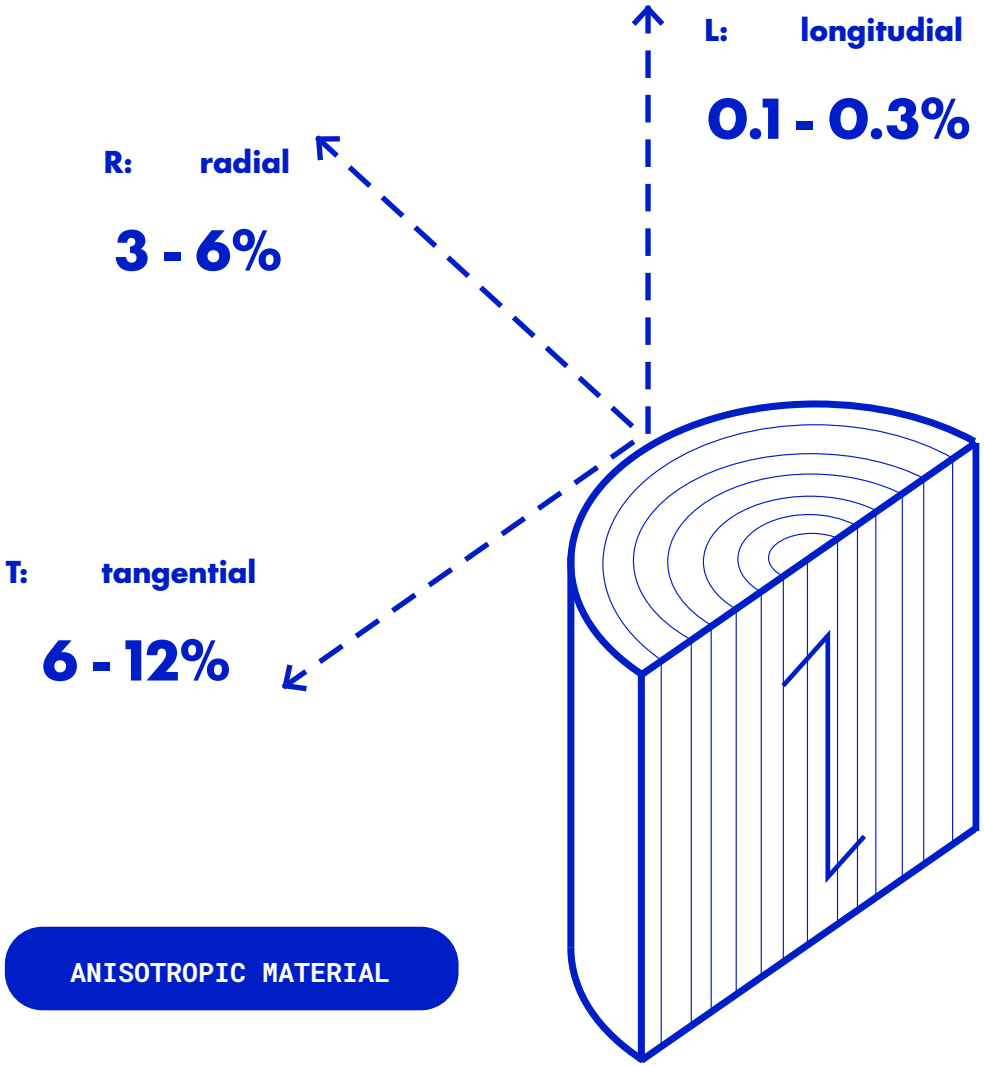
Solar Array
(Straubel et al., 2016)





Space antenna
(Kim et al., 2024)

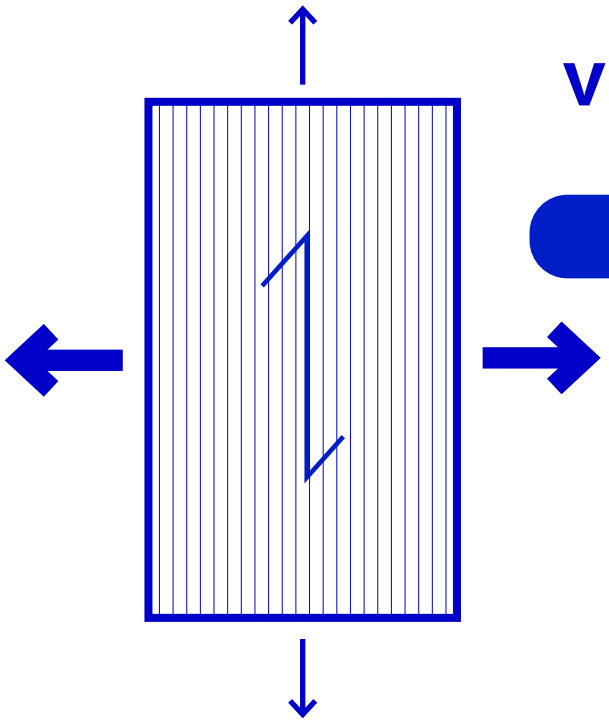
WHAT?



ANISOTROPIC MATERIAL

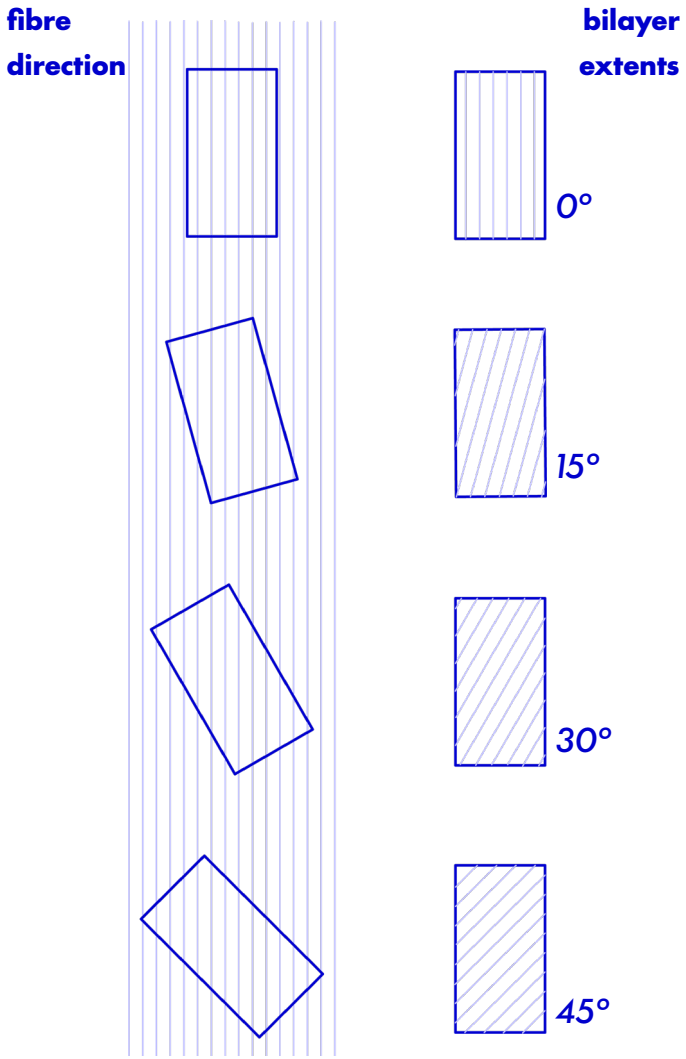
WHAT?

ALONG THE FIBRE



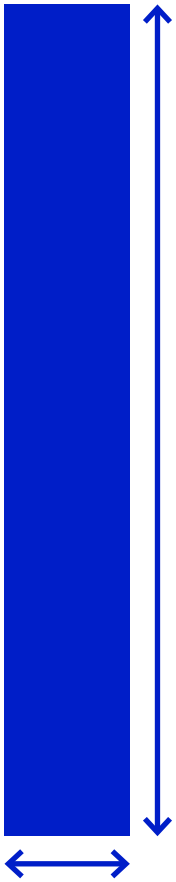
VS.

PERPENDICULAR

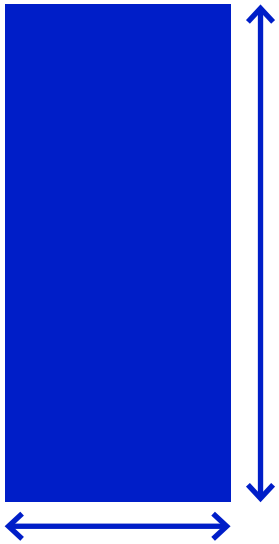


WHY?

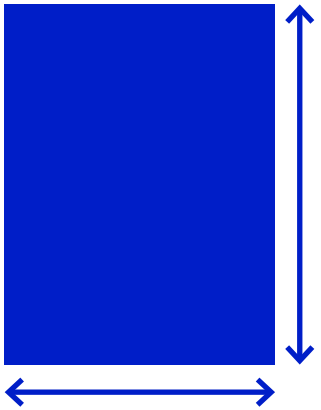
high aspect ratio



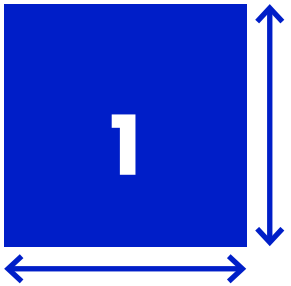
moderate aspect ratio



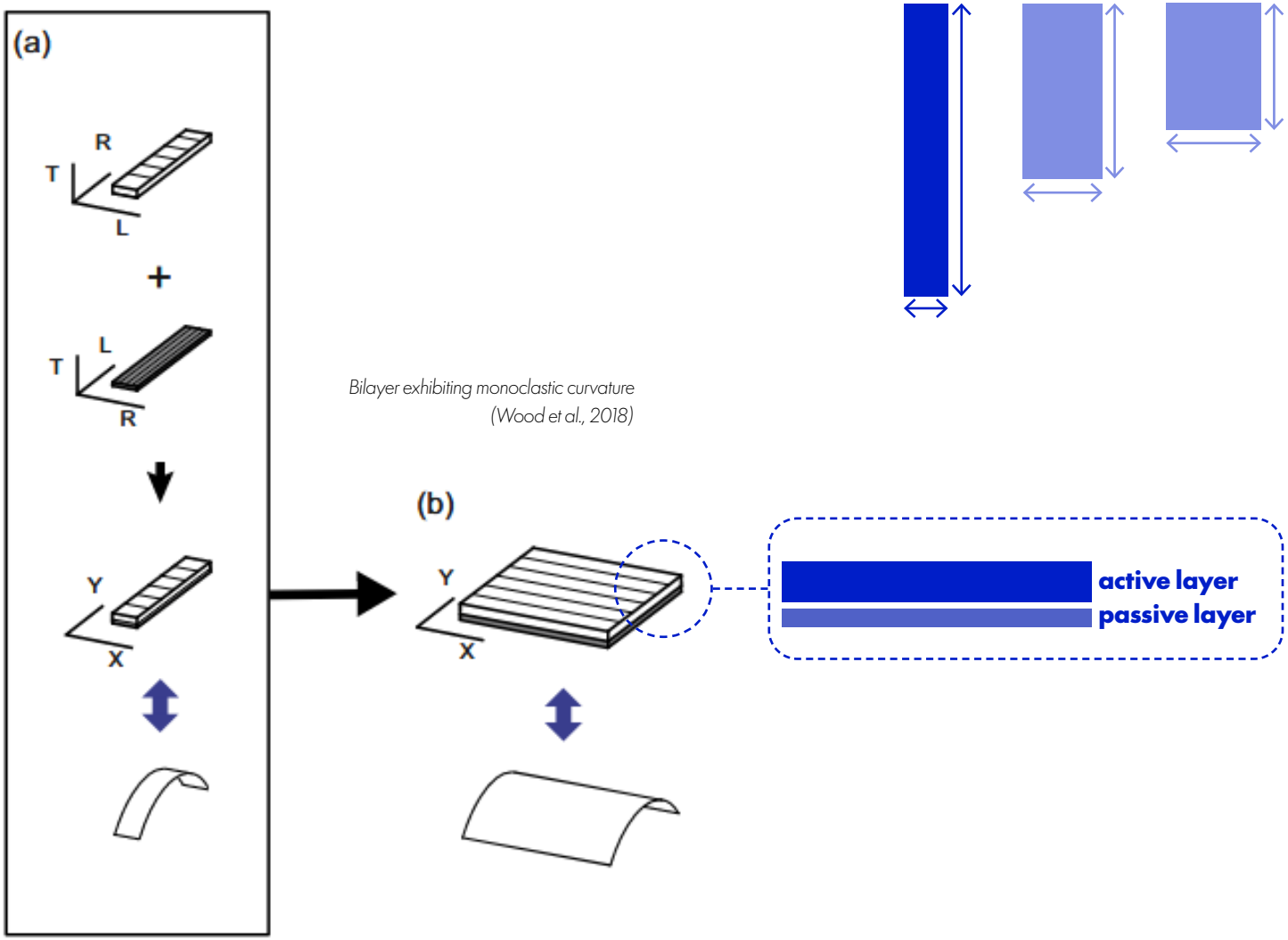
low aspect ratio



$$\frac{\text{LENGTH}}{\text{WIDTH}}$$

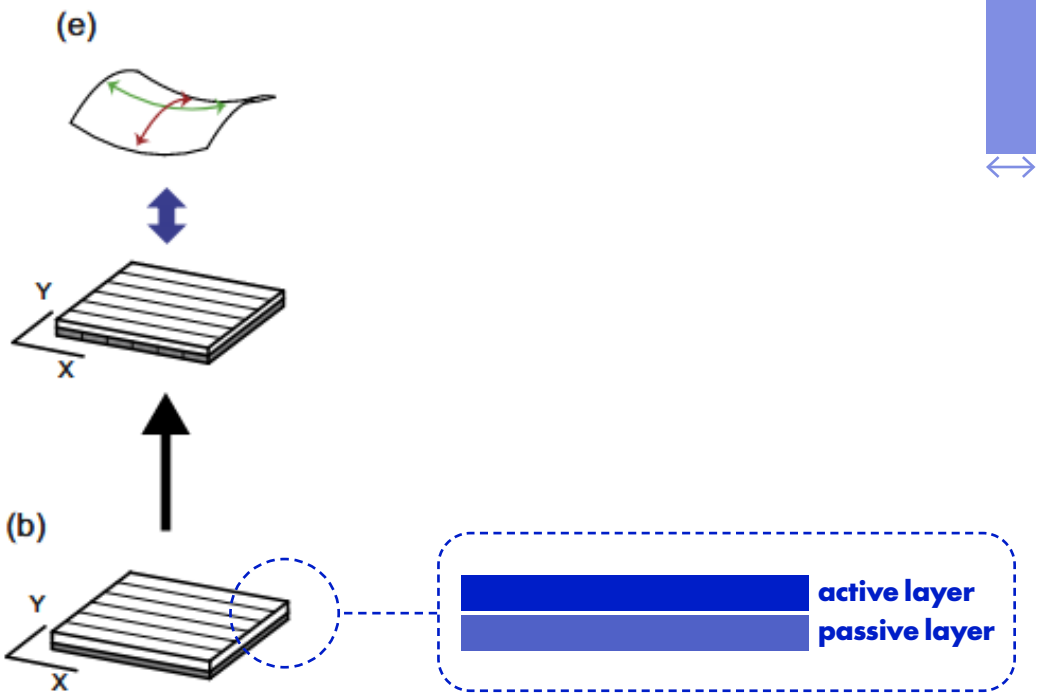


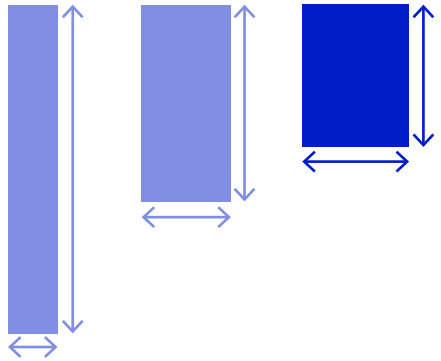
WHY?



Bilayer exhibiting monoclastic curvature
(Wood et al., 2018)

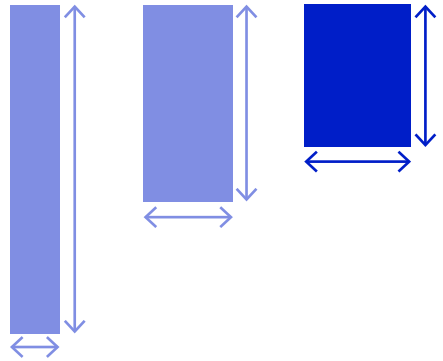
WHY?



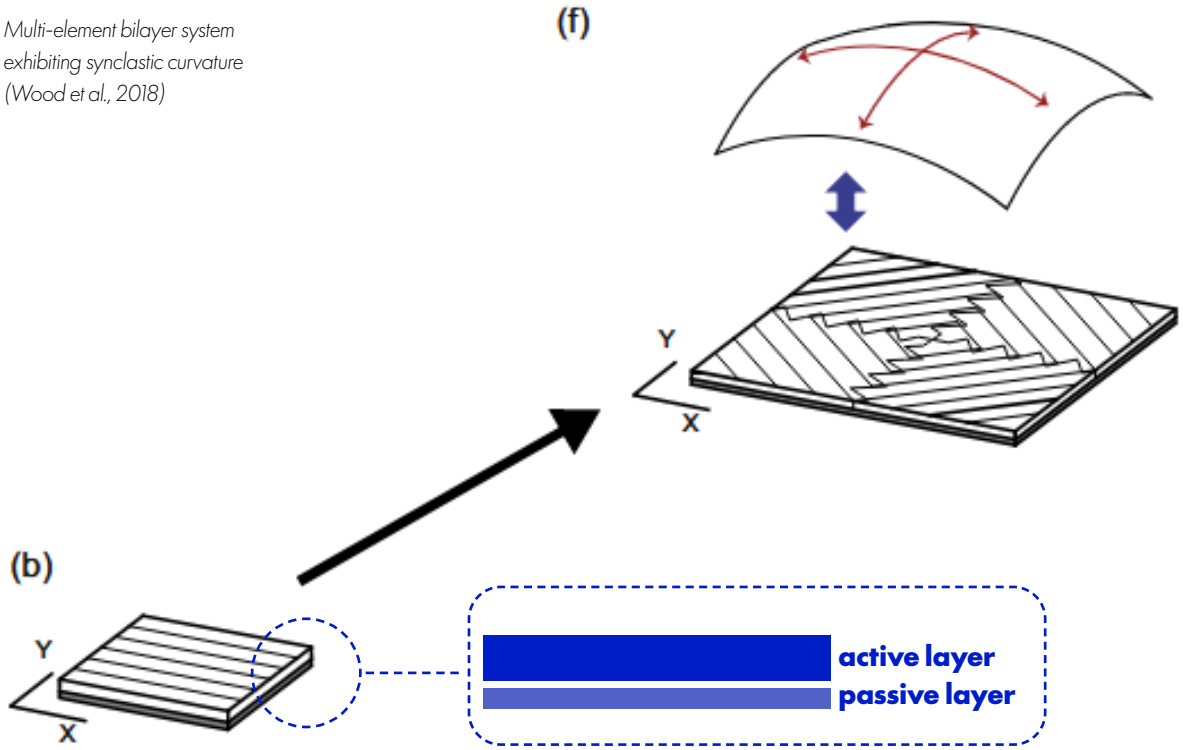


Bilayer exhibiting anticlastic curvature
(Wood et al., 2018)

WHY?

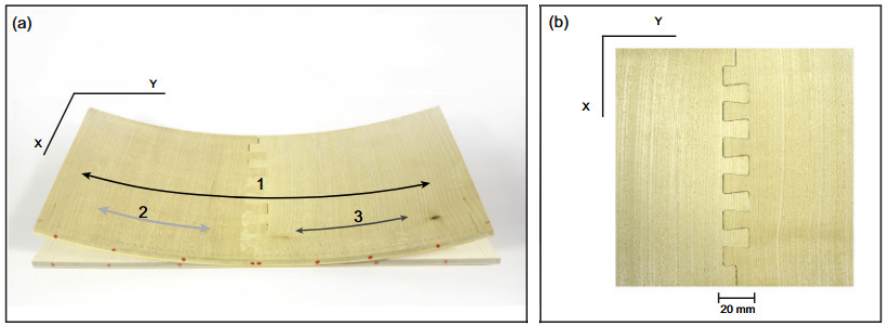


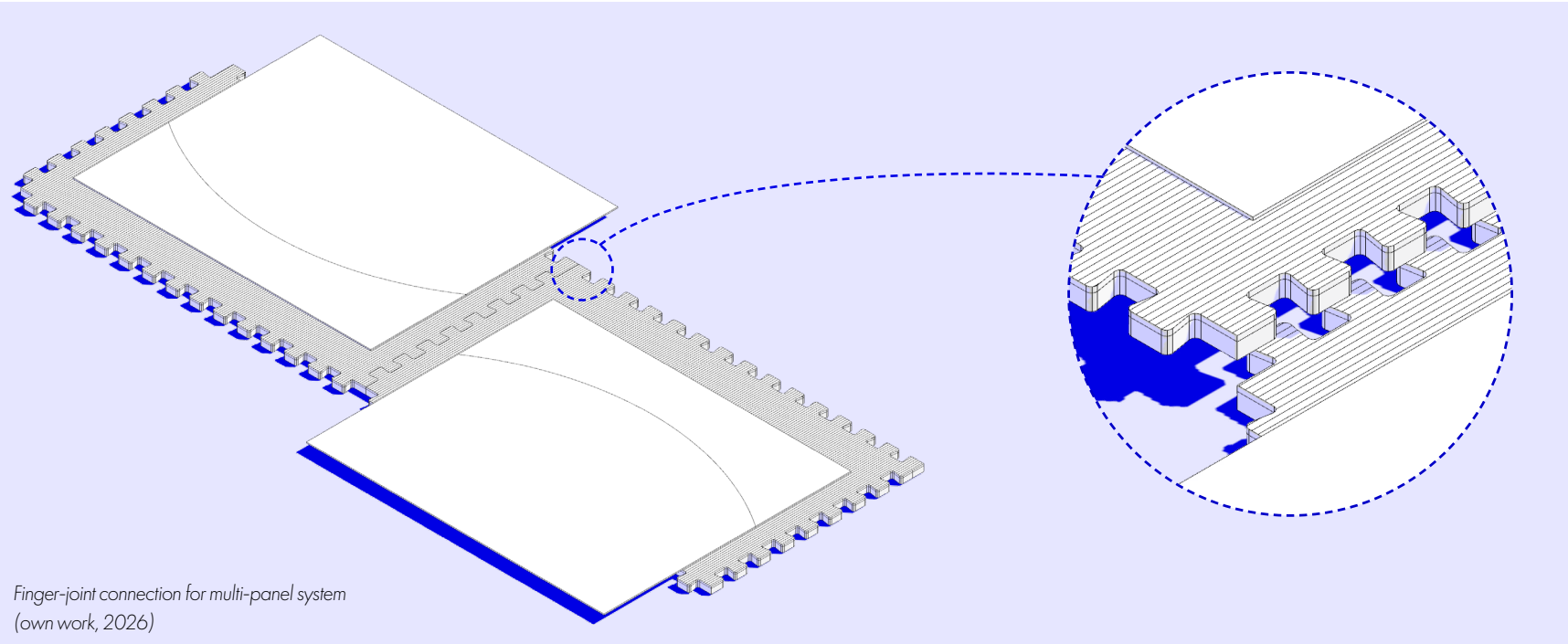
Multi-element bilayer system exhibiting synclastic curvature (Wood et al., 2018)



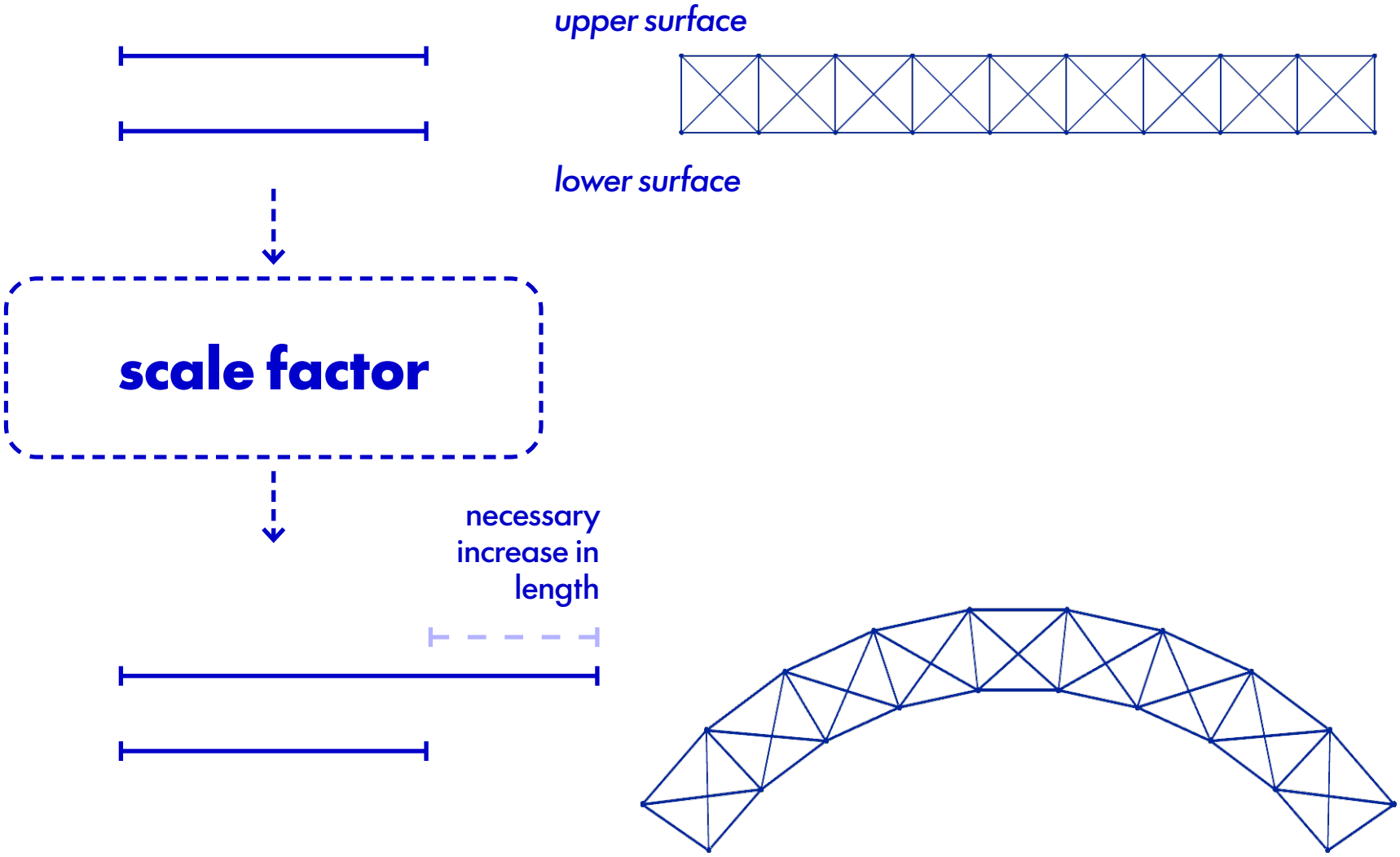
HOW?

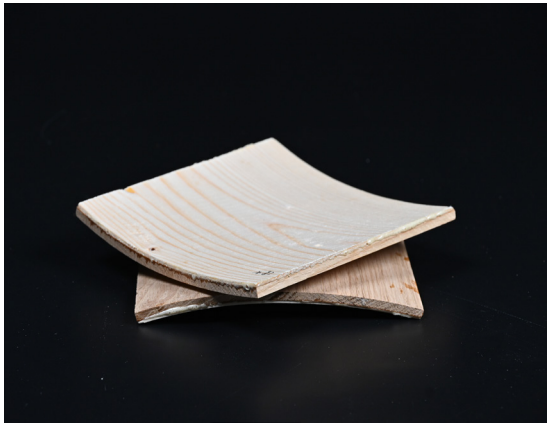
Finger-joint connection for simple connection (Wood et al., 2018)



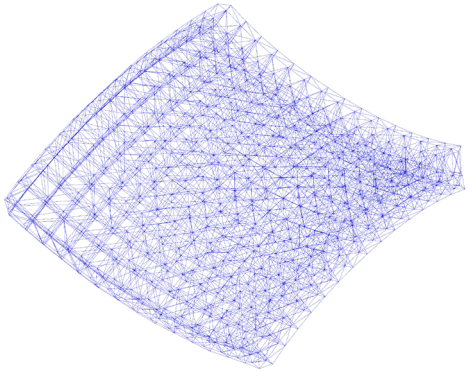


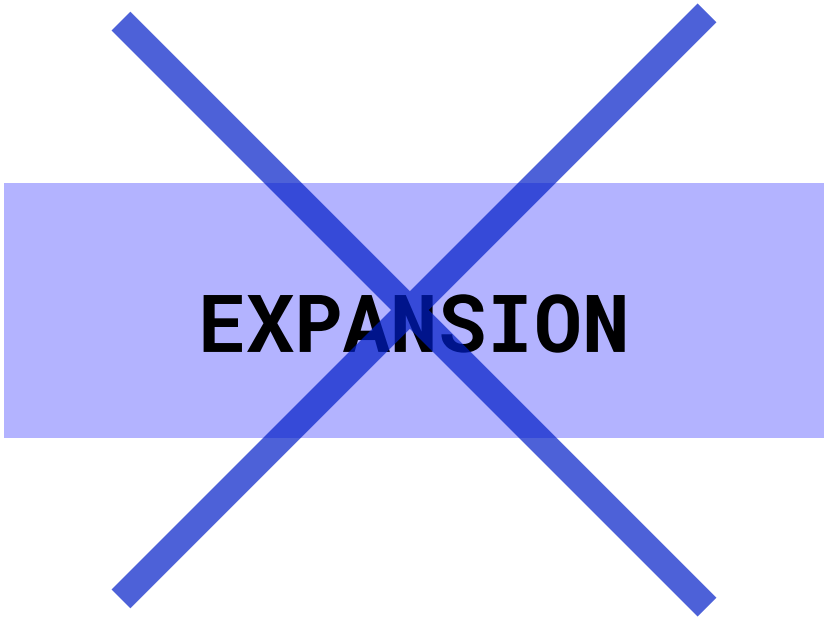
Finger-joint connection for multi-panel system (own work, 2026)

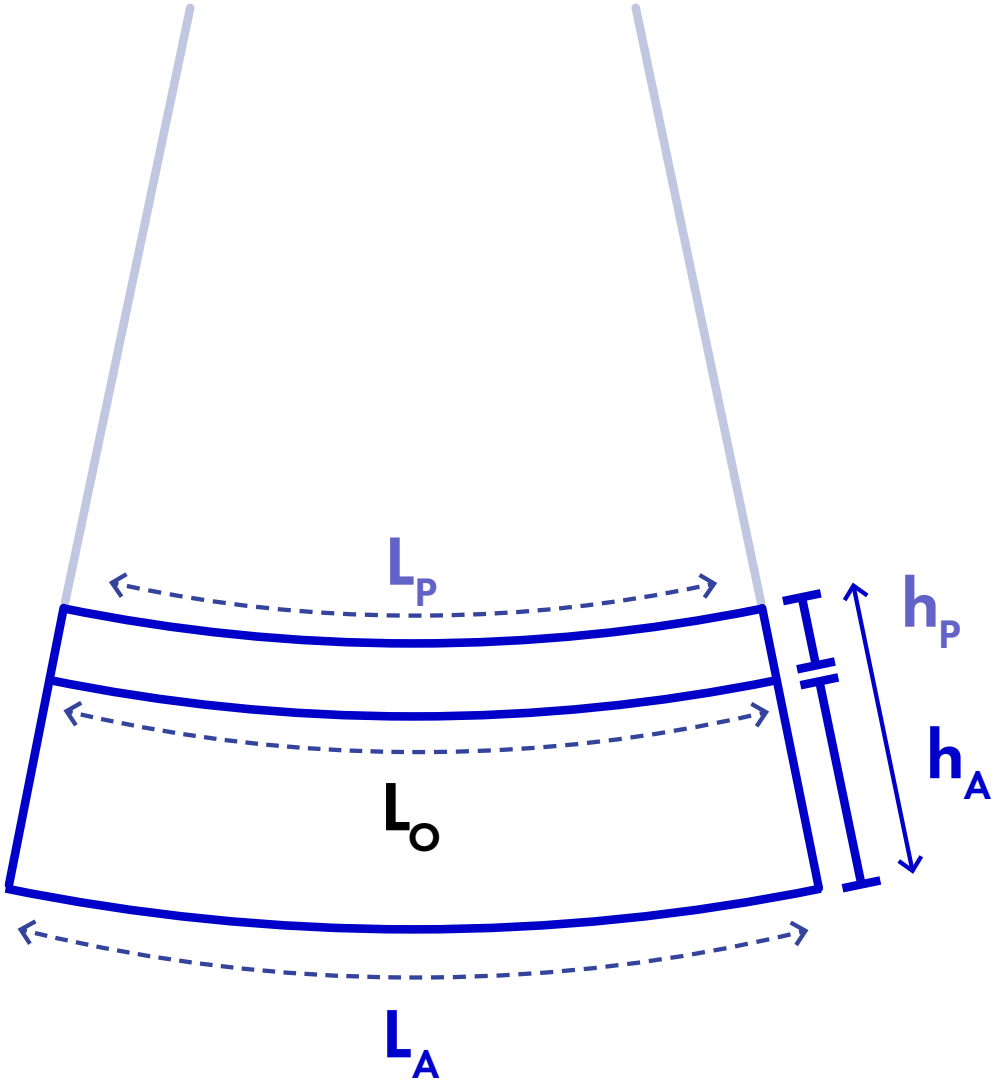

upper surface
lower surface
scale factor
necessary
increase in
length



numerical values

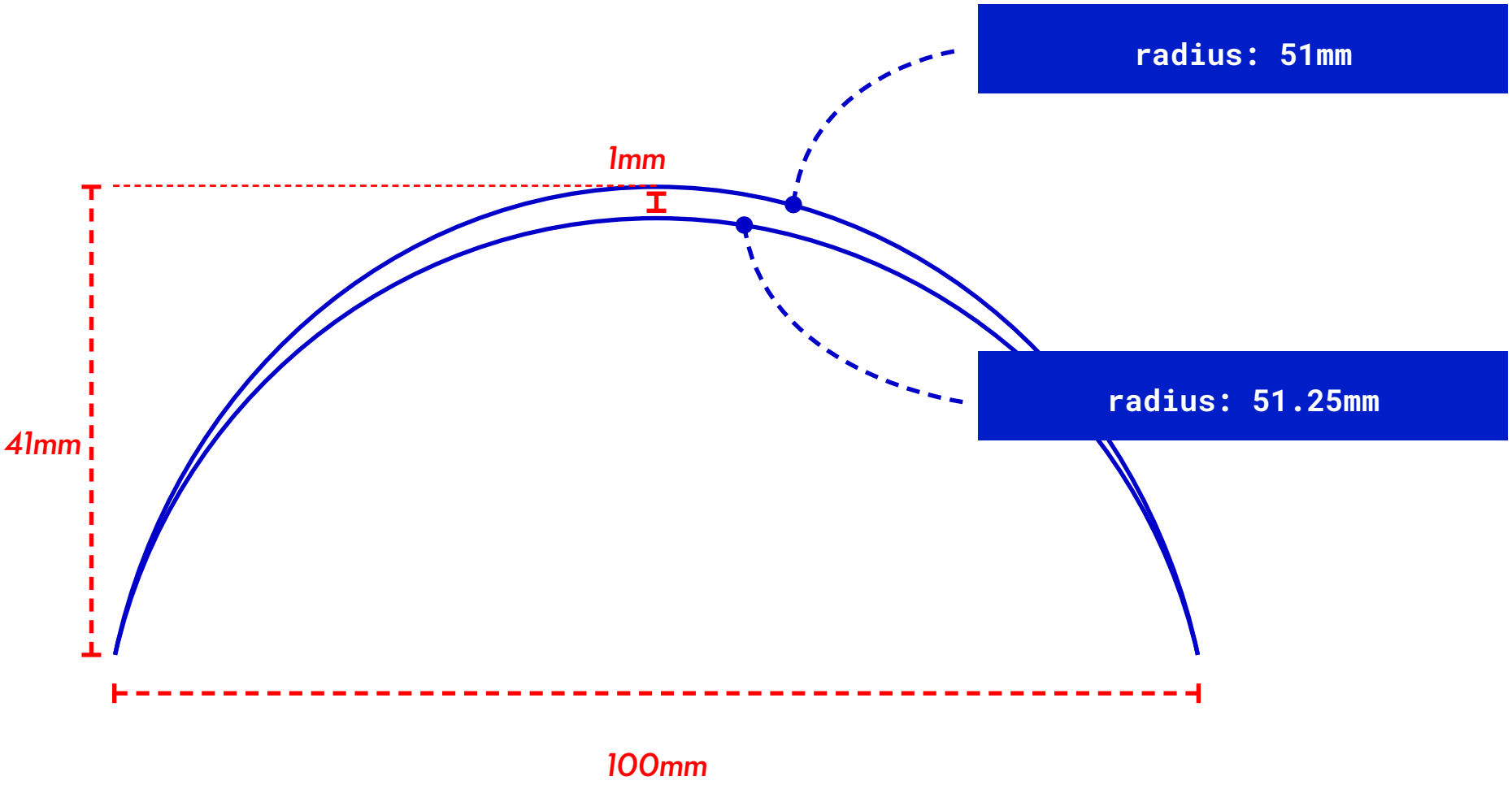



EXPANSION

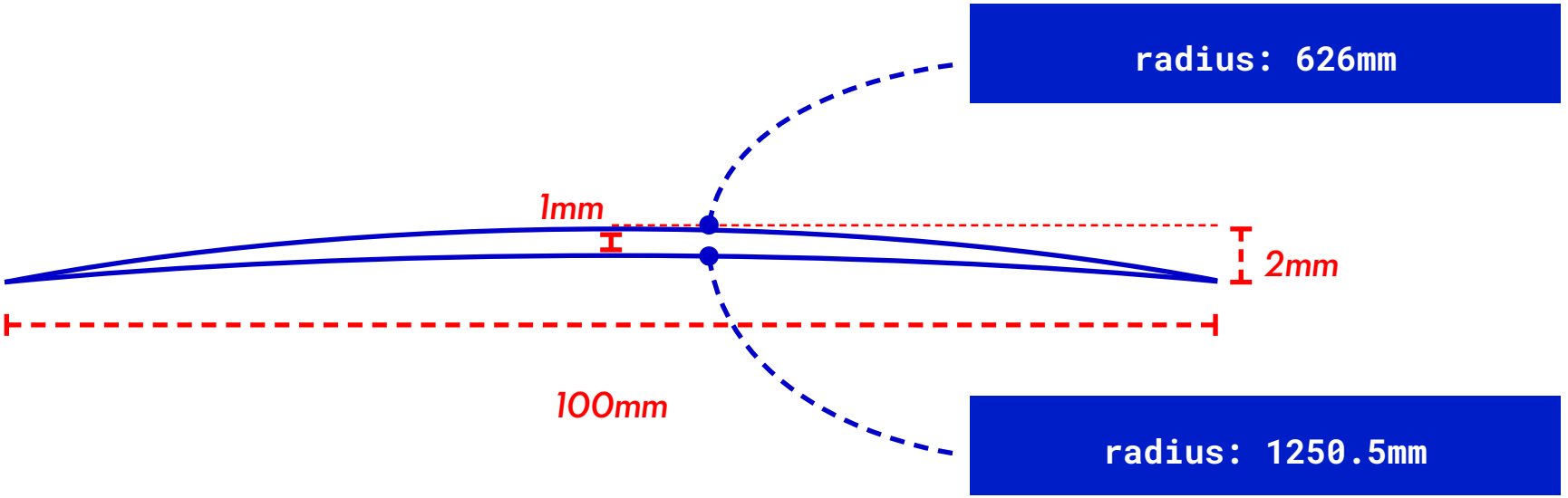


scale factor

$$\frac{L_A}{L_O} \quad \& \quad \frac{L_P}{L_O}$$



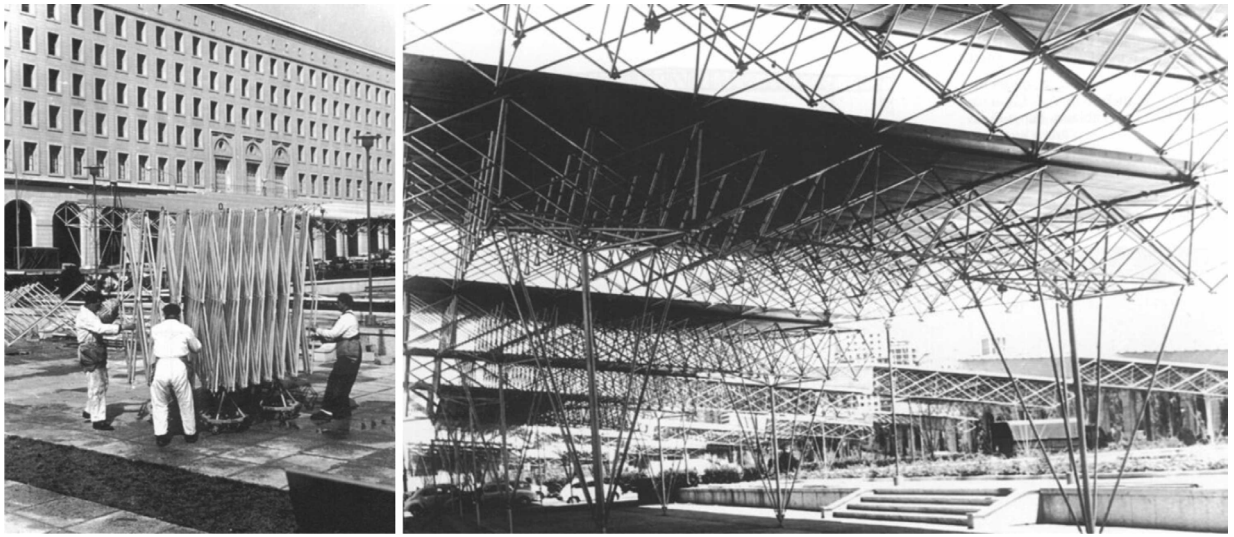
difference: 0.25mm



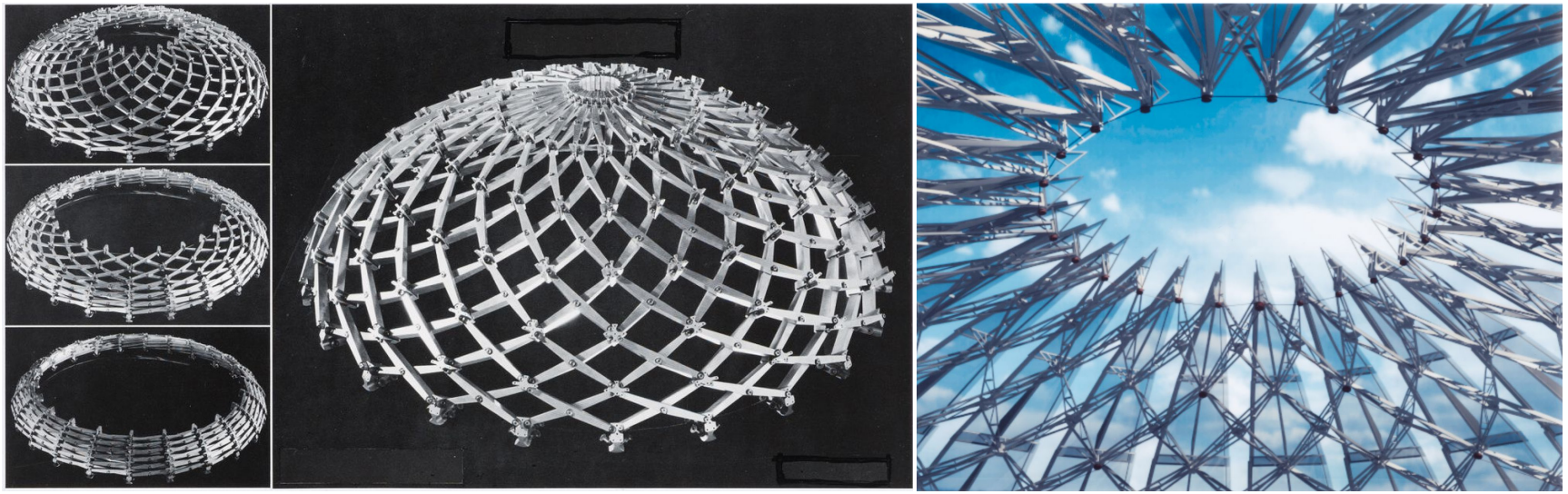
difference: 624.5mm



San Pablo swimming pool in Seville
(Escrig et al., 1995)



Transportable Pavilion by Emilio Perez Pinero (Pinero, 1964)



Iris Dome by Chuck Hoberman
(Hoberman, 1994)