



4D-Printed Shape Memory Polymers for Responsive Façades

From Deformation Behavior to Environmental Performance

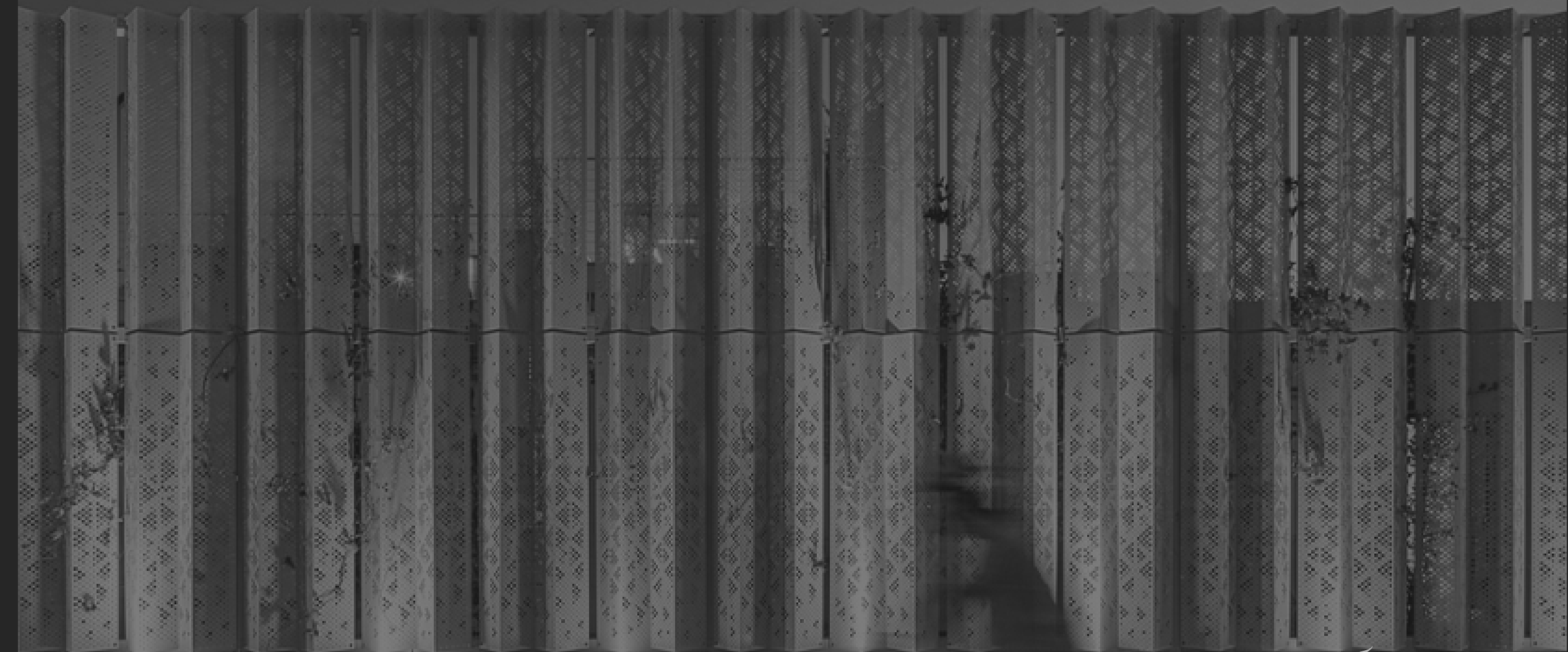
Yu Ai Jiang (Ellen) 2026.06.23









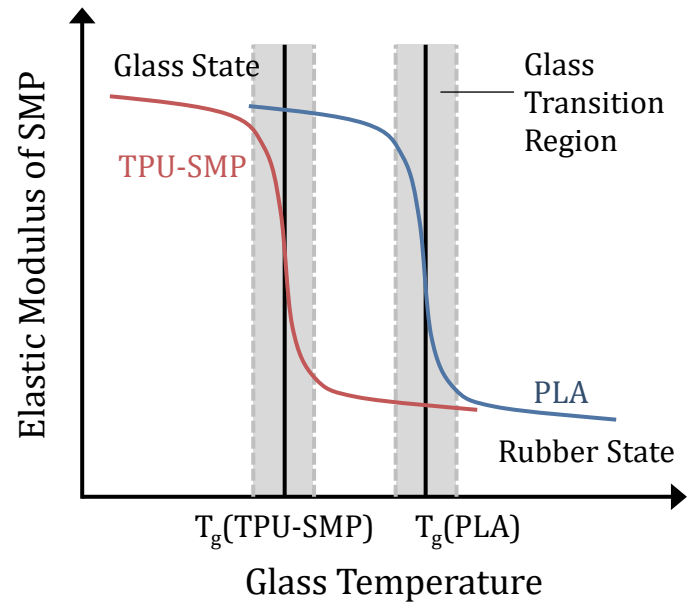


Why Passive Responsive Façade?

Ref <https://www.claddingci.com/facade-systems/full-cladding>



SMP Mechanism



What is Shape Memory Polymers?



A close-up, black and white photograph of a 3D printer nozzle printing a white, rectangular object on a dark, reflective surface. The nozzle is positioned directly above the object, and the background is blurred, showing the internal components of the printer.

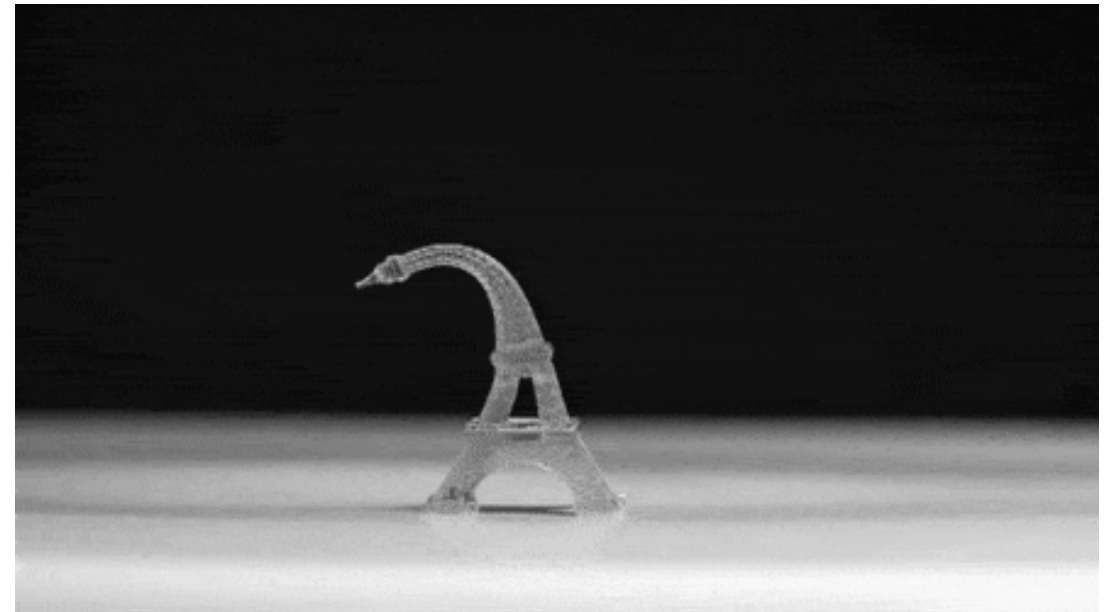
*“ The 4th dimension is identified as **TIME**. ”*

What is 4D printing?

“4D printing is the creation of objects which alter their shape when removed from a 3D printer. These objects self-assemble when exposed to the water, heat, and air, etc. due to the chemical reaction of material used. ”



Ref: https://news.cgtn.com/news/3d63544e314d444e/share_p.html



Ref: <https://medium.com/@1shirleyyang2008/the-potential-of-4d-printing-revolutionizing-industries-and-transforming-the-world-b84dfd704456>

What is 4D printing?

Main Research Question:

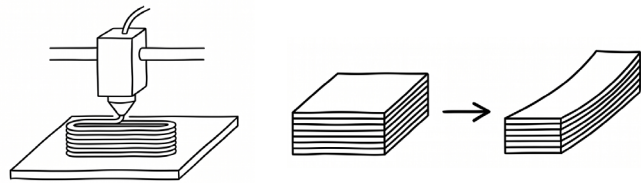
How can 4D-printed Shape Memory Polymers be used to create a climate-responsive façade?

How do 4DP parameters (infill pattern, thickness, and infill ratio) affect the deformation behavior of SMP elements?

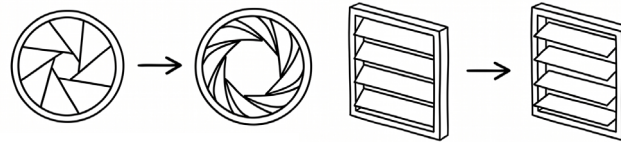
How can these programmed deformations be translated into effective passive adaptive façade mechanisms?

What performance improvements in Indoor Environmental Quality (IEQ) can be achieved through such systems?

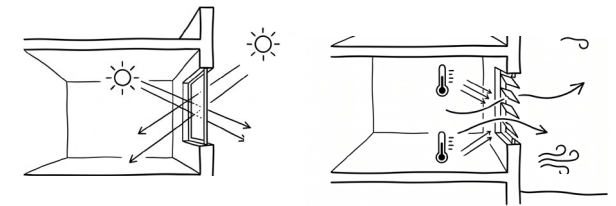
Material Behavior



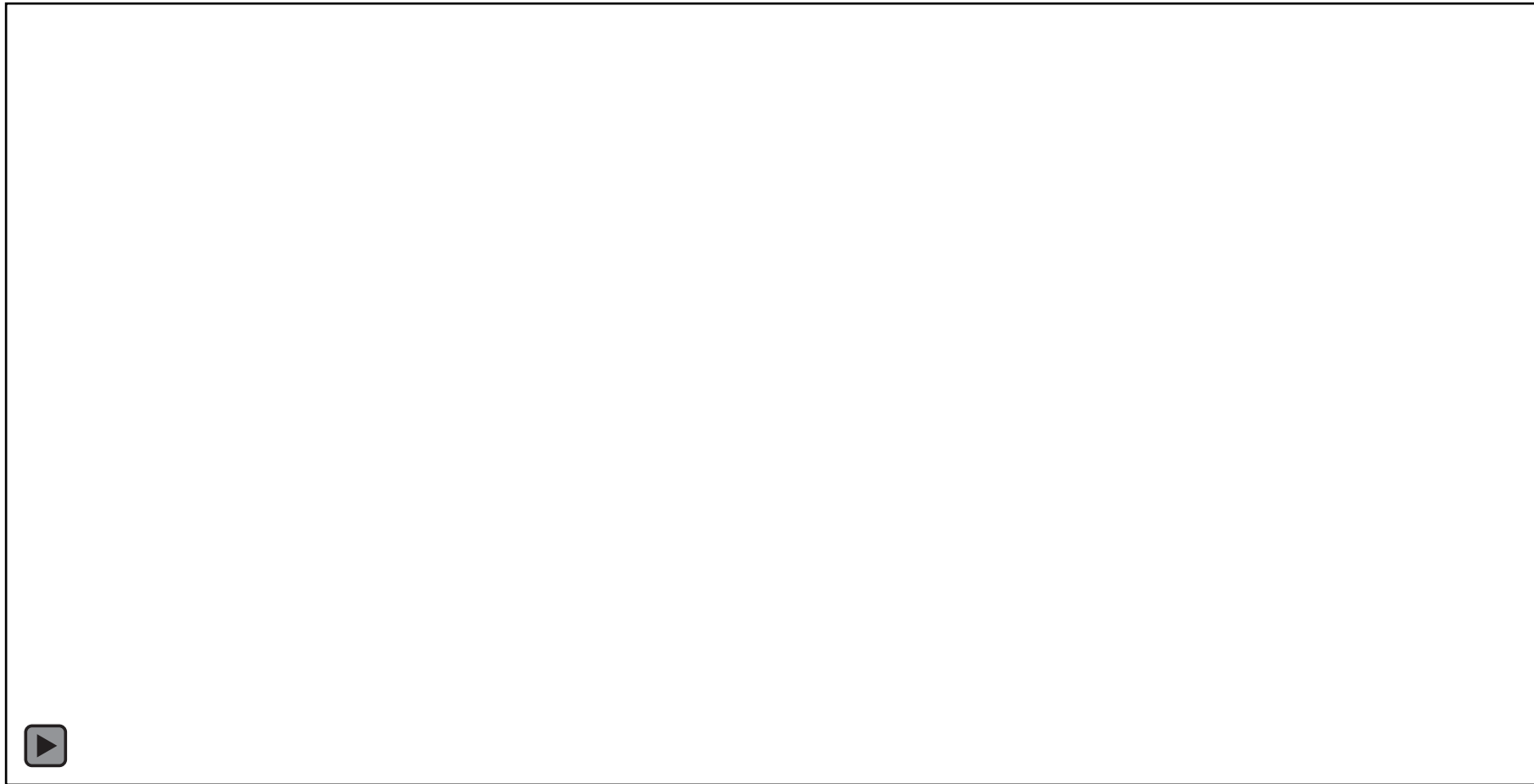
System Integration

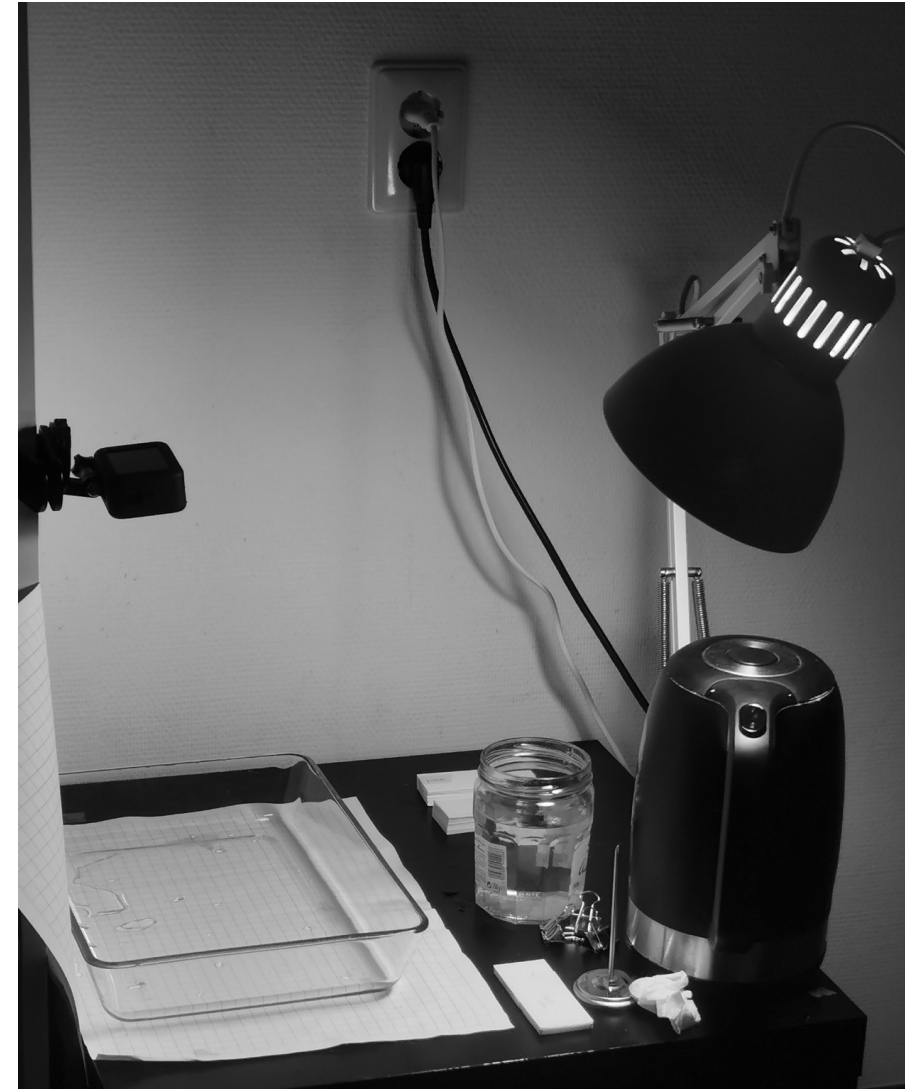
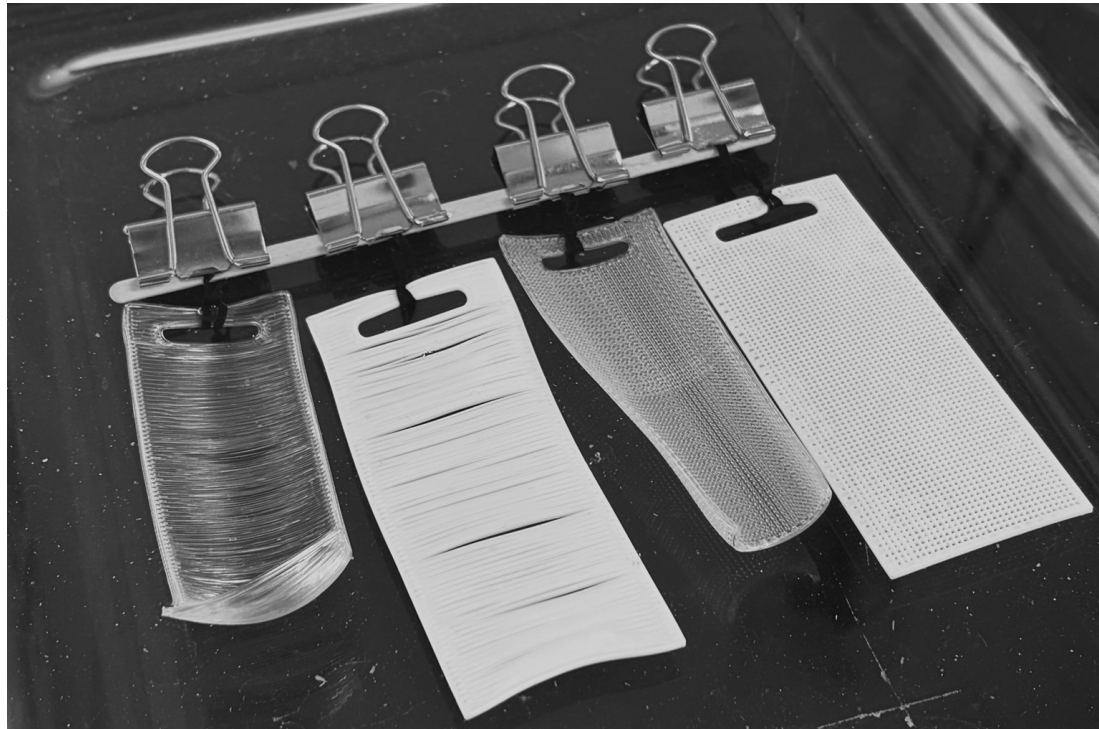
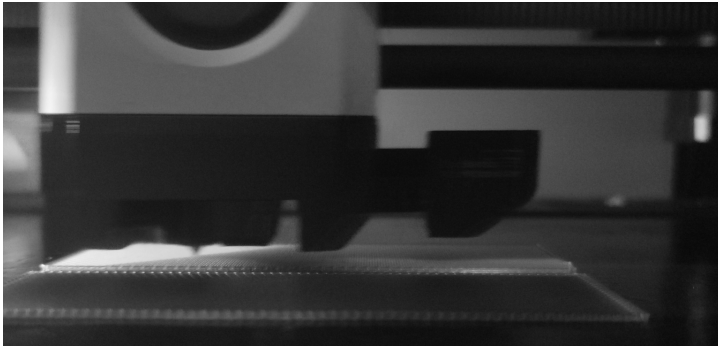


Performance Evaluation



How do 4D printing parameters affect the deformation behavior of SMP elements?

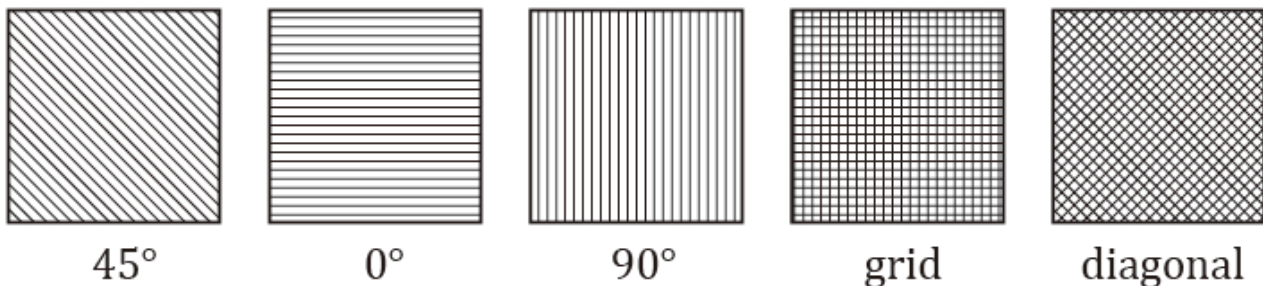




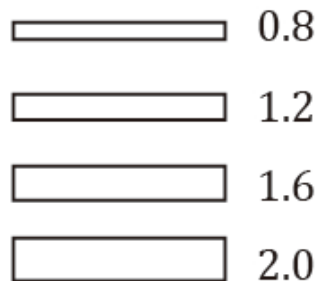
Experiment Workflow: Thermal Activation and Cooling

Printing Parameters

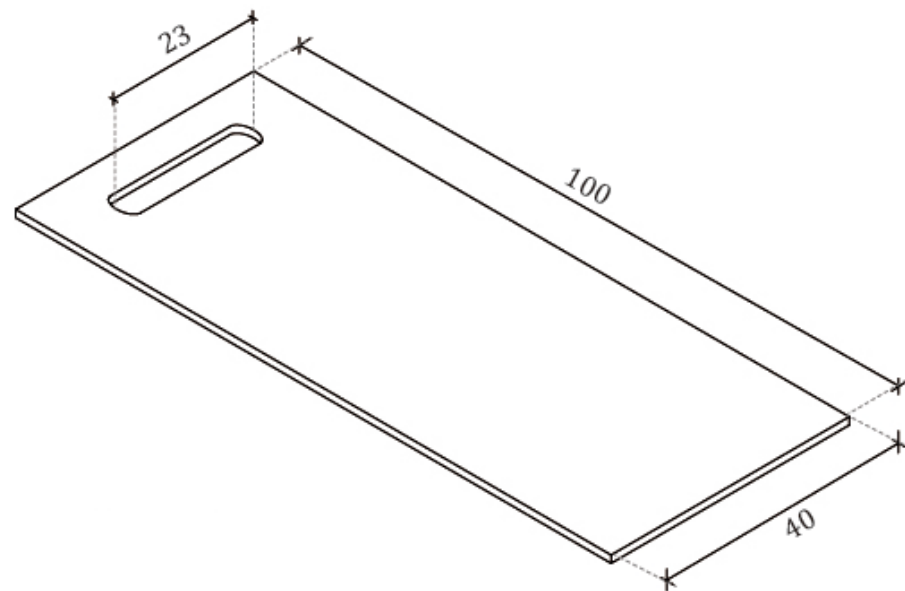
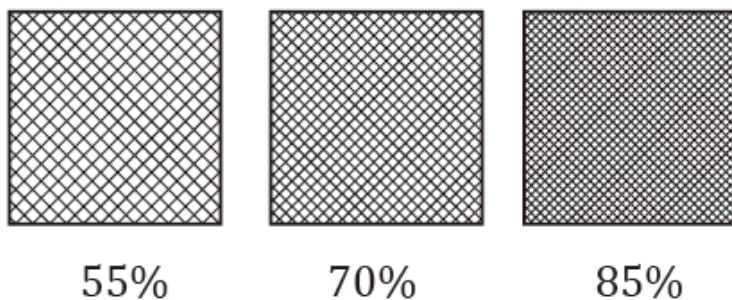
Infill Patterns



Thickness



Infill Ratio



TPU-SMP Before

After
SMP-TPU@70 °C

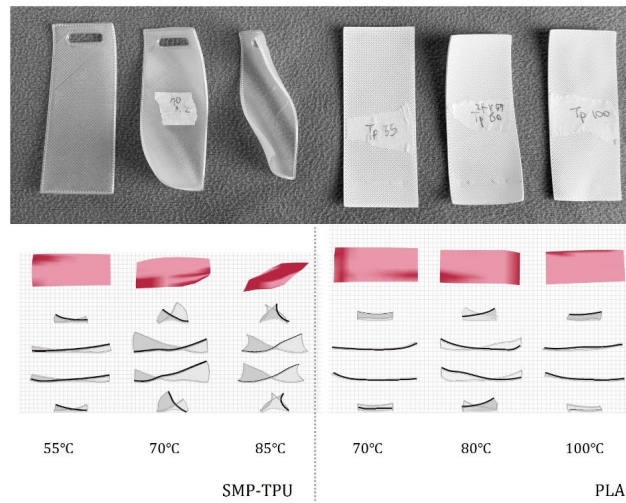
PLA Before

After
PLA@85°C

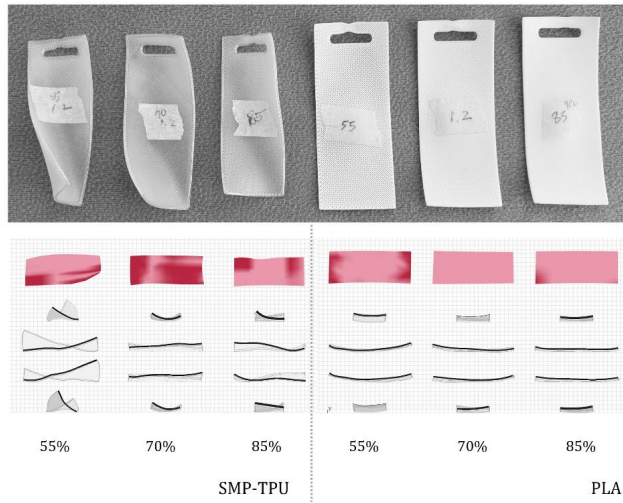


Experiment Results

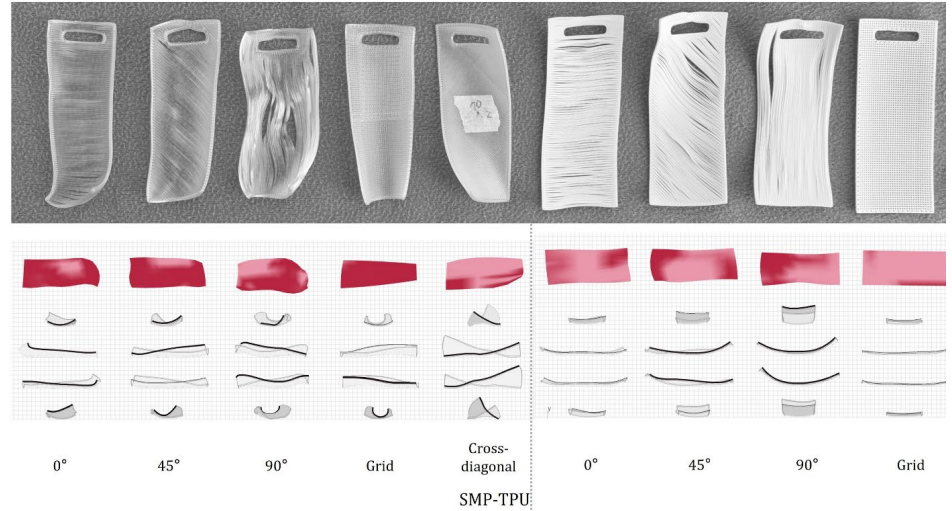
(a)



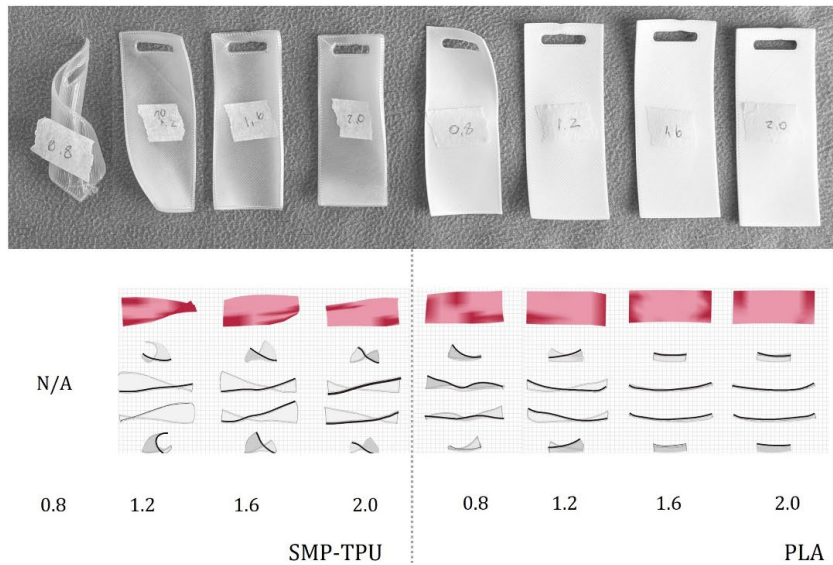
(b)



(d)



(c)



Parameter	Specimen ID	Parameter Value	κ_{\max} (mm ⁻¹)	κ_{mean} (mm ⁻¹)	δ_{\max} (mm)	A _r (%)	S _r (%)
Thickness [mm]	A-TPU-1	0.8	-	-	17.50	-	-
	A-TPU-2*	1.2	0.041	0.014	23.89	69.93	21.40
	A-TPU-3	1.6	0.030	0.017	8.86	69.22	26.79
	A-TPU-4	2.0	0.027	0.010	9.24	65.12	32.23
	A-PLA-1	0.8	0.031	0.012	17.496	79.73	15.03
	A-PLA-2*	1.2	0.047	0.013	10.02	87.56	9.96
	A-PLA-3	1.6	0.010	0.007	7.73	86.79	12.07
	A-PLA-4	2.0	0.018	0.008	4.82	89.07	10.16
Infill Ratio [%]	B-TPU-1	55	0.110	0.027	22.20	53.70	33.69
	B-TPU-2*	70	0.041	0.014	23.89	69.93	21.40
	B-TPU-3	85	0.048	0.012	17.93	60.71	33.65
	B-PLA-1	55	0.032	0.012	15.05	87.37	8.28
	B-PLA-2*	70	0.047	0.013	10.02	87.56	9.96
B-PLA-3	85	0.020	0.010	9.37	89.64	8.19	
Pattern	C-TPU-1	0°	0.078	0.025	14.96	64.56	28.54
	C-TPU-2	45°	0.058	0.022	13.80	68.45	22.57
	C-TPU-3	90°	0.848	0.033	15.32	67.85	21.69
	C-TPU-4	Grid	0.073	0.034	13.32	56.32	30.17
	C-TPU-5*	Cross-Diagonal	0.041	0.014	23.89	69.93	21.40
	C-PLA-1	0°	0.021	0.011	8.79	88.72	8.96
	C-PLA-2	45°	0.024	0.013	13.85	85.08	11.30
	C-PLA-3	90°	0.025	0.015	19.78	77.16	15.72
	C-PLA-4	Grid	0.029	0.009	5.38	92.33	6.59
	C-PLA-5*	Cross-Diagonal	0.047	0.013	10.02	87.56	9.96

Experiment Results

Short Summary

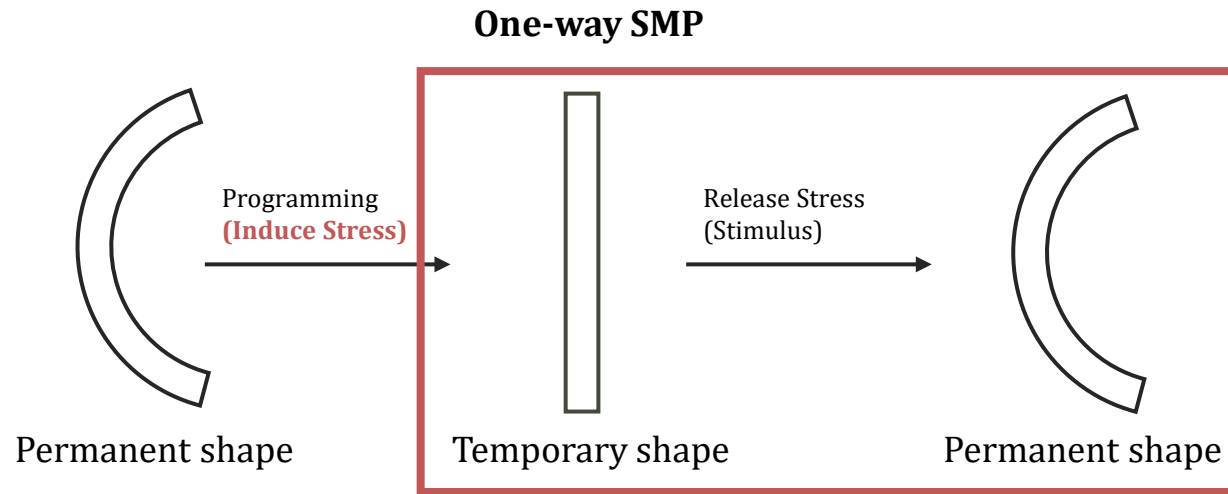
Fabrication parameters alone can program and control SMP deformation behavior

- TPU-SMP outperforms PLA
- Thickness: thicker → fixed end ; thinner → free end
- Infill Ratio: smaller ratio → larger deformation ; larger ratio → smaller deformation
- Infill pattern: deforms along printing paths

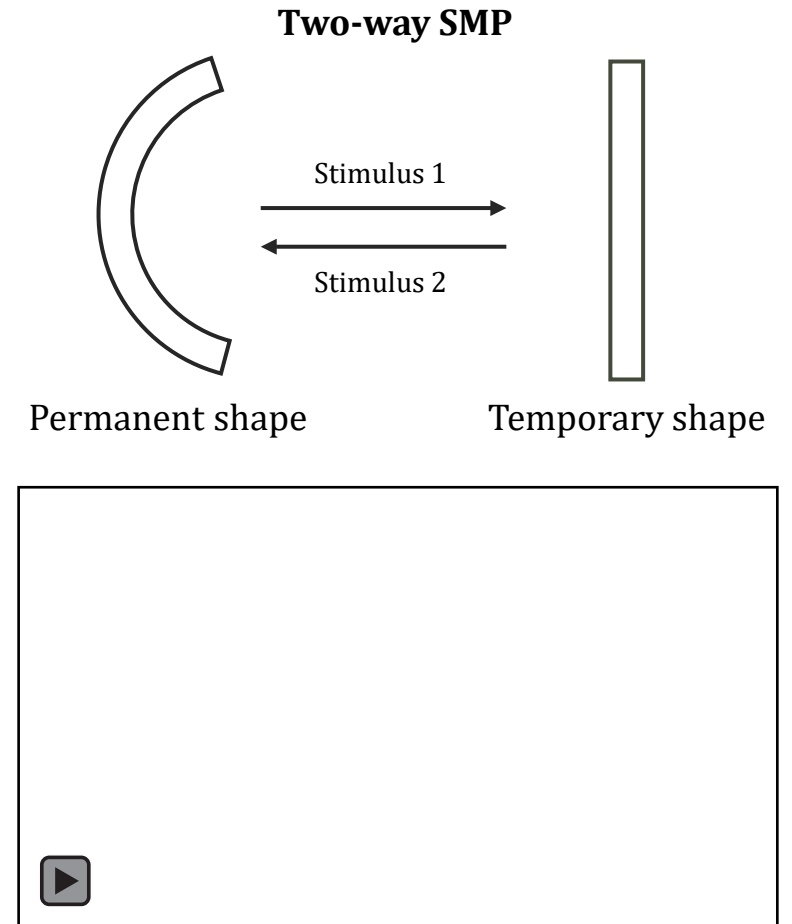
How can these programmed deformations be translated into effective adaptive façade mechanisms?



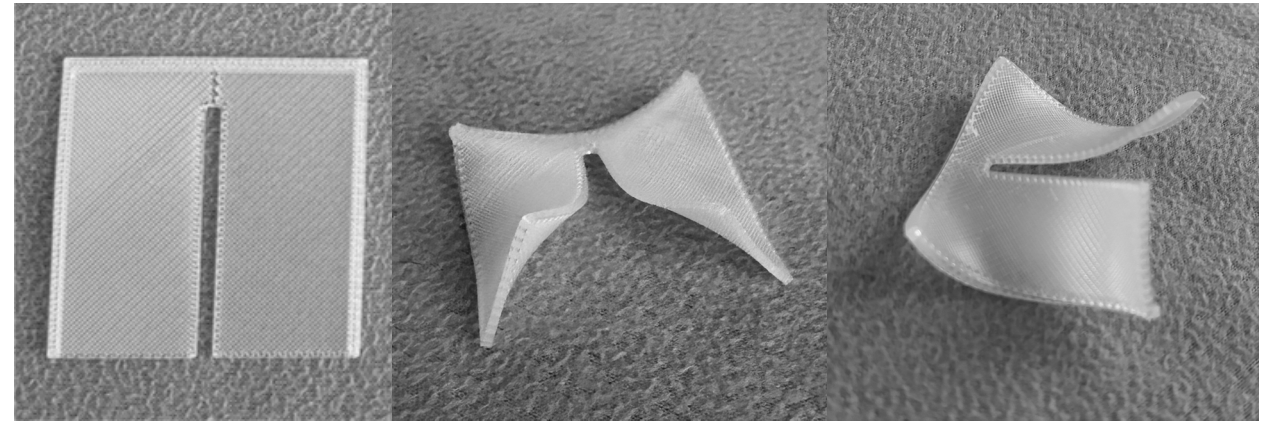
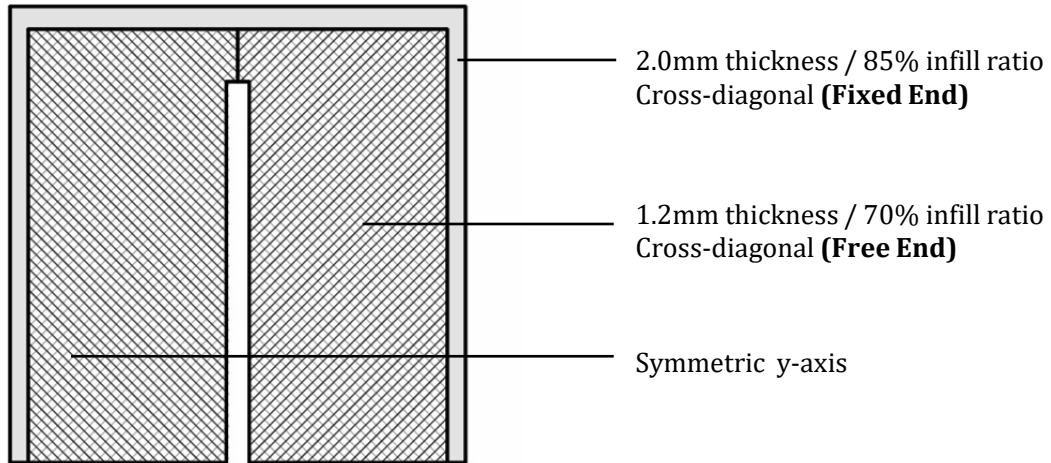
SMP Mechanism



Material Behavior Experiment
As Printed – Permanent



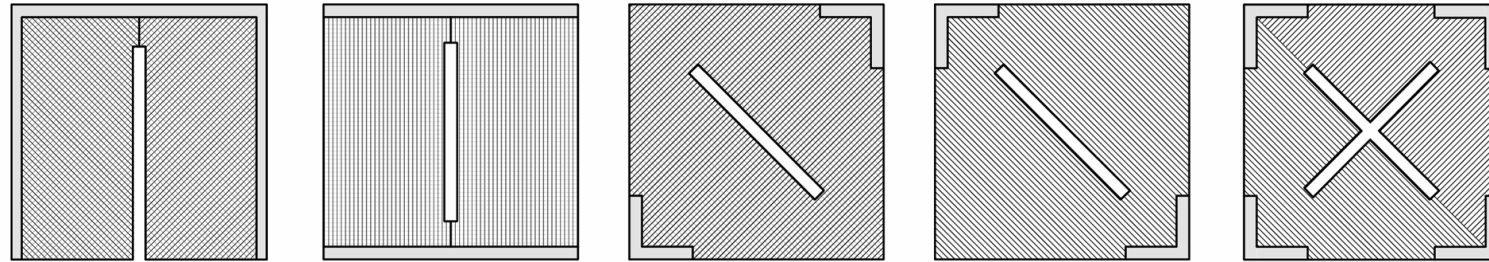
Parameter-Controlled Geometry



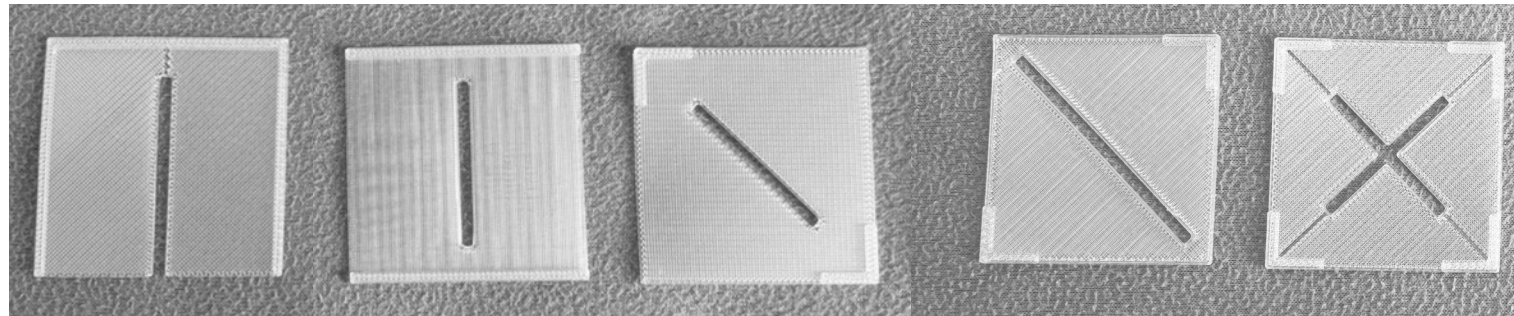
As-Printed Shape

Permanent Shape

Pattern Design

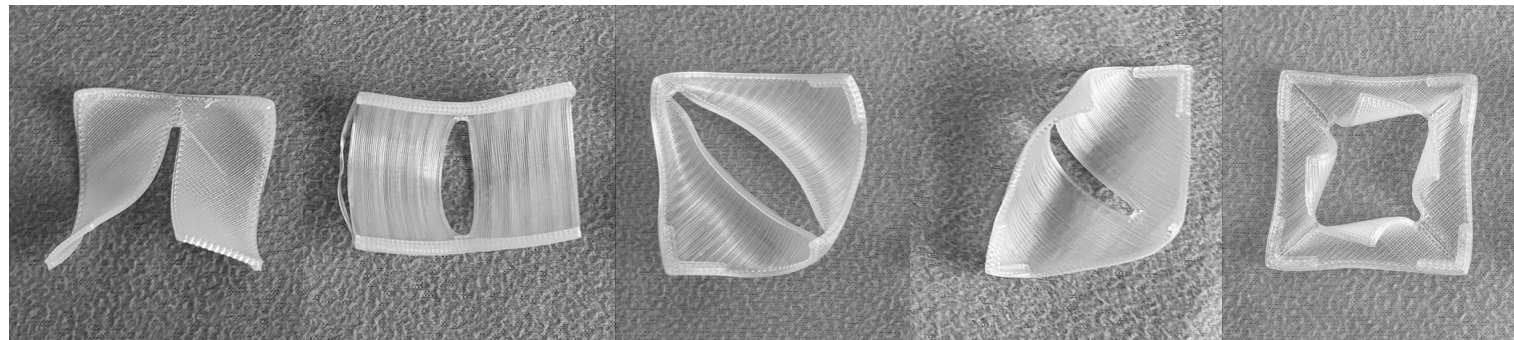


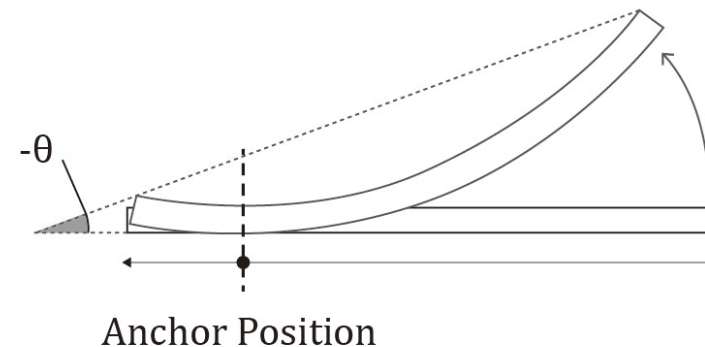
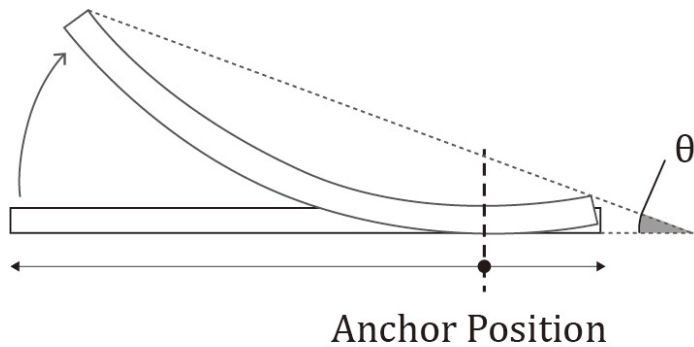
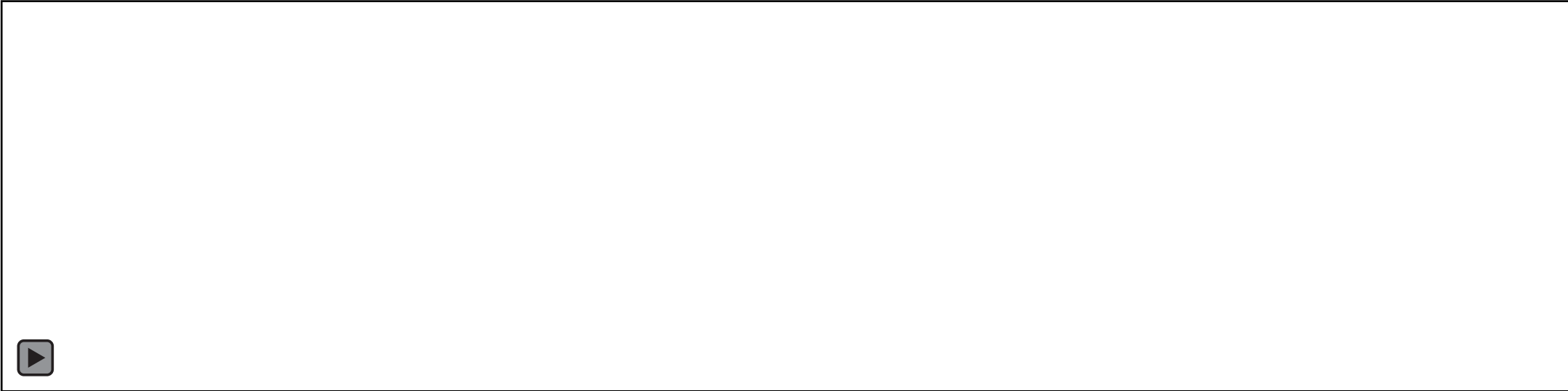
**SMP-TPU
As-Printed**



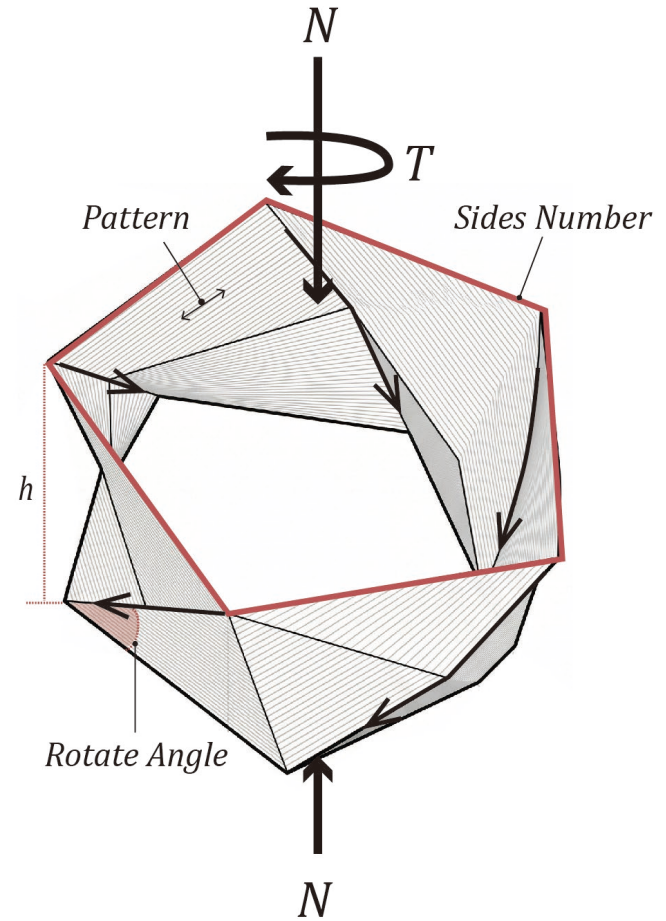
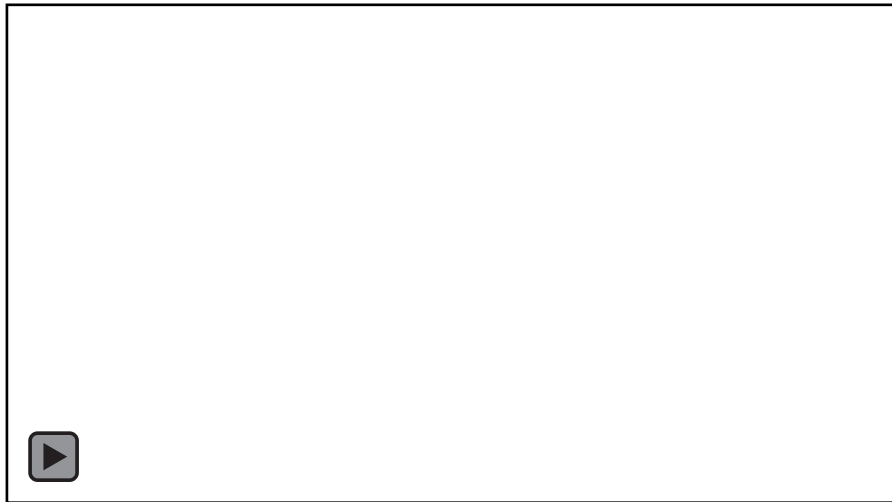
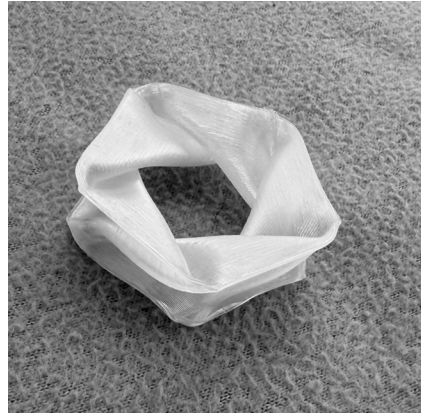
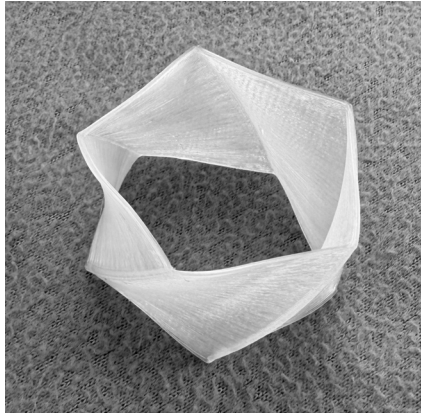
Permanent Shape

SMP-TPU@74 °C



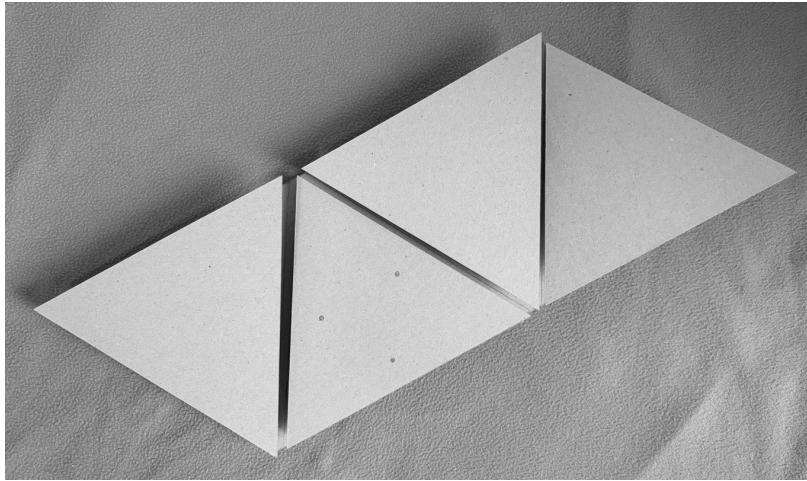


Design Concept 02: Smart Louver Mechanism

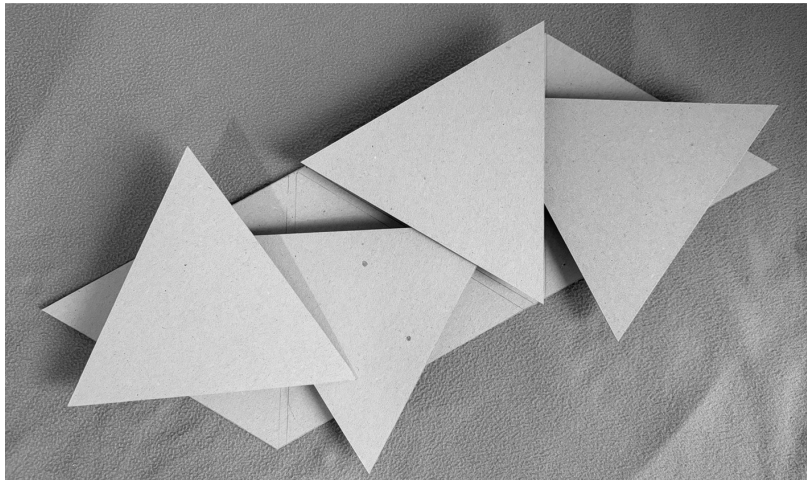


Design Concept 03: Origami Hinge

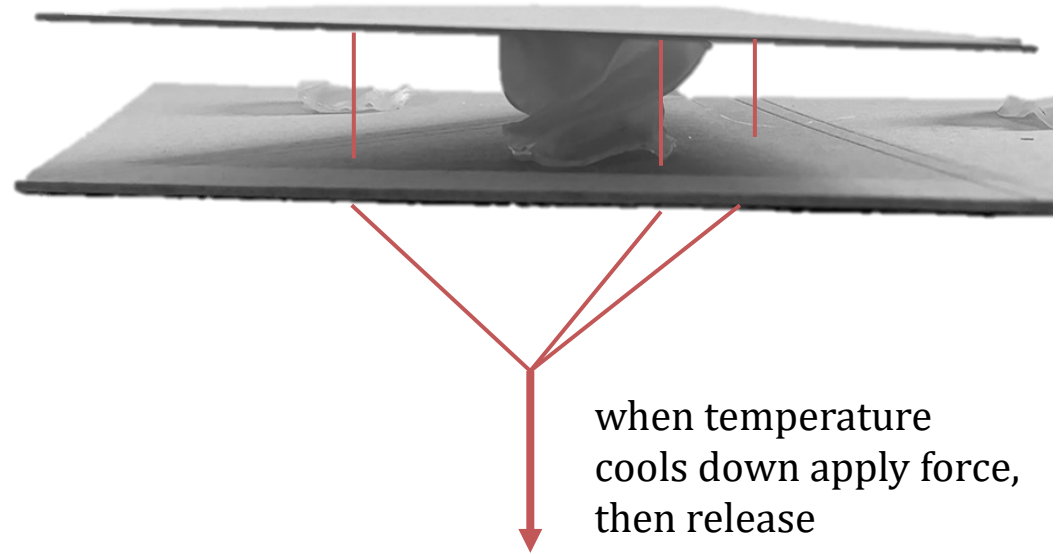
Warm

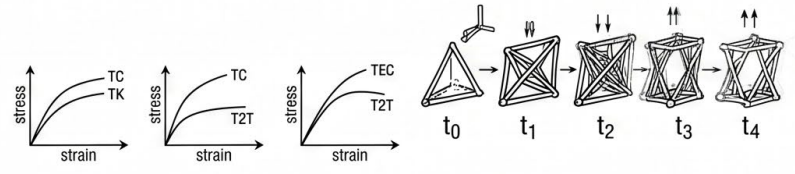
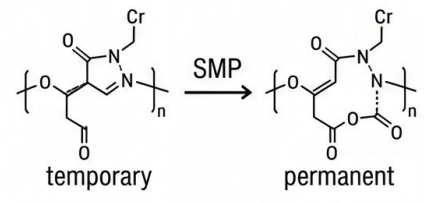
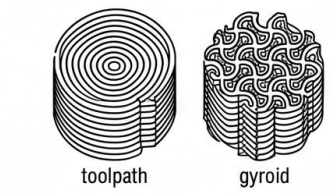
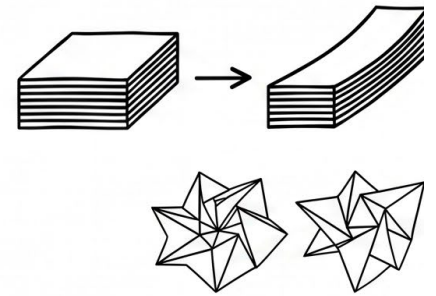
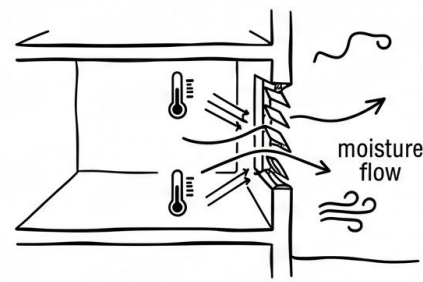
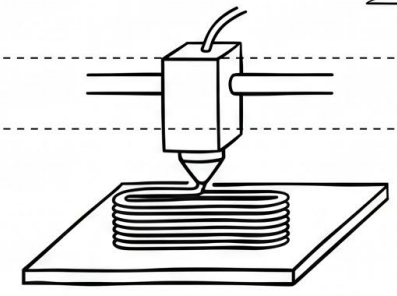
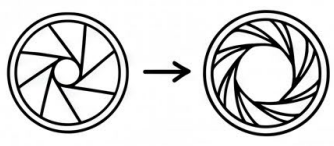
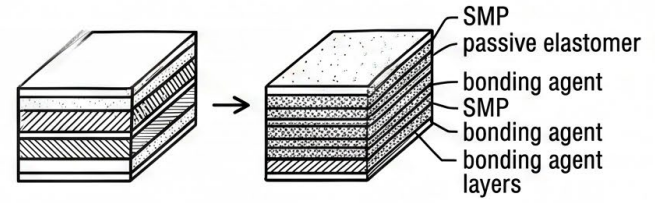
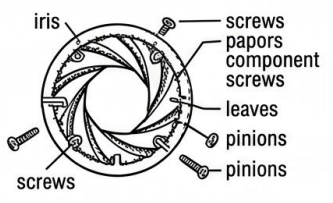
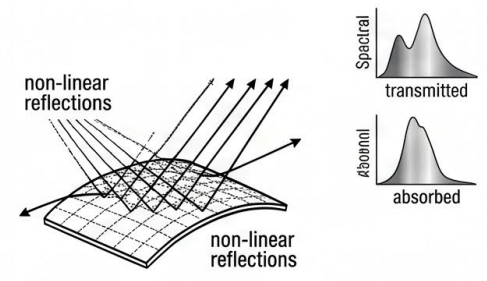
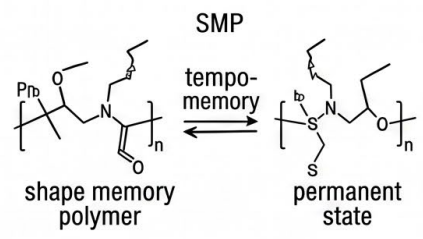
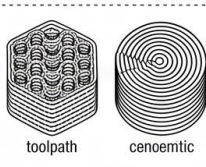
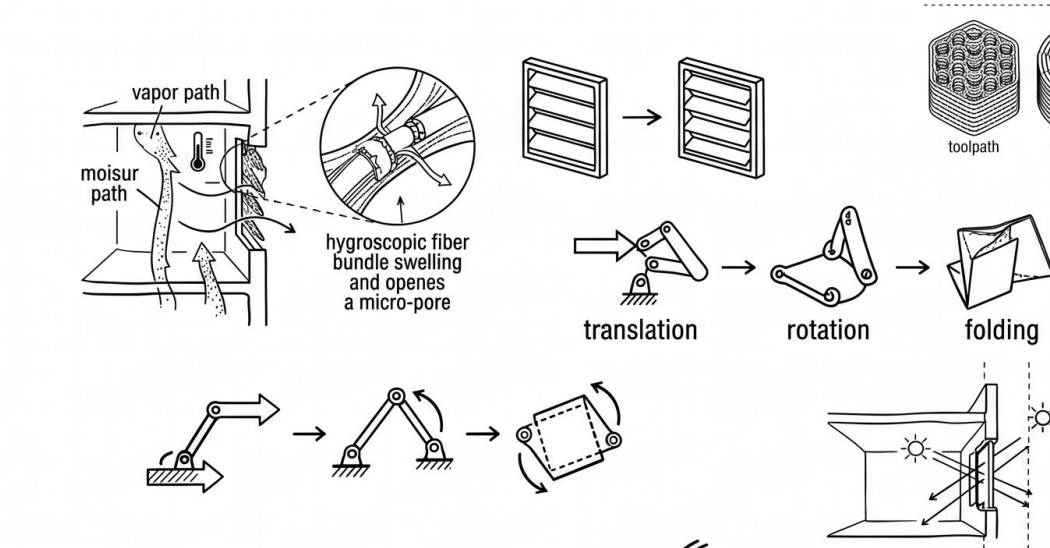


Cool

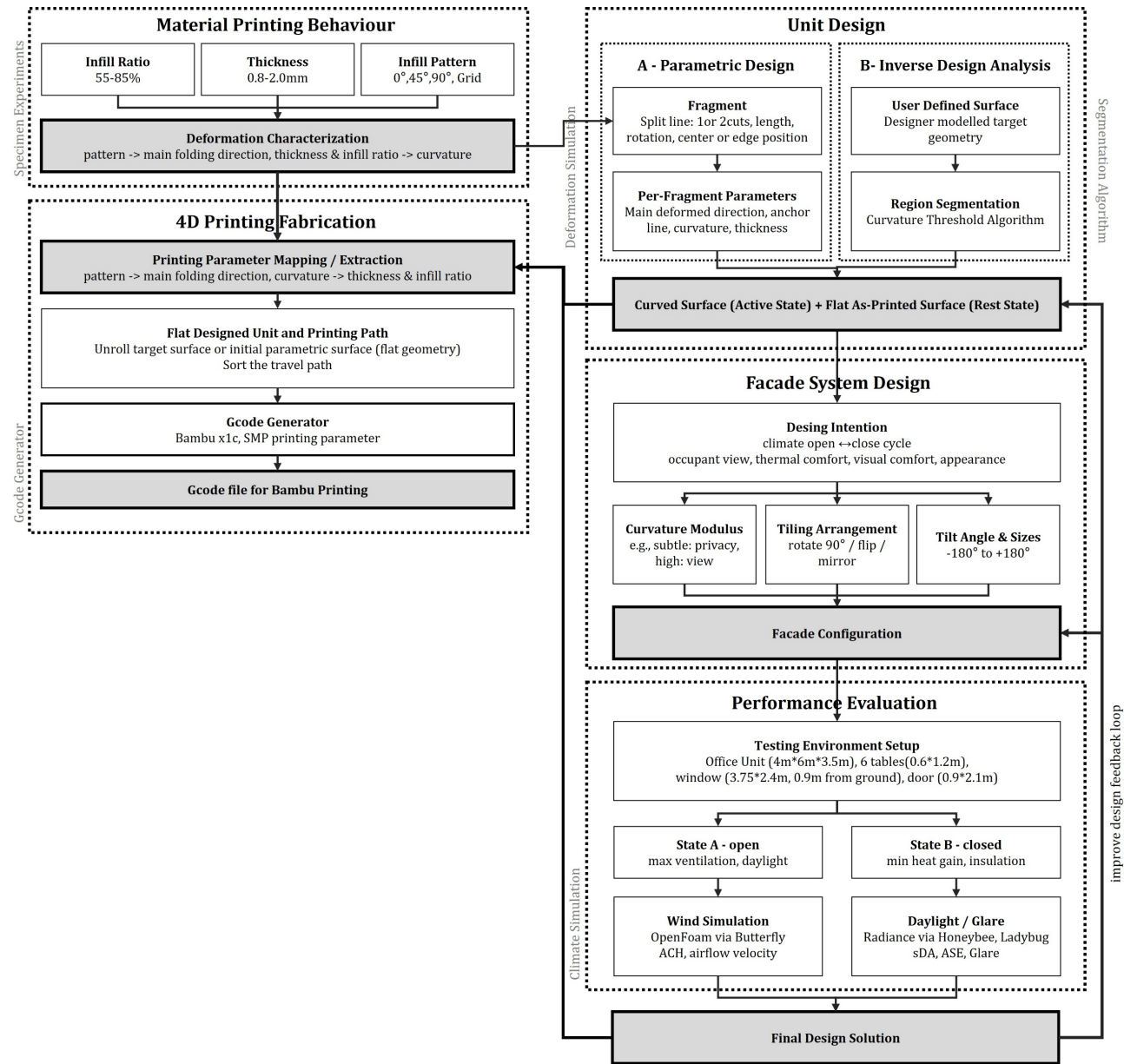


Shading Device
(Section)

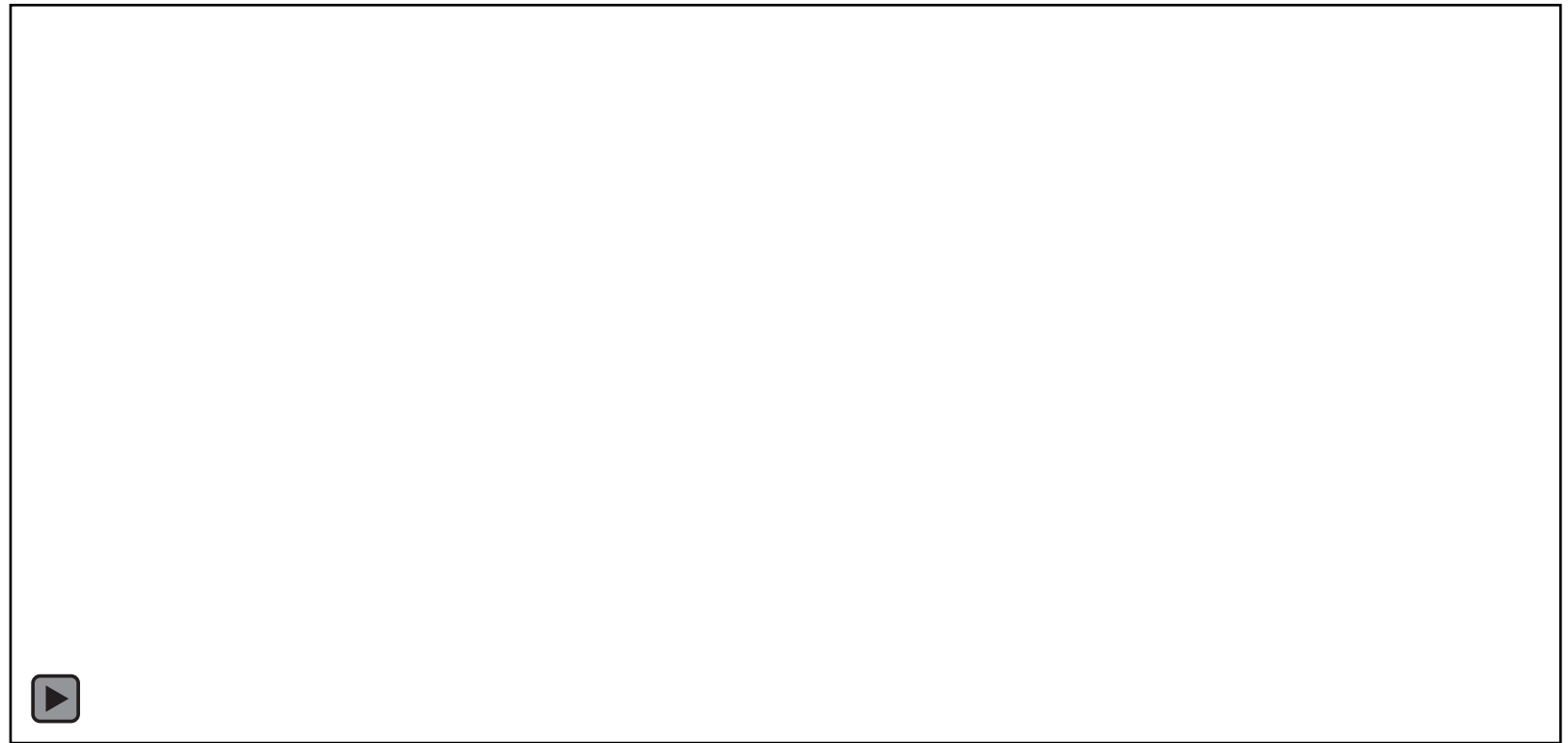
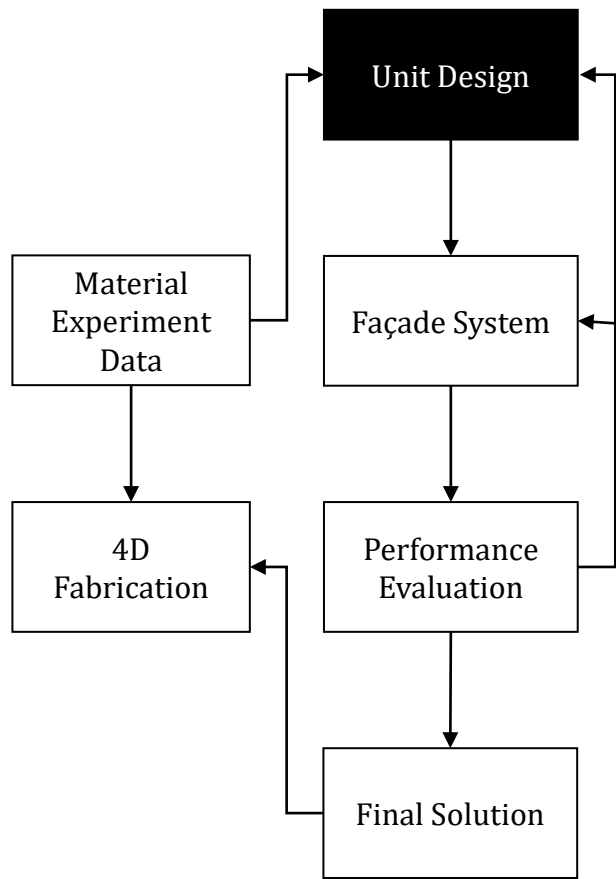


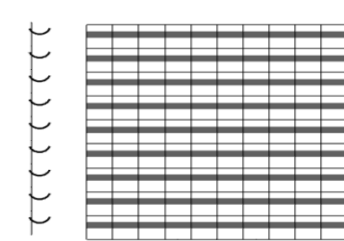
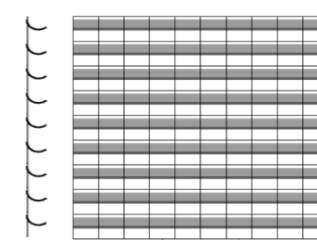
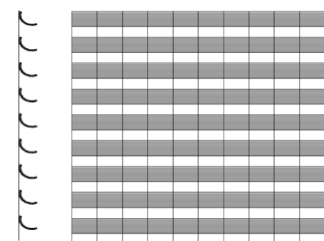
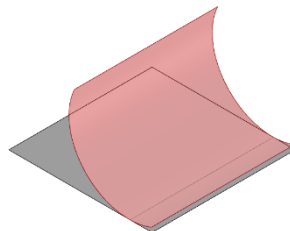
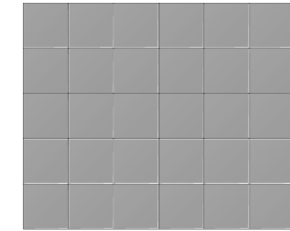
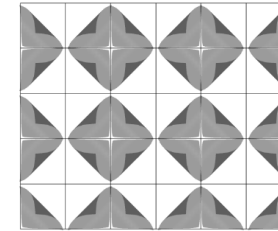
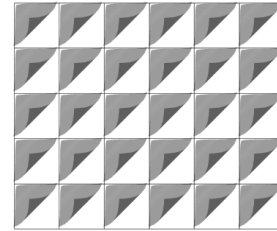
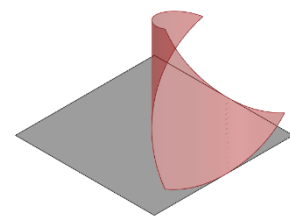
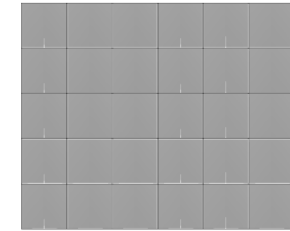
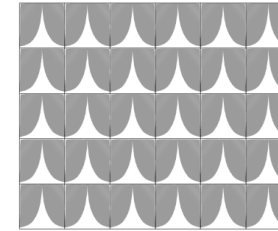
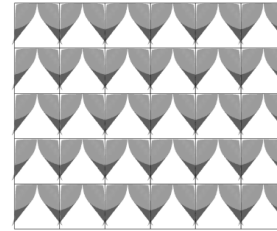
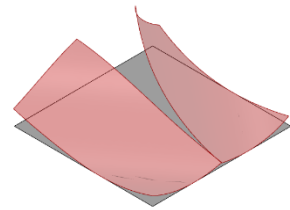
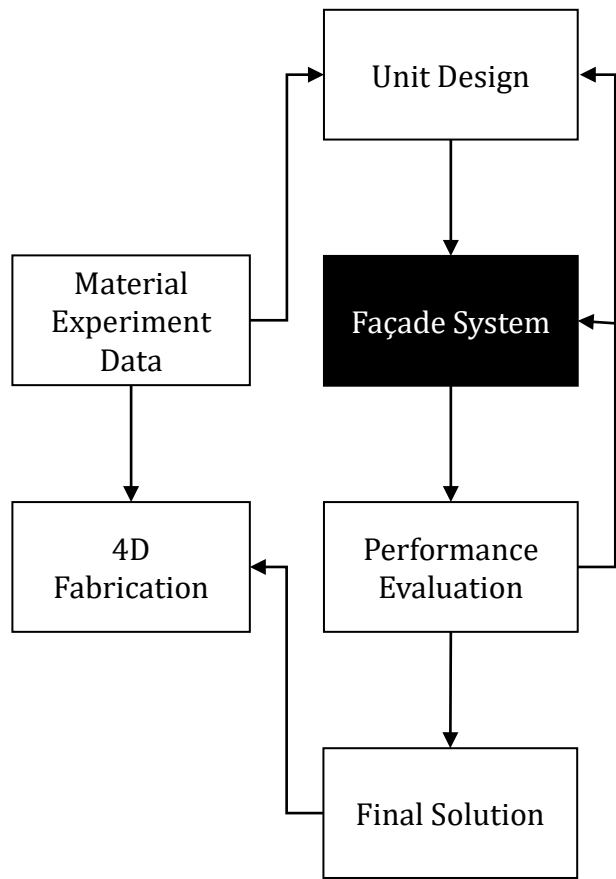


Why we need a tool?



Design Workflow and Framework



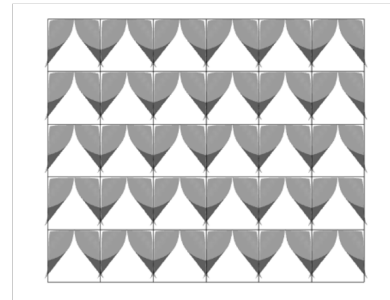
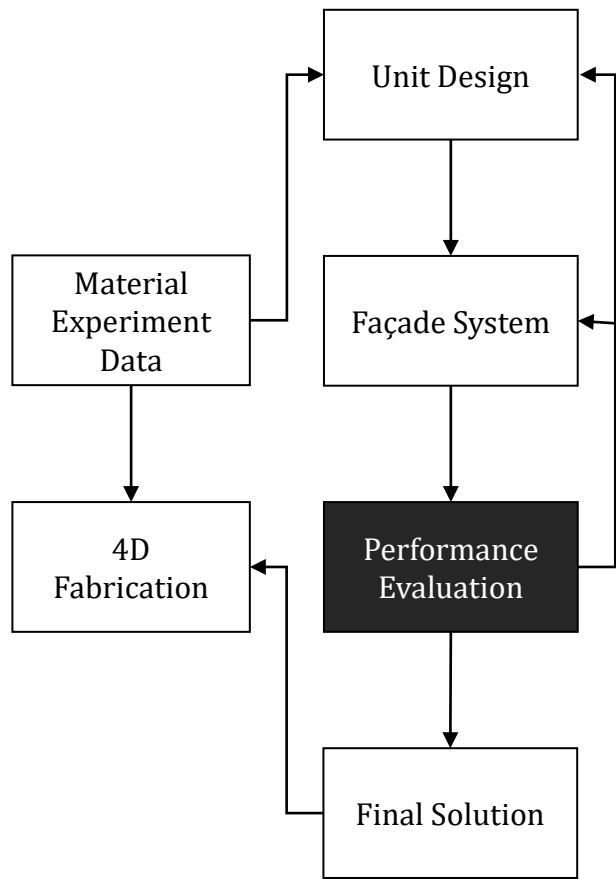


Tilt angle: 45°

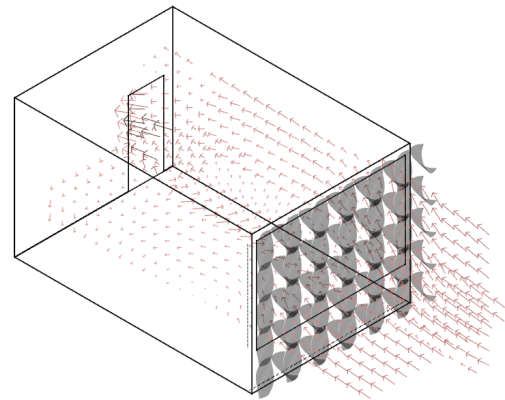
Tilt angle: 27°

Tilt angle: 0°

System Design Matrix



Airflow on 1.2m plane: 0.34
ACH: 68.33

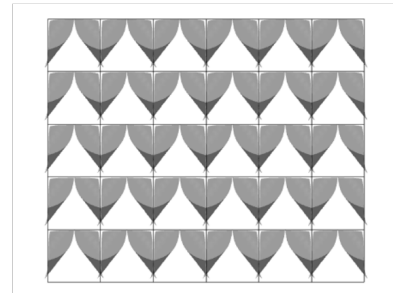
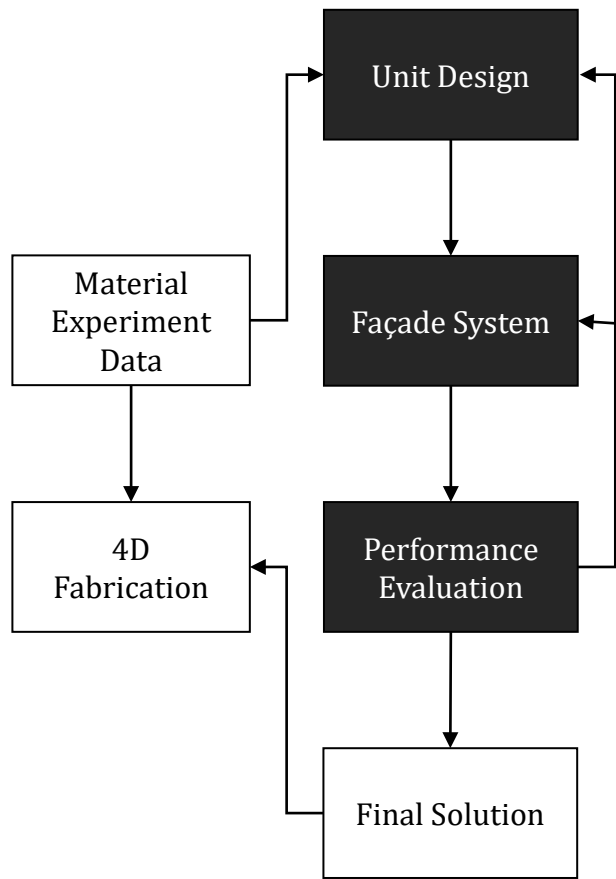


Ventilation

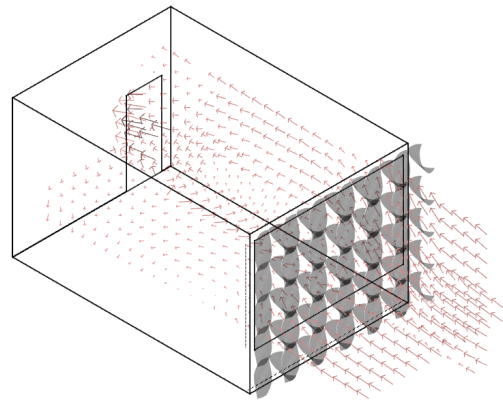
Daylight

sDA: 56.25%
ASE: 5.21%

DGP:0.2394



Airflow on 1.2m plane: 0.34
ACH: 68.33

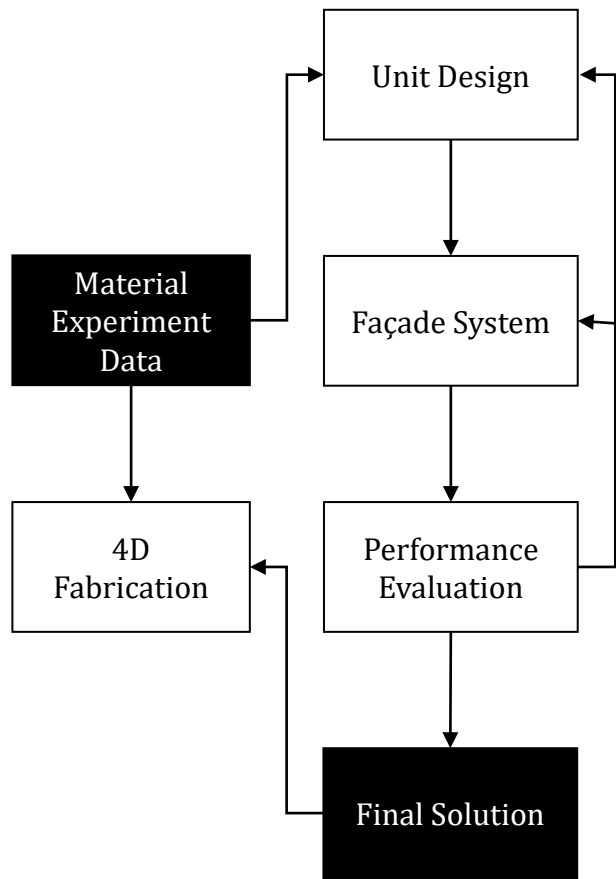


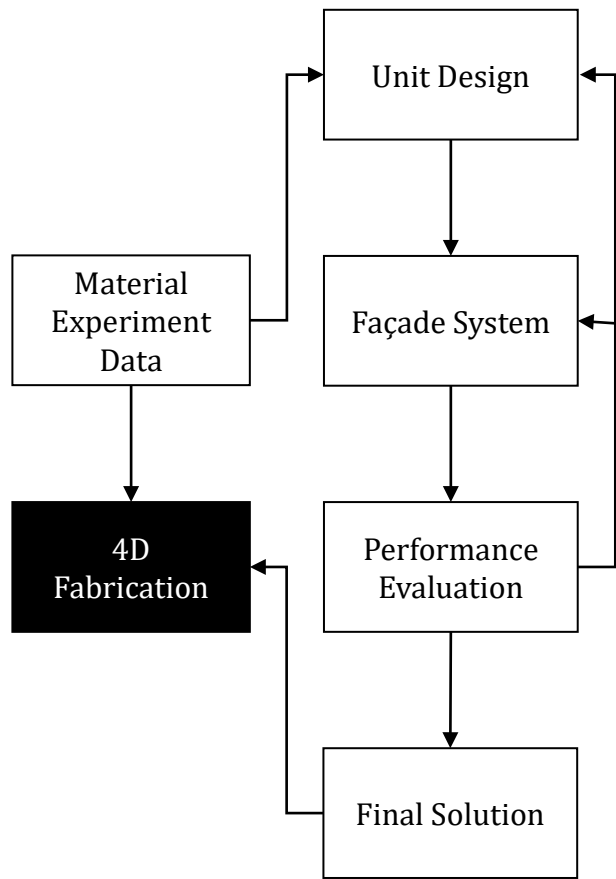
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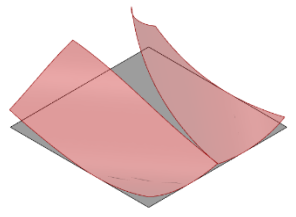




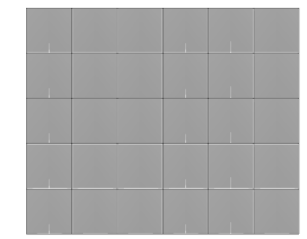
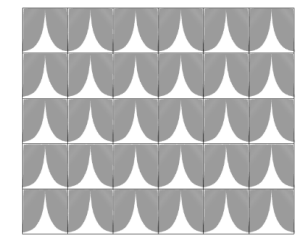
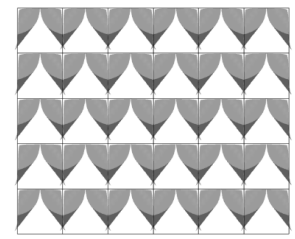


What performance improvements in indoor environmental quality can be achieved through such systems?

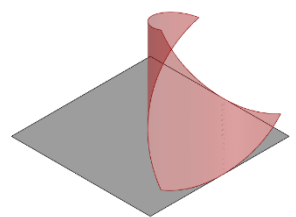
Design 01



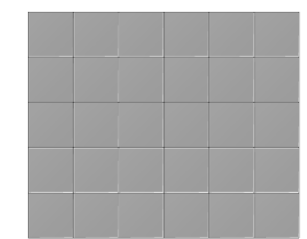
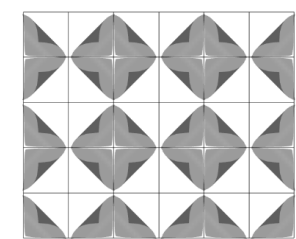
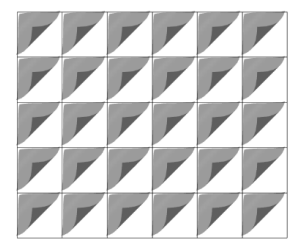
Cut count: 1
 Cut Edge position
 angle parameter: $0.625, 0^\circ$
 Curvature: $(0.1428, 0.1428)$
 Thickness (Left, Right): $(1.2, 1.2)$ mm
 Infill ratio: $(30\%, 30\%)$
 Infill pattern: $(52^\circ, -52^\circ)$
 Anchor location: $(-0.25, -0.25)$



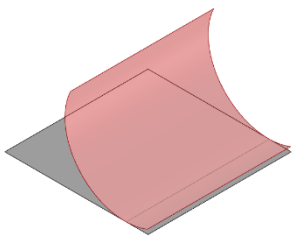
Design 02



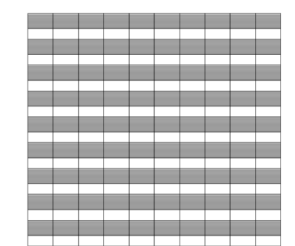
Cut count: 0
 Curvature: 0.0714
 Thickness: 1.6 mm
 Infill ratio: 30%
 Infill pattern: 45°
 Anchor location: -0.25



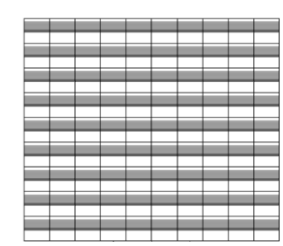
Design 03



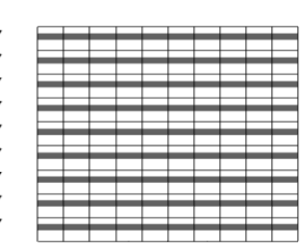
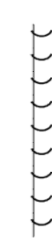
Cut count: 0
 Curvature: 0.0526
 Thickness: 1.6 mm
 Infill ratio: 40%
 Infill pattern: 0°
 Anchor location: -0.34



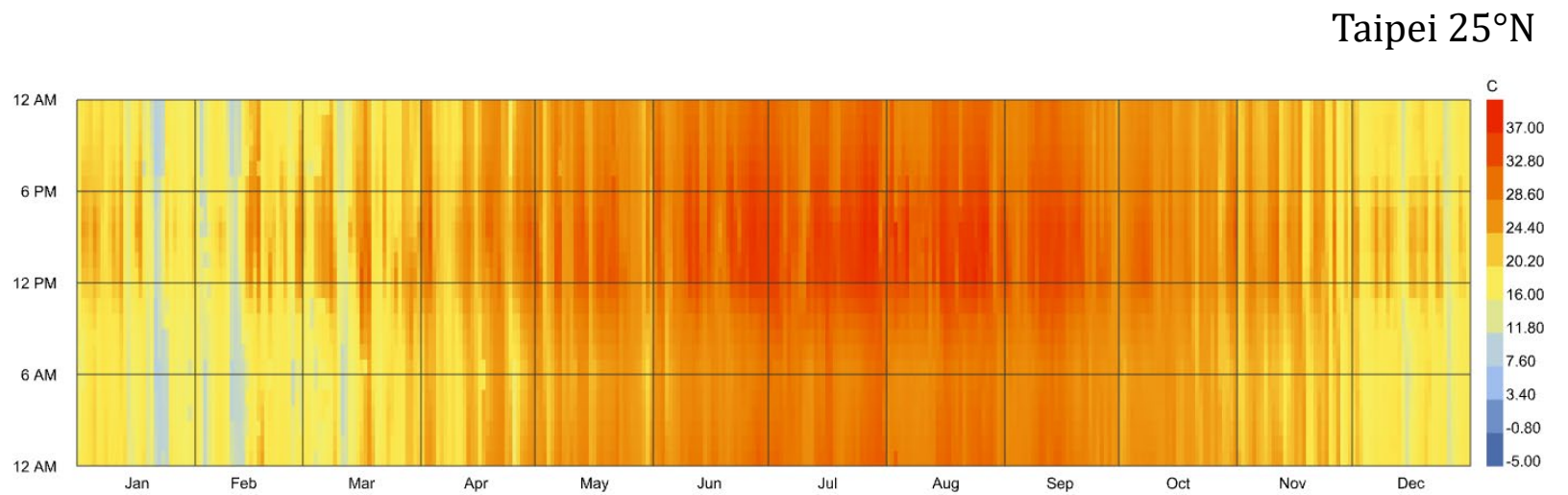
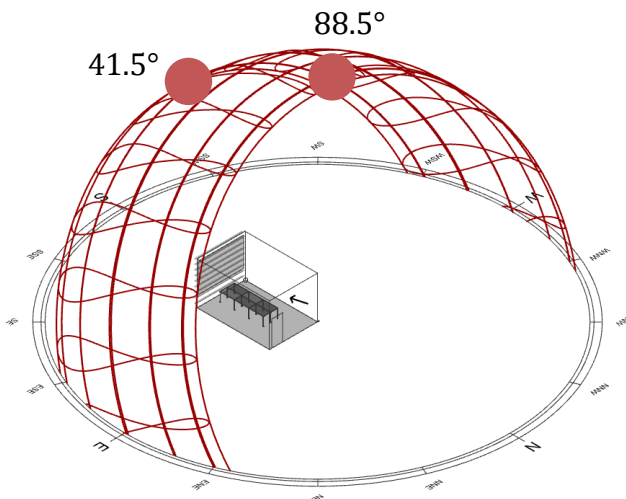
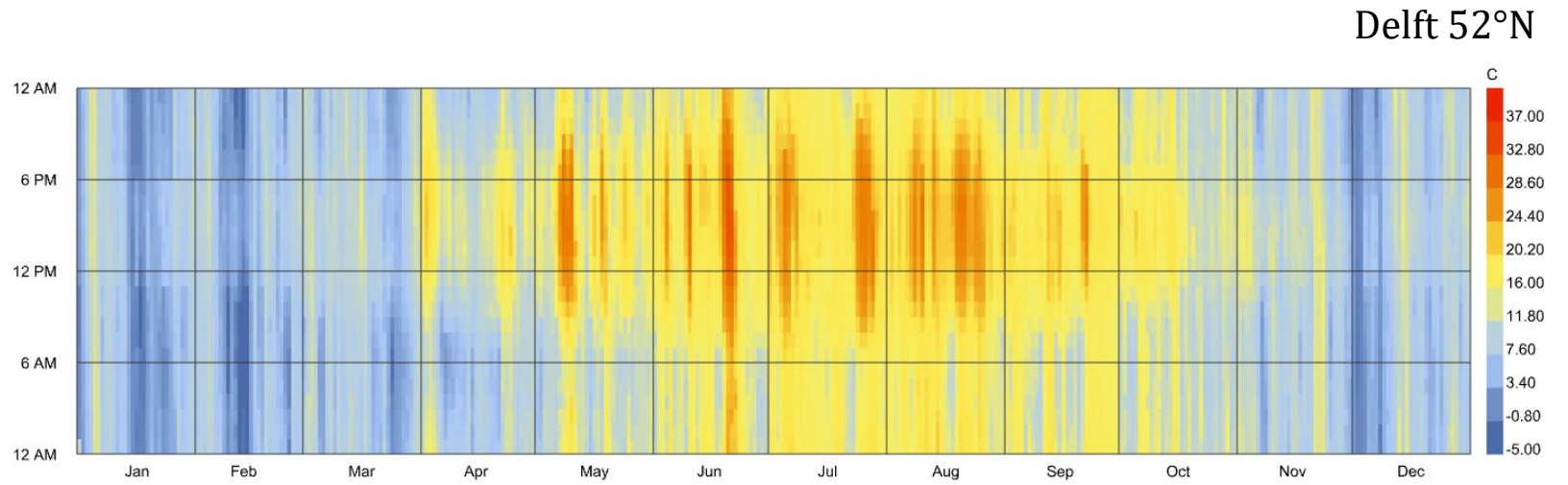
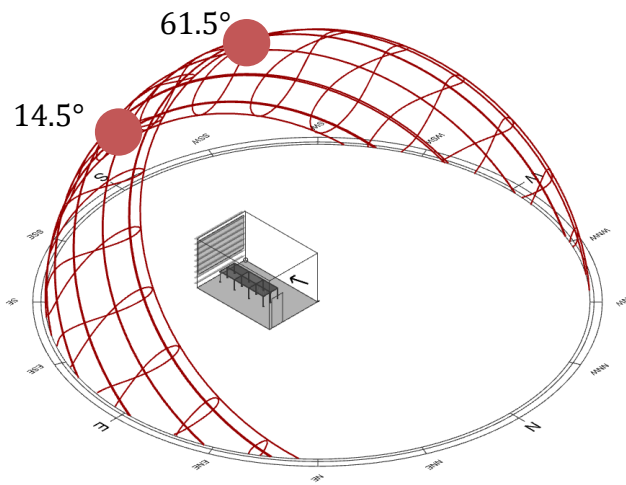
Tilt angle: 45°



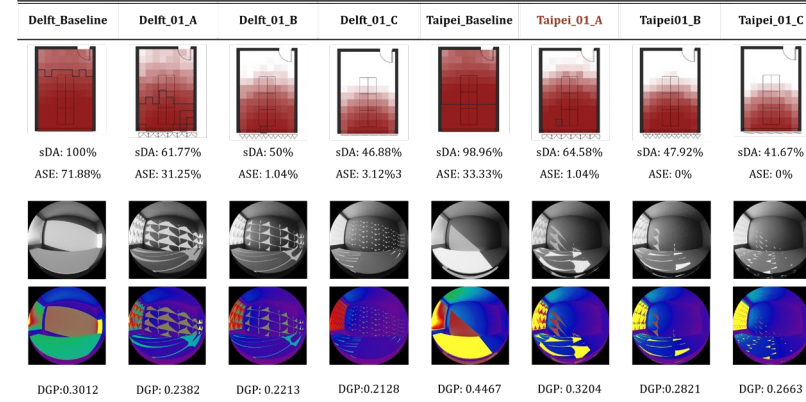
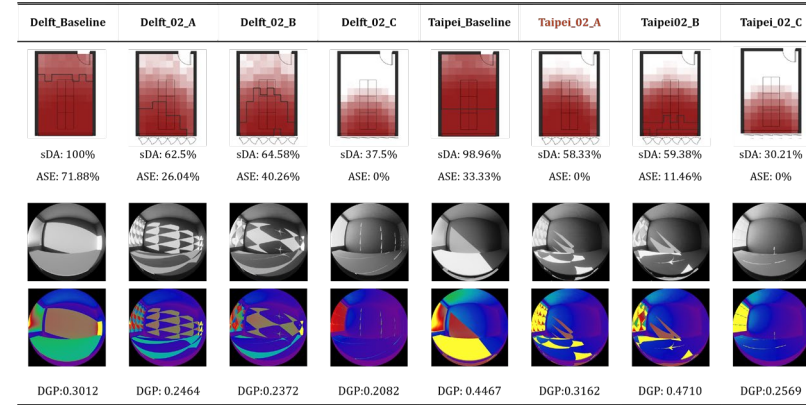
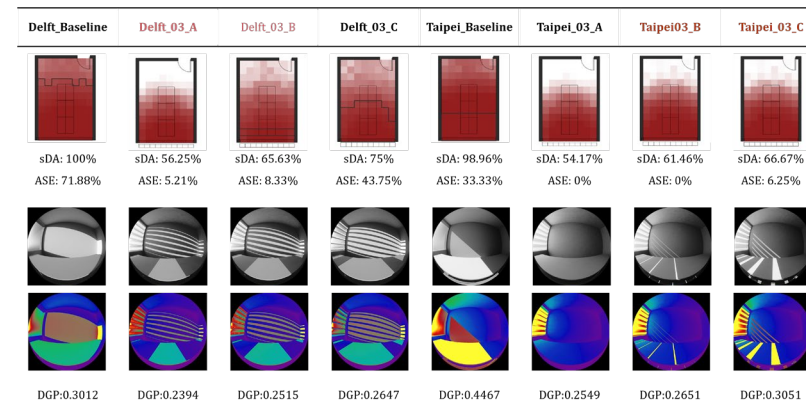
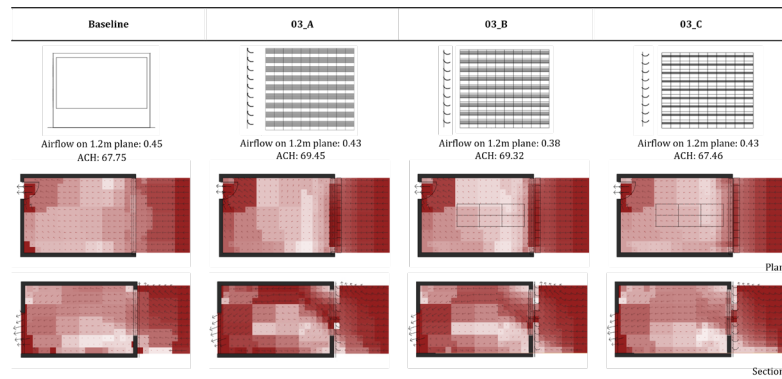
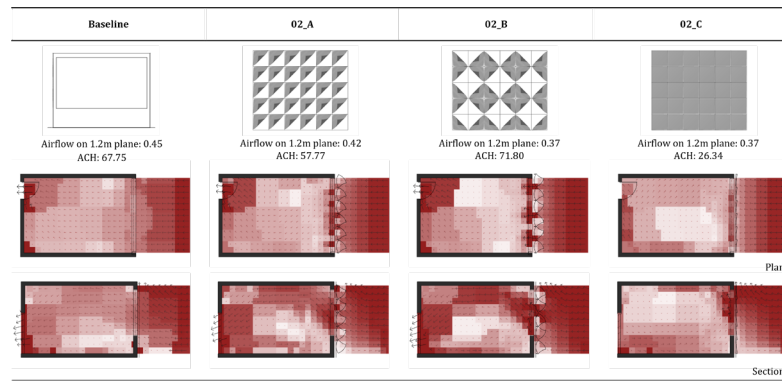
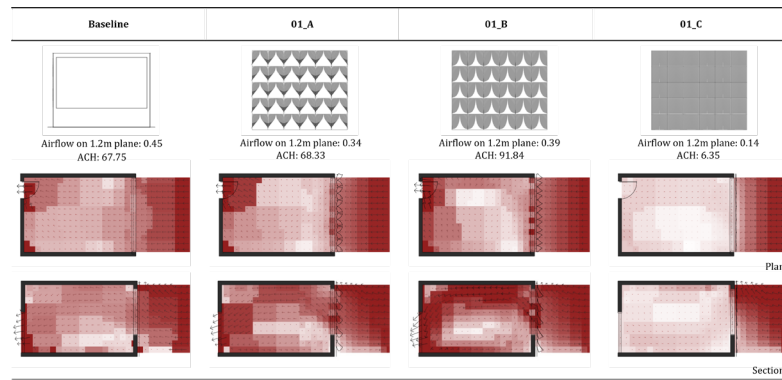
Tilt angle: 27°



Tilt angle: 0°

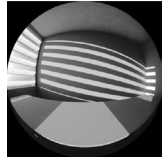
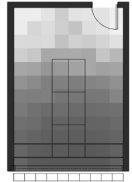


Method: Climate Comparison

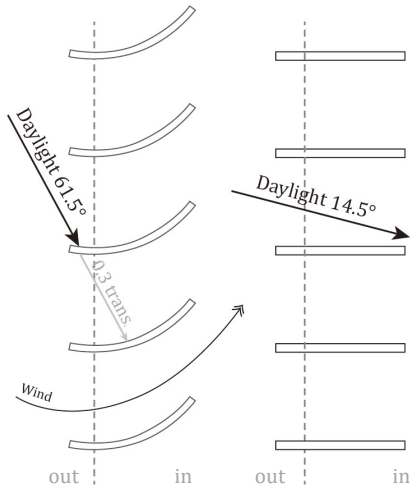


Ventilation and Daylight Evaluation Results

SMP Louver



Delft_03_B
sDA: 65.63%
ASE: 8.33%



27°
(summer)

0°
(winter)

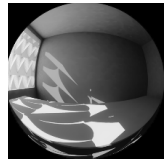
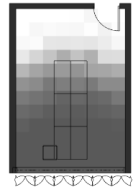


27° (summer)



0° (winter)

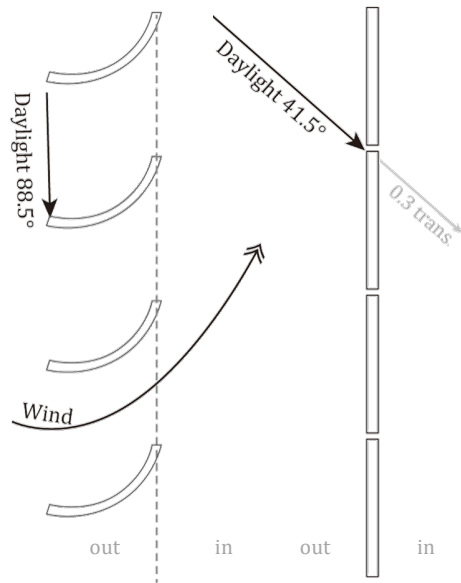
SMP Panel



Taipei_01_A

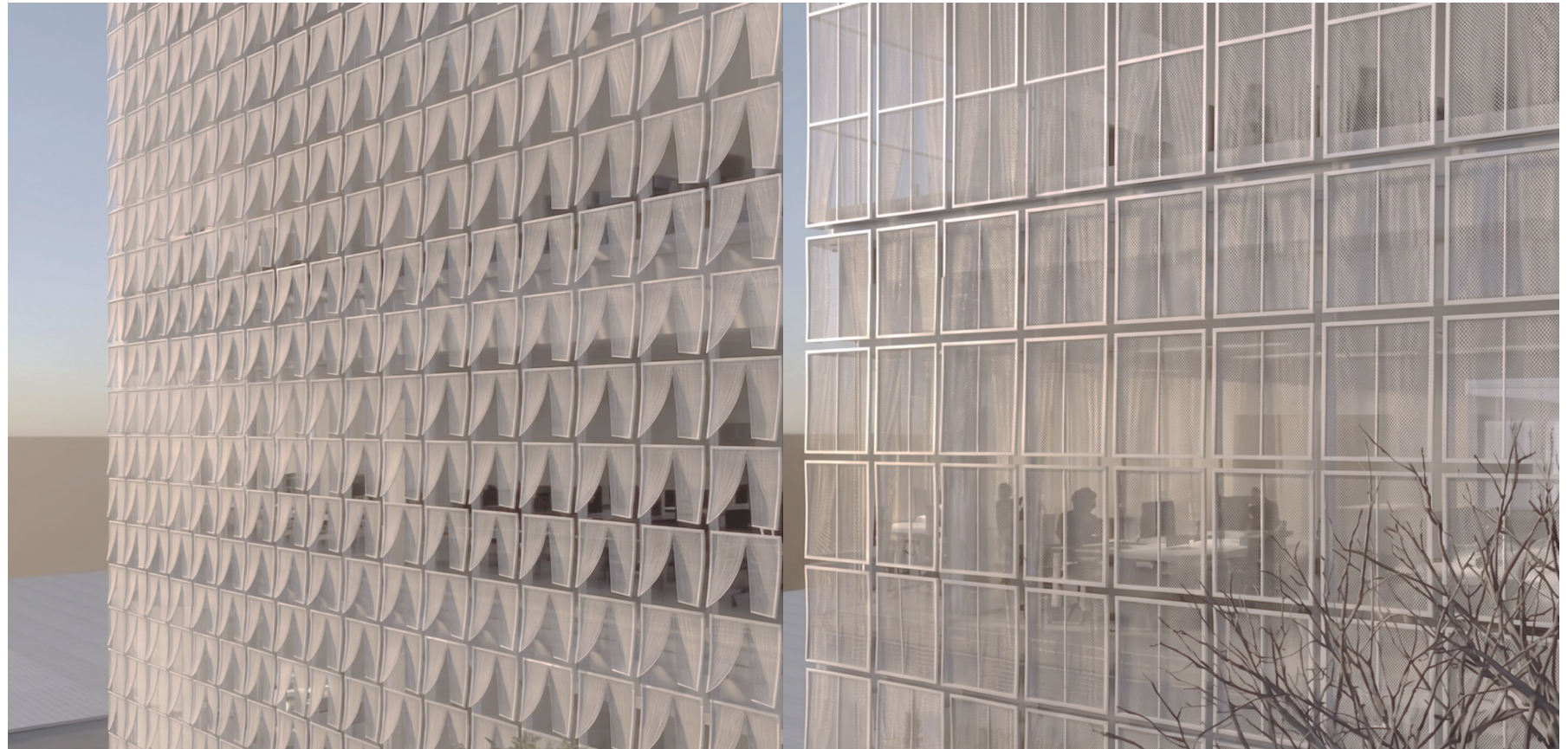
sDA: 64.58%

ASE: 1.04%



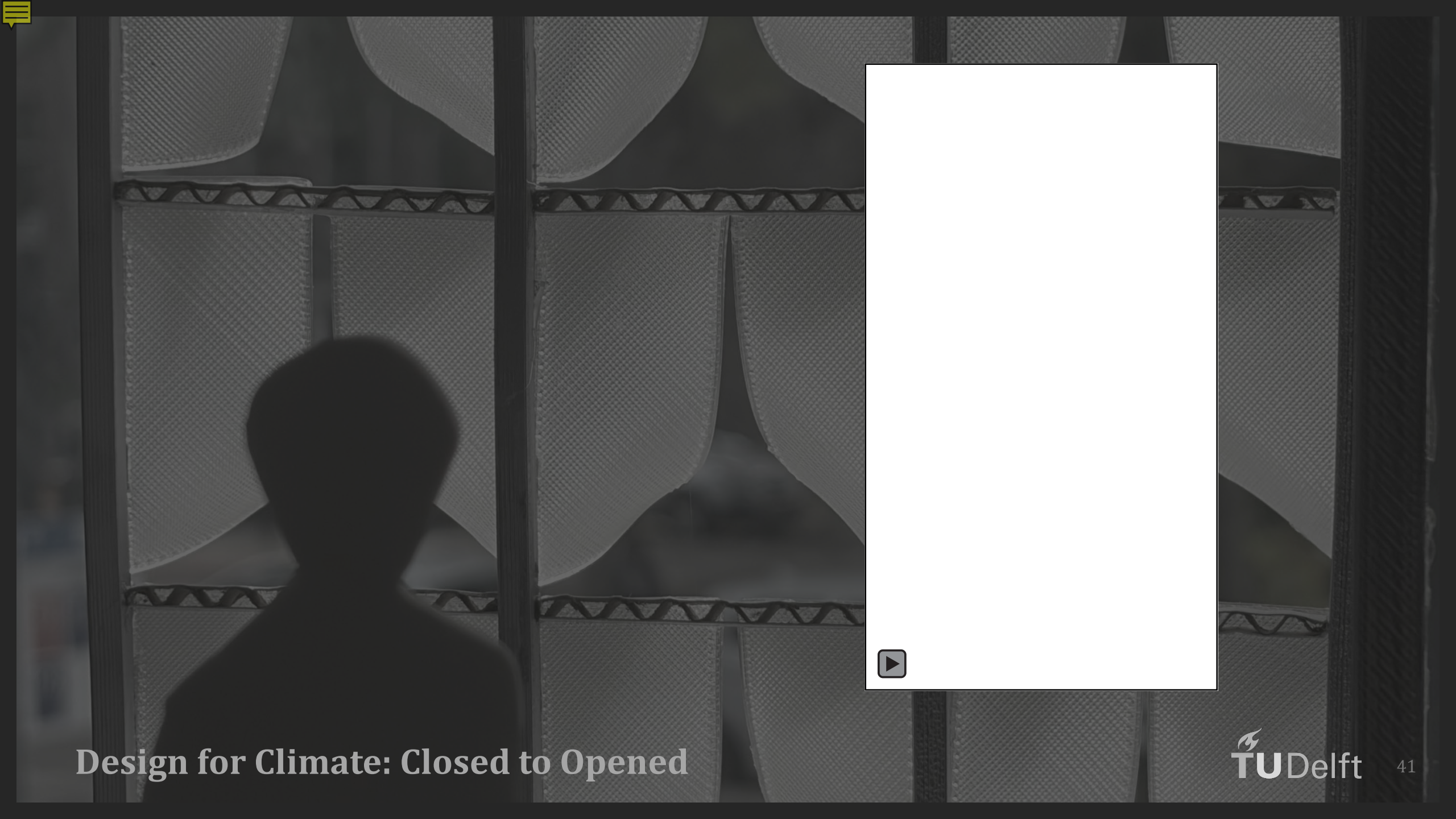
Open
(summer)

Close
(winter)



Open (summer)

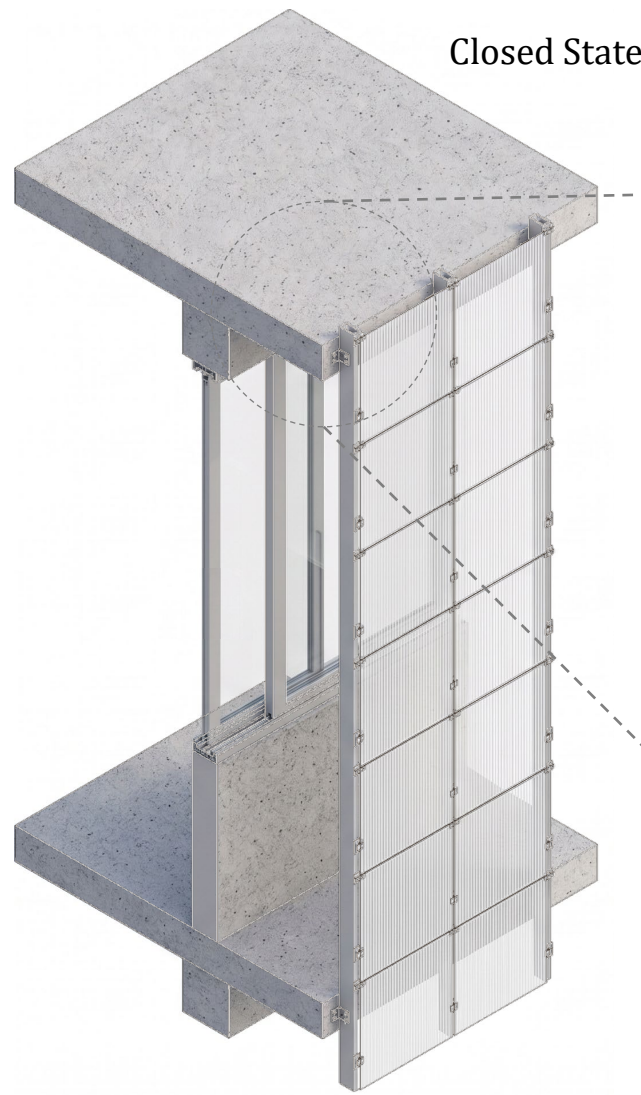
Closed (winter)



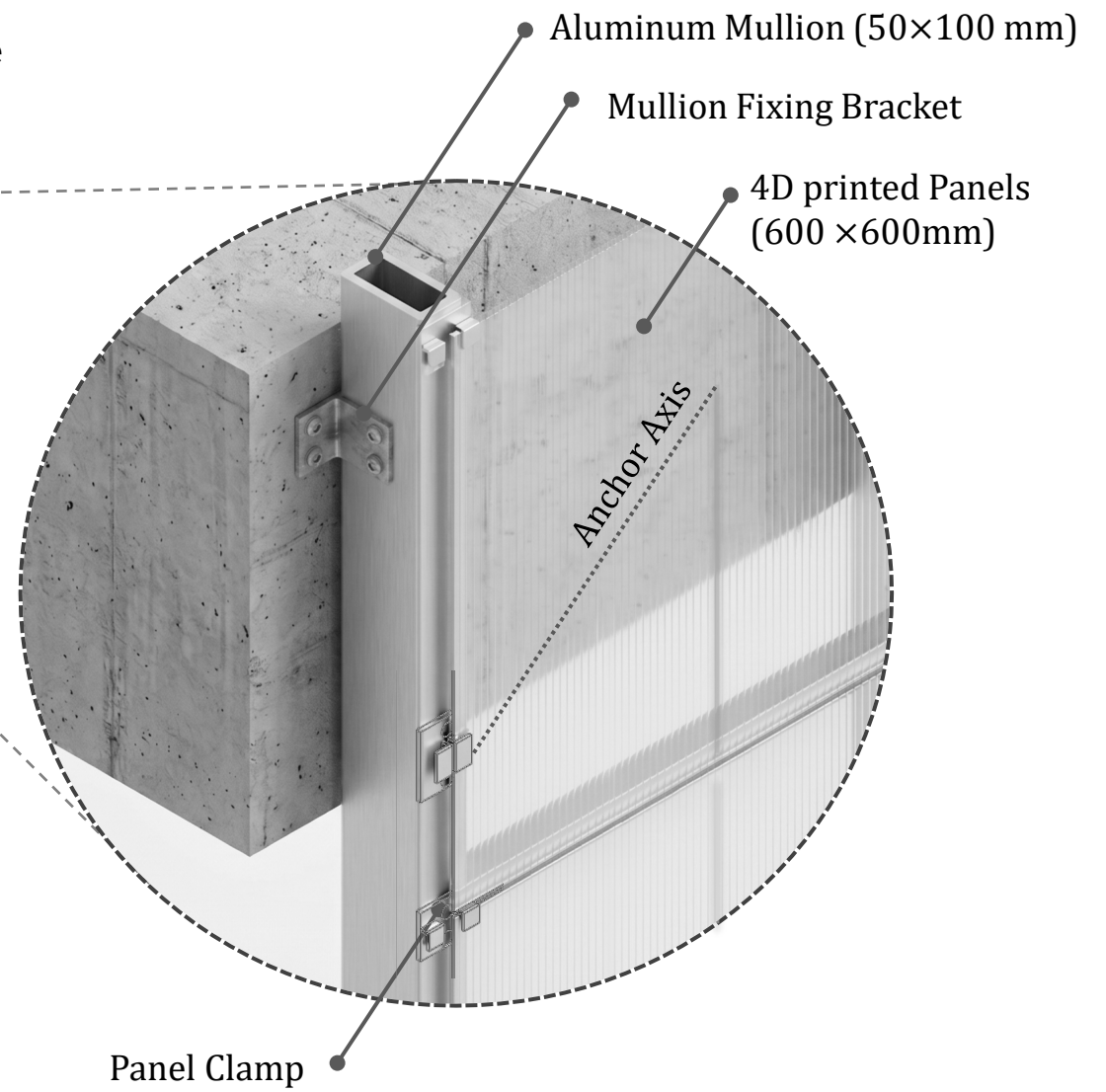
Design for Climate: Closed to Opened



Open State



Closed State



Aluminum Mullion (50×100 mm)

Mullion Fixing Bracket

4D printed Panels (600 × 600mm)

Anchor Axis

Panel Clamp

Façade Detail



Scale Up!

A close-up photograph of several 3D printed mechanical components, likely made of a translucent or semi-transparent material. The parts are arranged in a complex assembly, with one large cylindrical part in the foreground and other smaller parts behind it. The lighting is dramatic, highlighting the fine details and textures of the printed surfaces.

Limitations

- One-Way Material Reality
- Durability, Structure Stability, Sustainability

Future Work

- 1:3 Scale-up Material Models
- Two-Way Material Validation



01 Empirical Parameter Map: Programmable Material Behavior

02 Façade Application Designs: SMP Louver, Panel, Hinge

03 CAD Tool: Single Design Workflow

Thank You for Listening!

Happy to Take Any Questions

Scan the Code

Source Code

