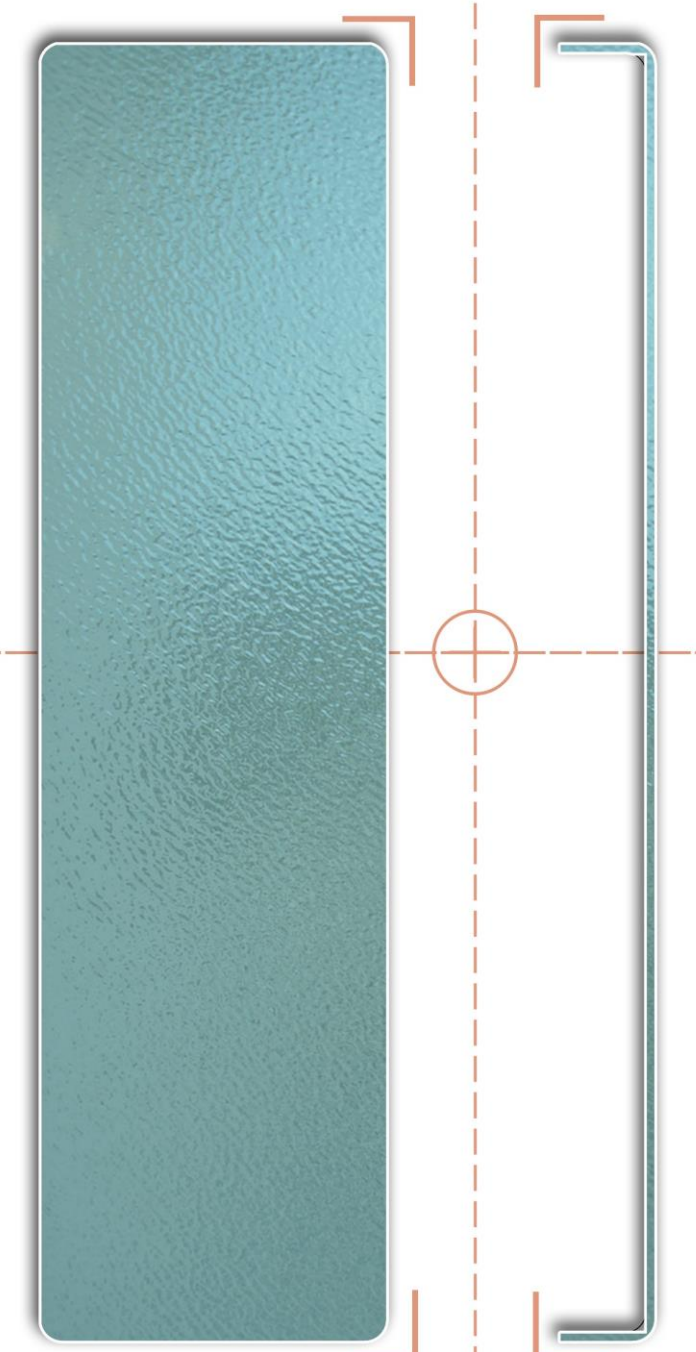
Hybrid Glass Blocks

Load-bearing glass blocks with thermal properties

Graduation presentation | Twinkle Nathani | 5069041



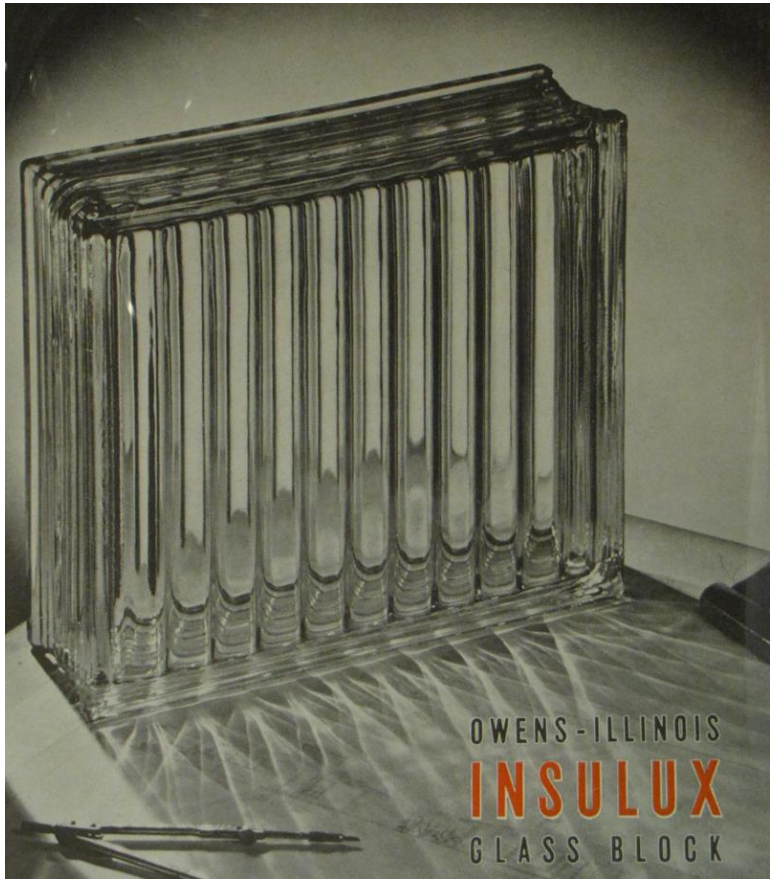
Mentor Team
Dr. ir. Faidra Oikonomopoulou | Structural Design and Mechanics
Dr. ir. Martin Tenpierik | Building Physics

Desirable Optical Properties

Desirable Optical Properties

Durability

Falconnier hollow glass blocks



Insulux – Owens-Illinois,

Hollow Glass Blocks

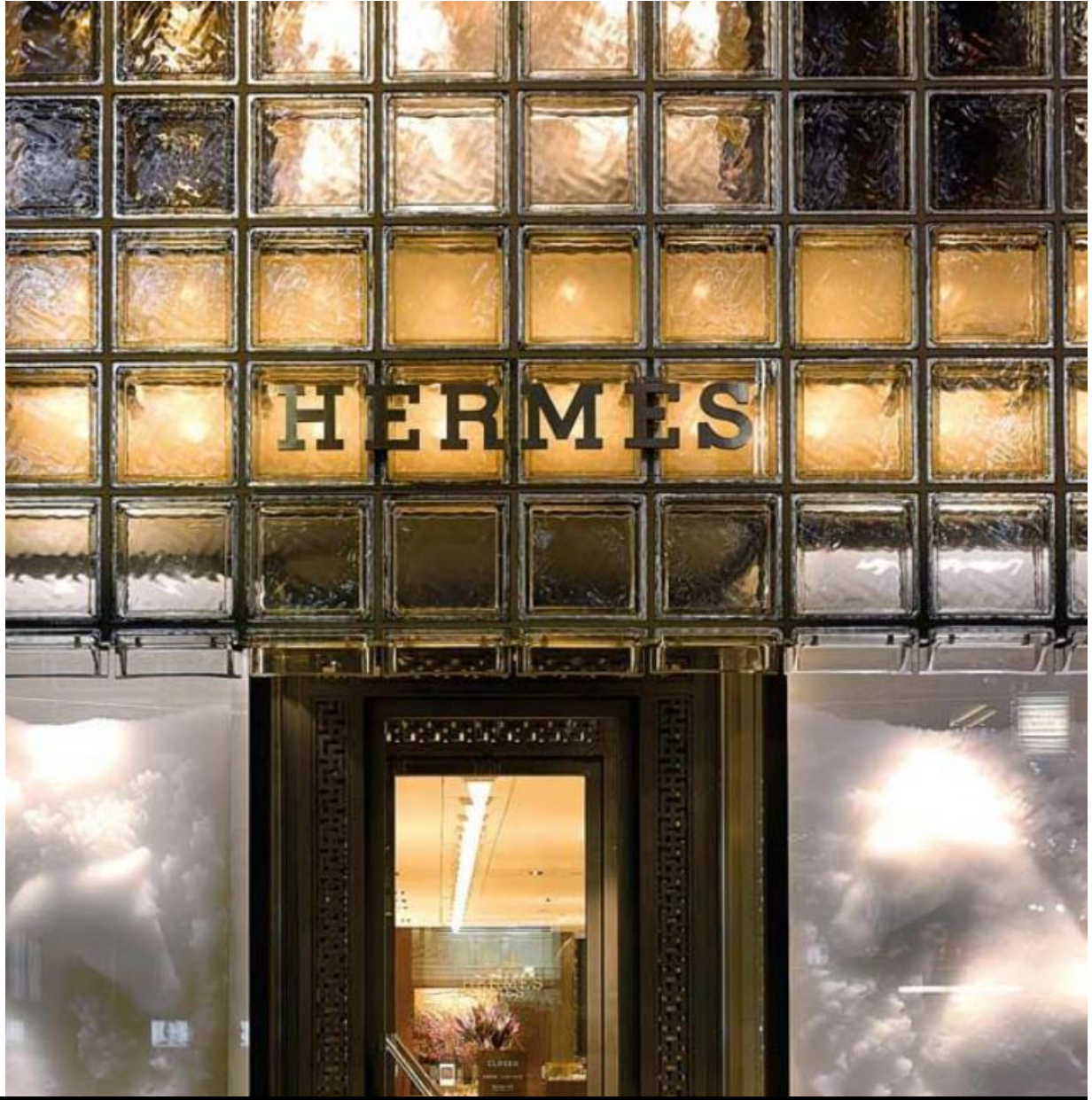
Translucent
Curtain Wall system supported by a metal frame
Because of the air-cavity, it is thermally and acoustically sound

Hollow Glass Blocks

Translucent
Curtain Wall system supported by a metal frame
Because of the air-cavity, it is thermally and acoustically sound

Solid Glass Bricks

Clear
Load-bearing wall.
Acts as a single glass pane

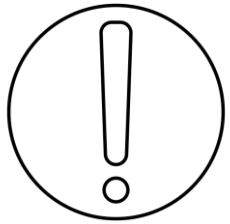


Maison Hermes – Renzo Piano

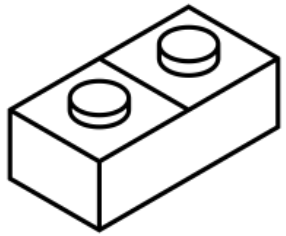
Source: ☑ Maison Hermès Tokyo - Data, Photos & Plans - WikiArquitectura. (2020). Retrieved 9 November 2020, from https://en.wikiarquitectura.com/building/maison-hermes-tokyo/

Crystal House – MVRDV

Source: Author



Evident gap between solid glass brick’s stability and the hollow block’s efficiency.



Hybrid Glass Blocks

- Exhibits good load bearing strength
- Exhibits good thermal properties.

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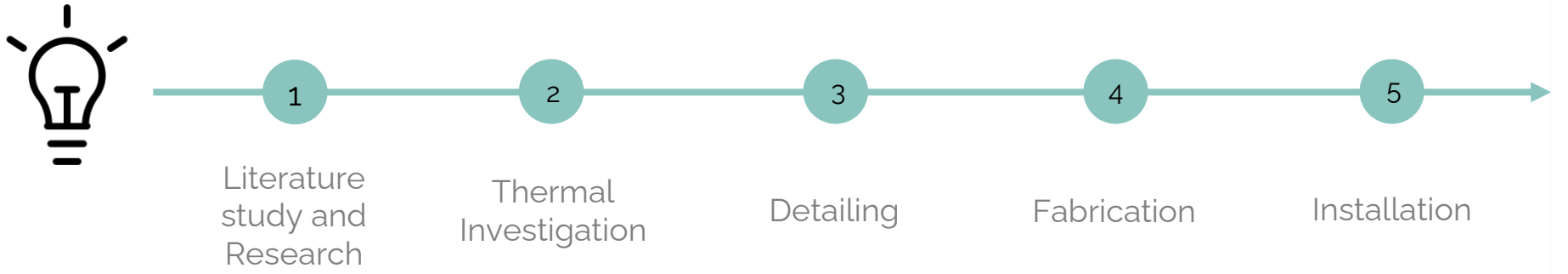
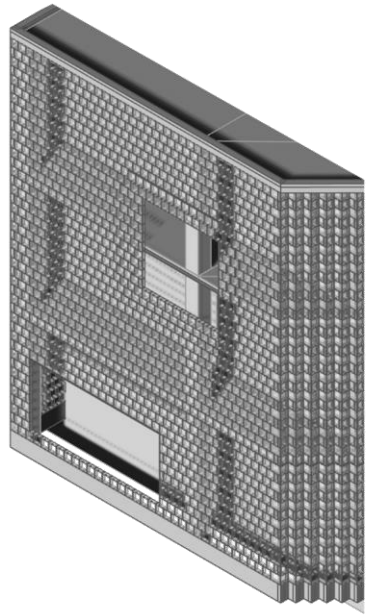
MAIN RESEARCH QUESTION

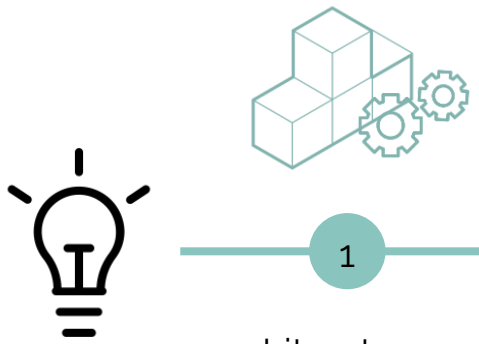
“In what ways can we develop a Hybrid glass block that exhibits a combination of structural and thermal properties and can be efficiently manufactured?”

RESEARCH METHODOLOGY





SUB-RESEARCH QUESTIONS



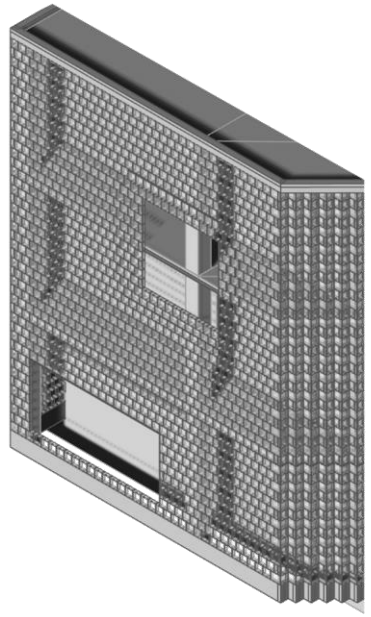
1 Literature study and Research

2 Thermal Investigation

3 Detailing

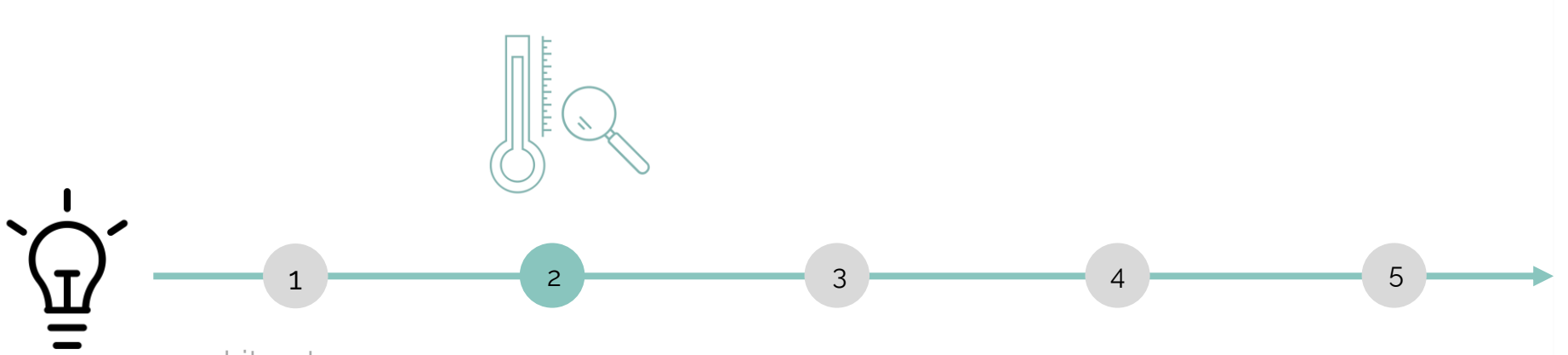
4 Fabrication

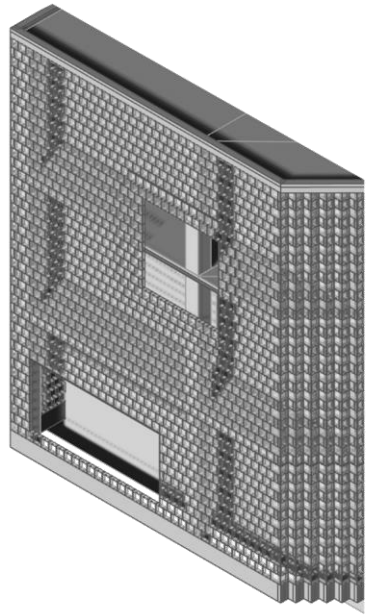
5 Installation



SUB-RESEARCH QUESTIONS

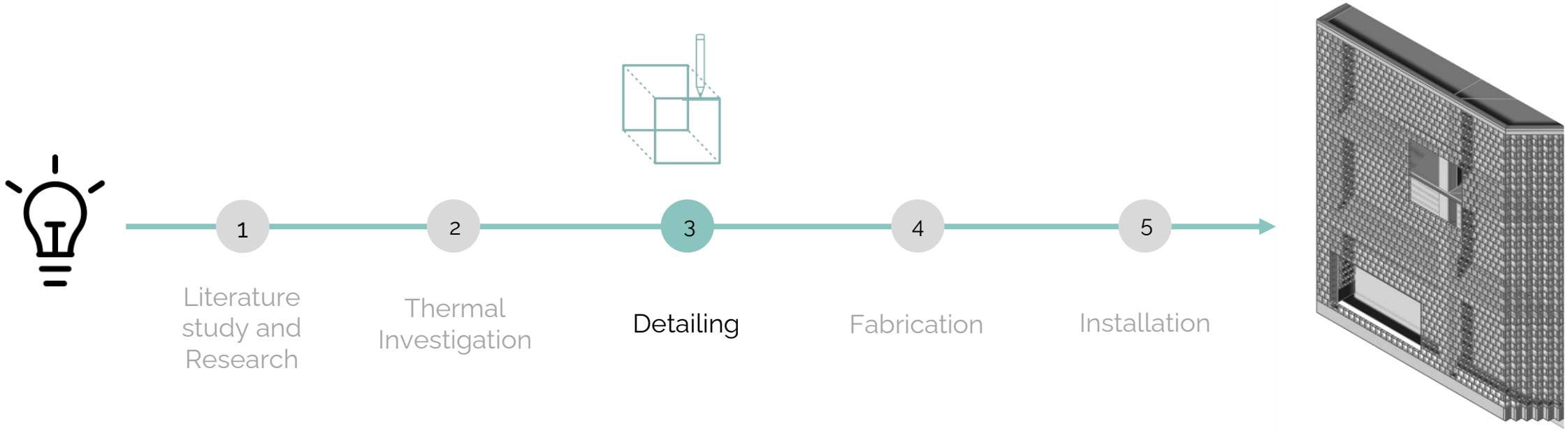
Which are the main factors influencing the thermal performance of the system? What methods can be employed to increase the efficiency and what are the advantages and limitations of these methods?





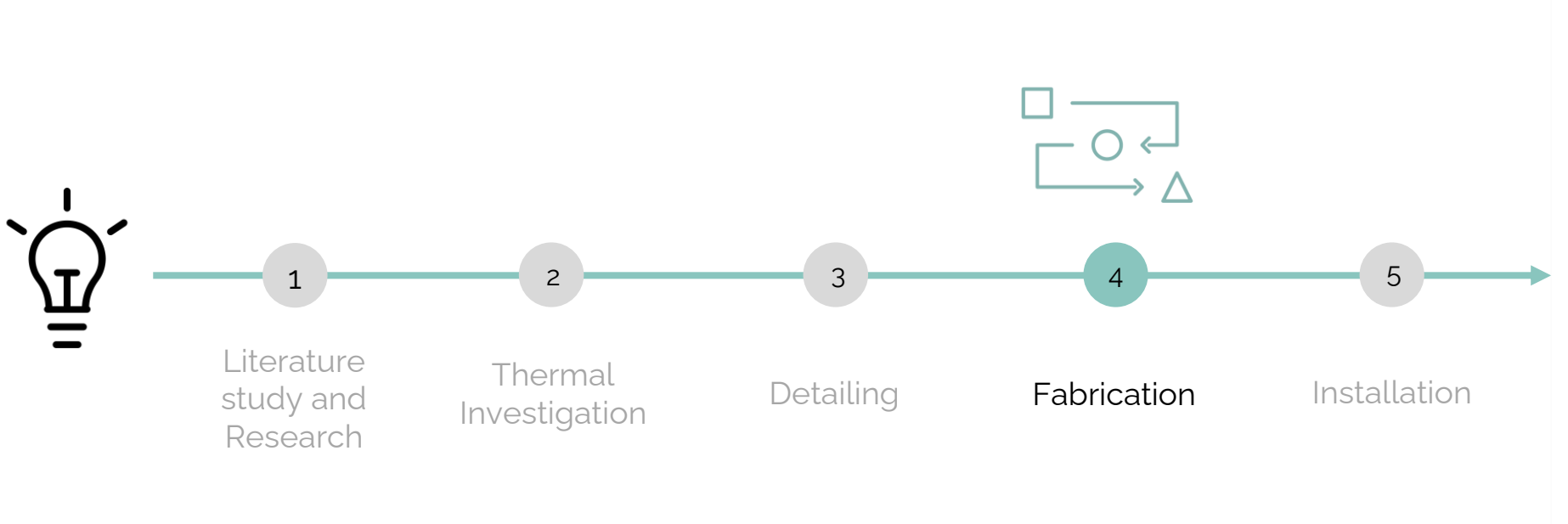
SUB-RESEARCH QUESTION

What are the main engineering criteria and challenges involved in the development of a Hybrid block?



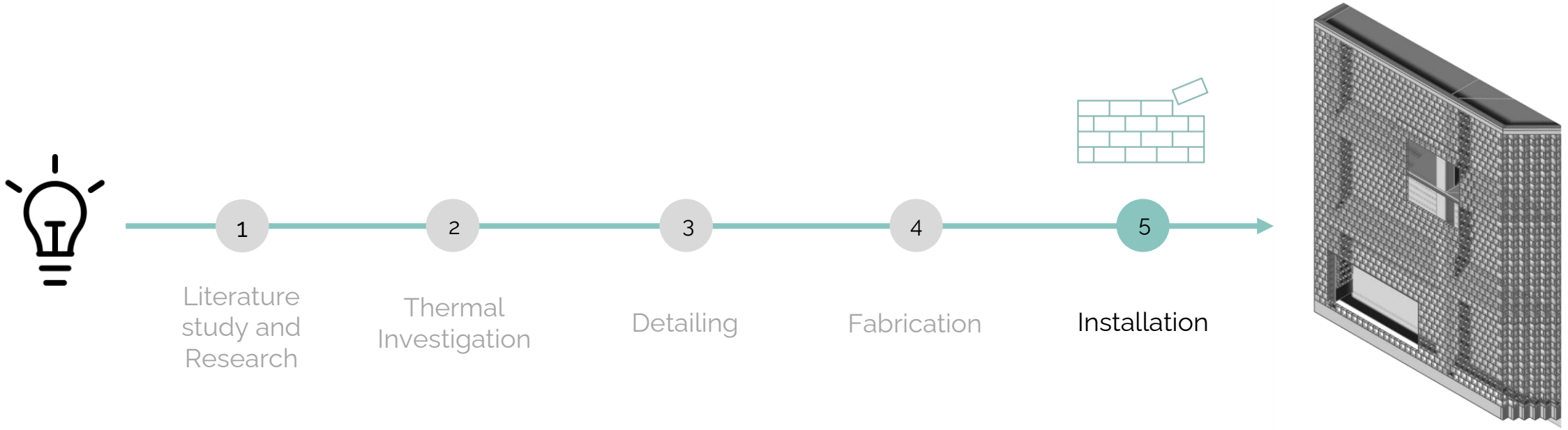
SUB-RESEARCH QUESTION

Which are the main factors affecting the manufacturing process of these blocks? What methods can be employed and what are the advantages and limitations of these methods?



SUB-RESEARCH QUESTION

What are the main factors affecting the build-ability of Hybrid blocks in a structure?



- Glass Block Technology
- Glass Types
- Production Method
- Glass Connection

HOLLOW BLOCK

Properties

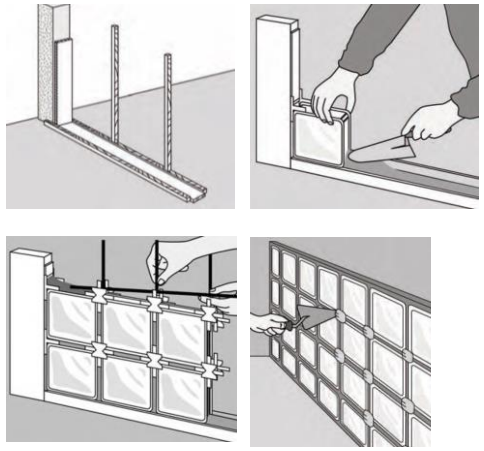
Non-load bearing

Thermally sound

Manufacturing

Process: Casting and Fusing
Glass Type: Soda-lime
Mold Used: Pressed mold

Installation



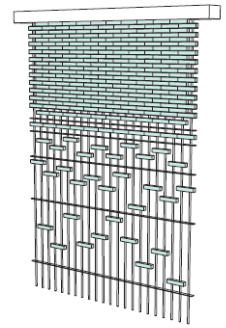
Standardized Process

SOLID BLOCK

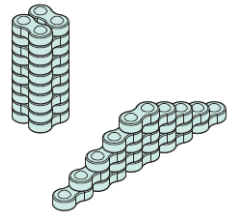
Load bearing

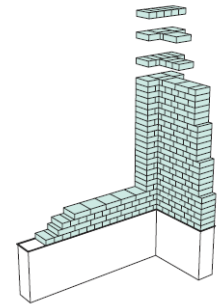
Poor thermal performance

No standardized process



1. With a metal substructure
2. Adhesive based
3. Interlocking





No standardized Process

- Glass Block Technology
- Glass Types
- Production Method
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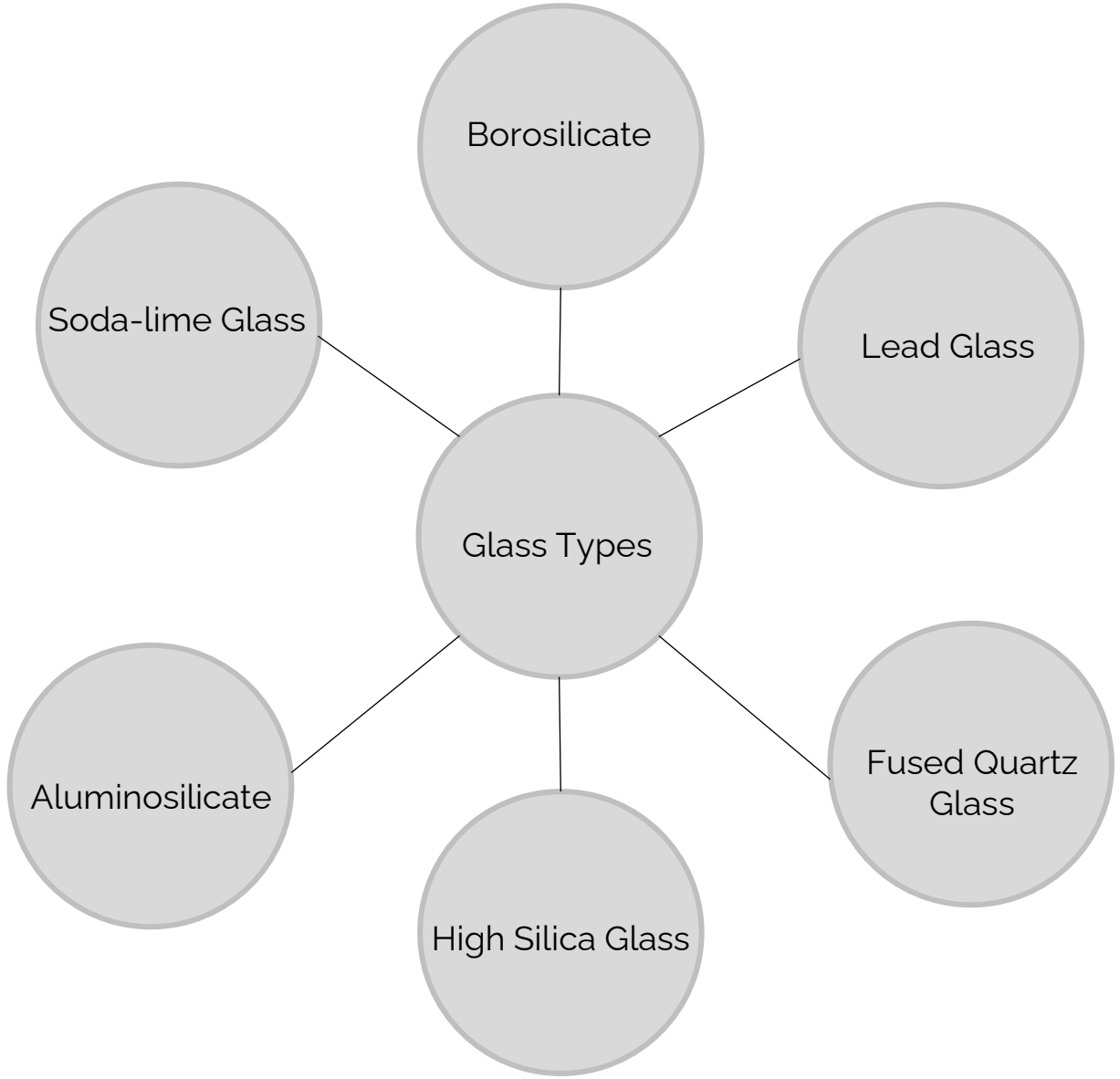

- Glass Block Technology
- Glass Types
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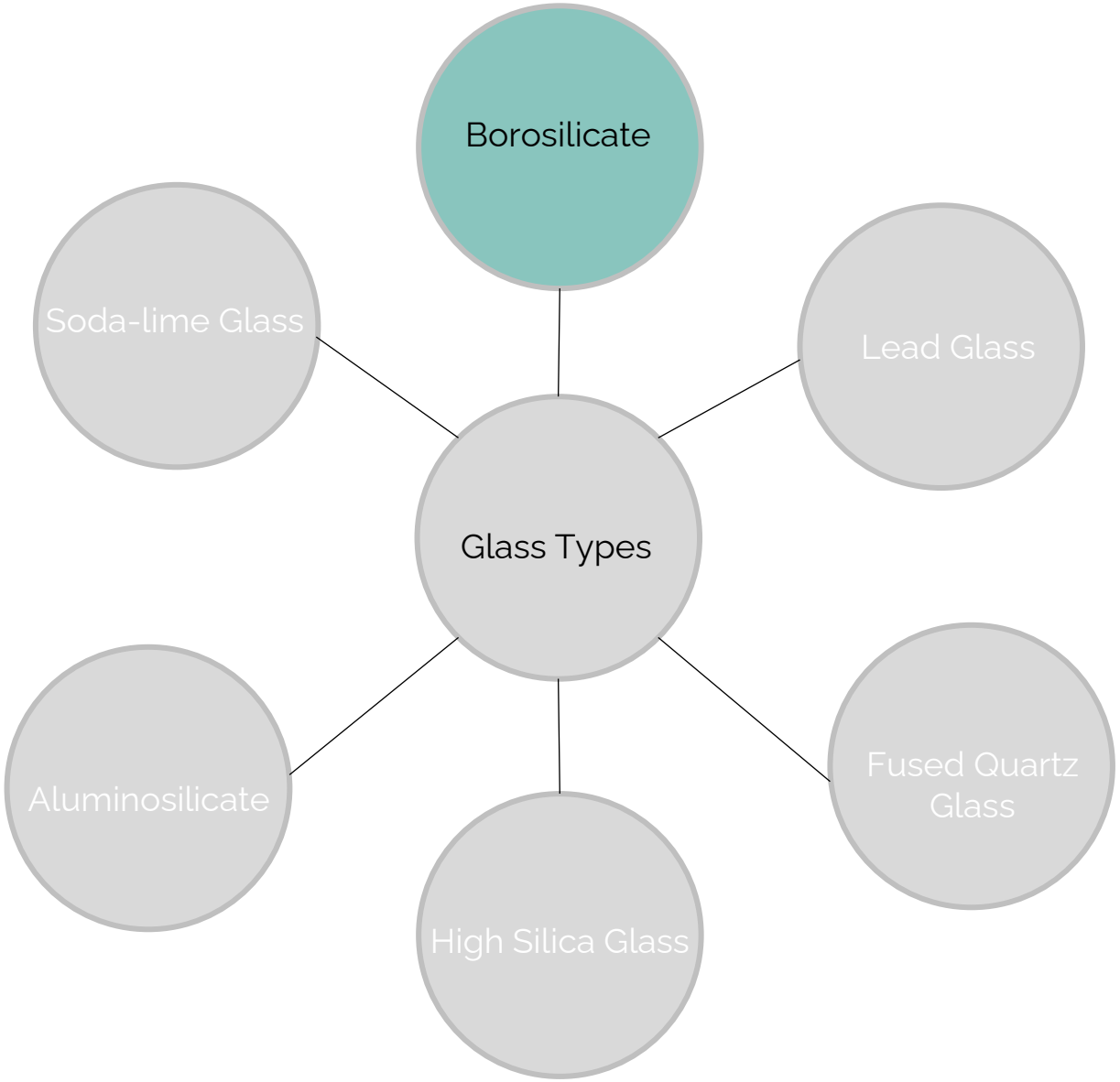
Borosilicate

Softening Point: 780˚C
Annealing Point: 525˚C
Density: 2230 kg/m²

It has lower thermal coefficient value and exceptional performance at high temperatures.



- Glass Block Technology
- Glass Types
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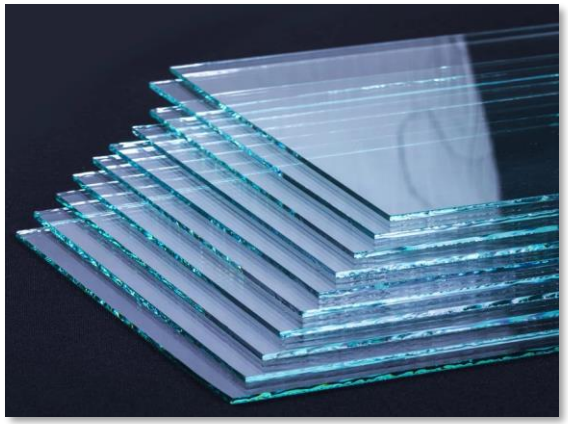
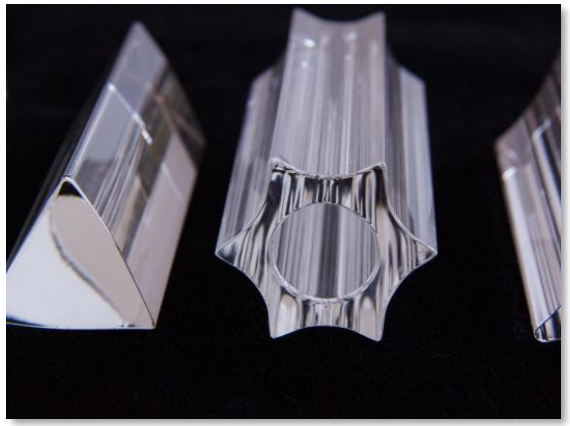
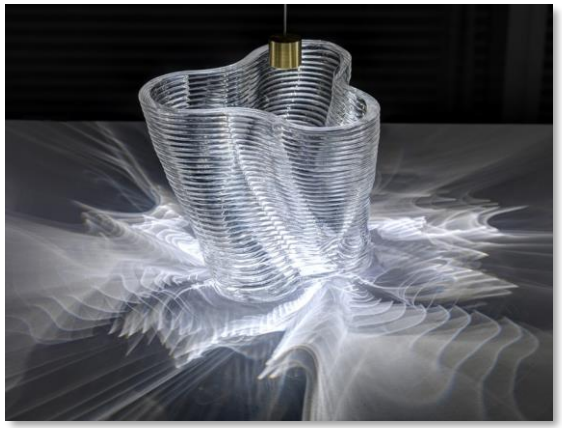


Float Glass



Extruded Glass

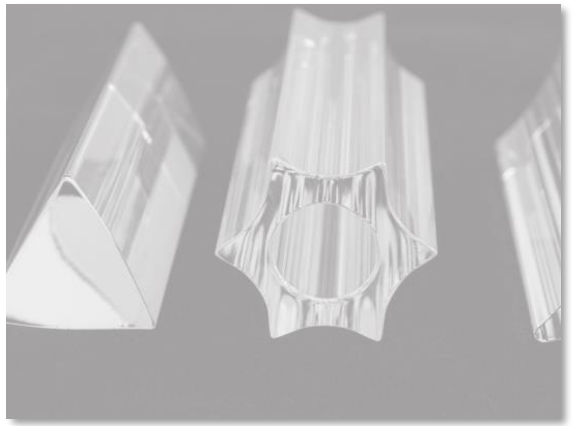


3D print

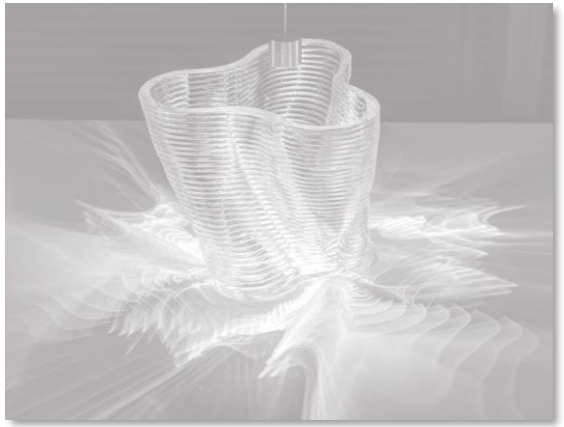
Cast Glass

- Glass Block Technology
- Glass Types
- **Production Method**
- Glass Connection

Float Glass



Extruded Glass



3D print

Cast Glass

Optical characteristics

Smooth, Transparent

Glass type applied

Soda-lime, Borosilicate, Lead

Standard size

upto 20,000 kgs

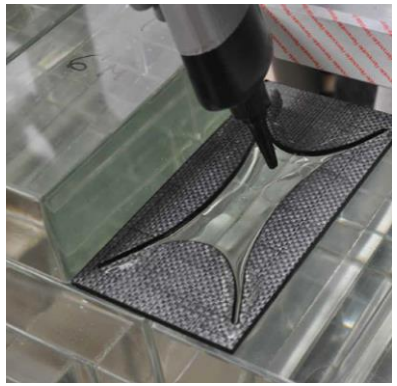
Notes

Provides greatest freedom in the volume and size of the resulting glass object with good optical quality.

- Glass Block Technology
- Glass Types
- Production Method
- Glass Connection

Clamped Connection

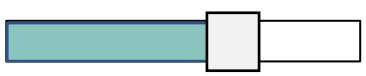
Bolted Connection

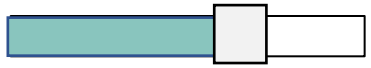


Adhesive Connection

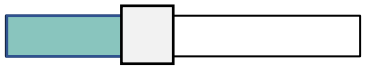
Embedded Connection

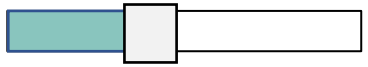
Performance under load

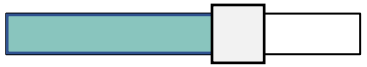




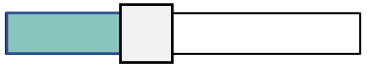
Unobstructed View

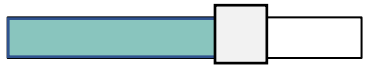






Reversibility



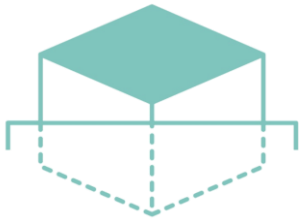


Compressive Strength

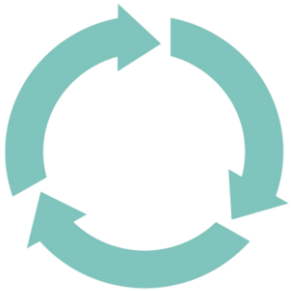
Thermal Performance

U-value < 2.2 W/m2K

Dutch Building Code <1.65 W/m2K
Eurocode <2.2 W/m2K
Local code <2.5 W/m2K
(Chinese National Building Codes)



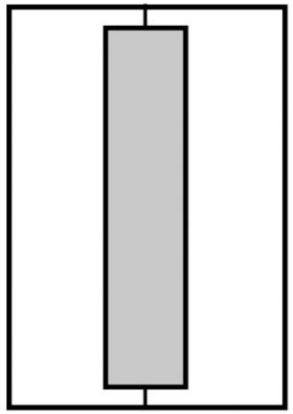
Ease of Manufacturing



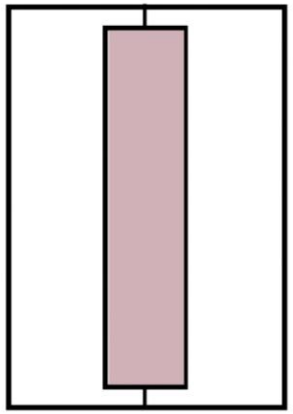
Recyclability

Optical quality

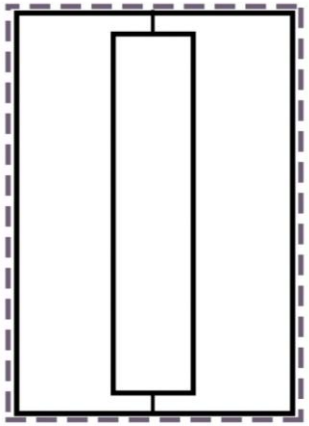
CONCEPTS TO IMPROVE THERMAL PERFORMANCE



Concept 1a:
Altering Cavity sizes

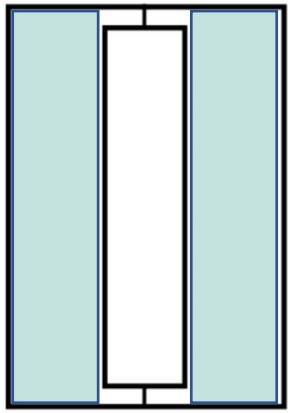


Concept 1b:
Adding inert gas

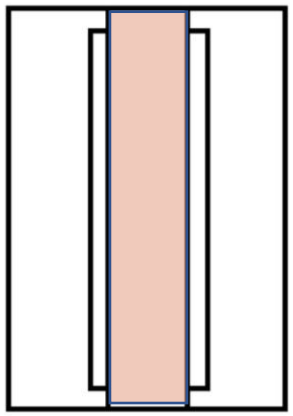


Concept 1c:
Applying coatings

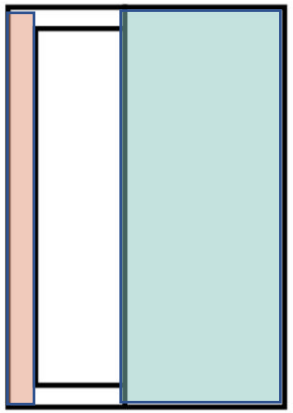
CONCEPTS TO IMPROVE STRUCTURAL PERFORMANCE



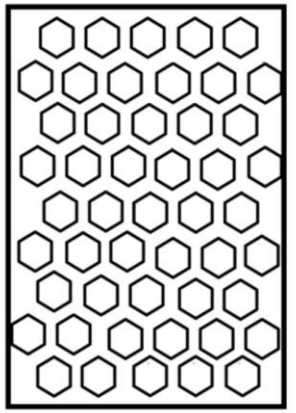
Concept 2a: Altering the cross-section thickness



Concept 2b: Providing coated glass in middle



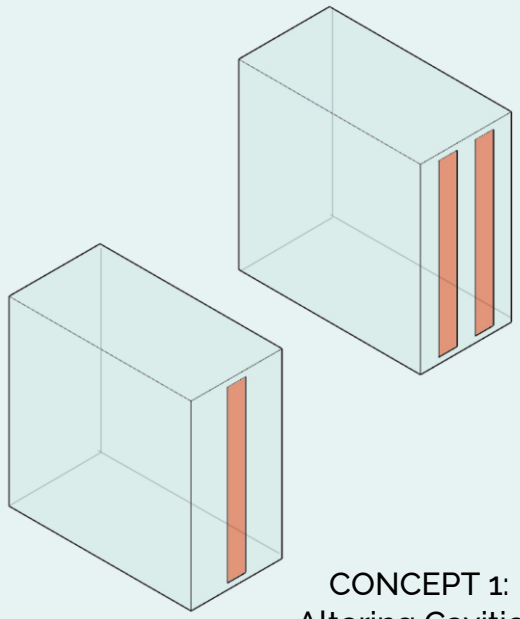
Concept 2c: Merging hollow with solid



Concept 2d: Honeycomb Structure

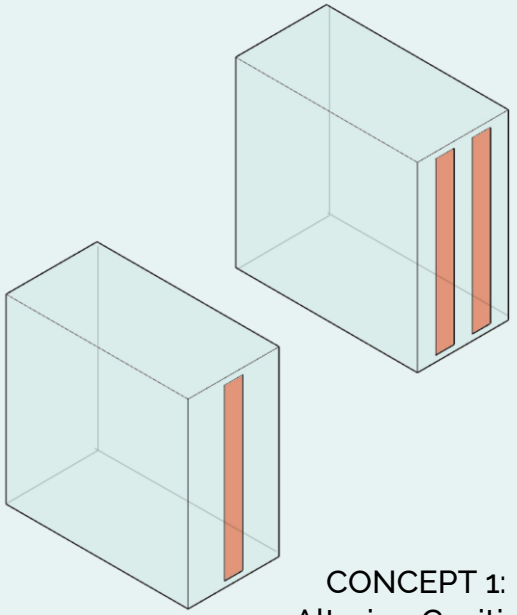

Concepts to improve thermal performance
+
Concepts to improve structural performance
=
Final design concepts

CONCEPTS



CONCEPT 1:
Altering Cavities

CONCEPTS



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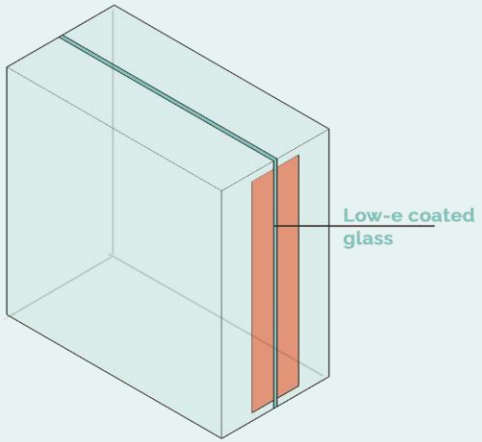
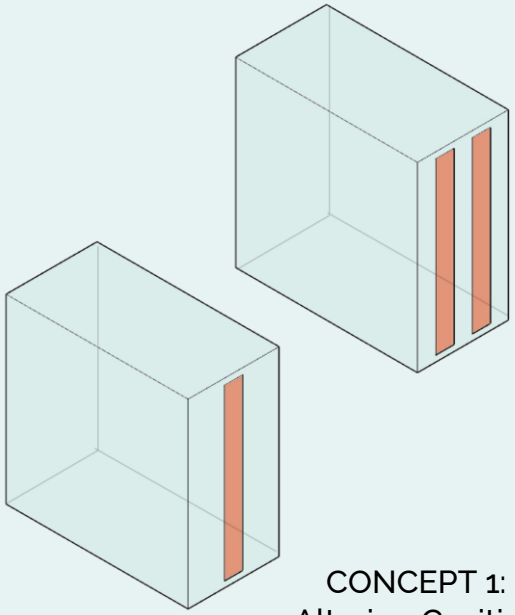


CONCEPT 2: Providing
coated glass in middle

CONCEPTS



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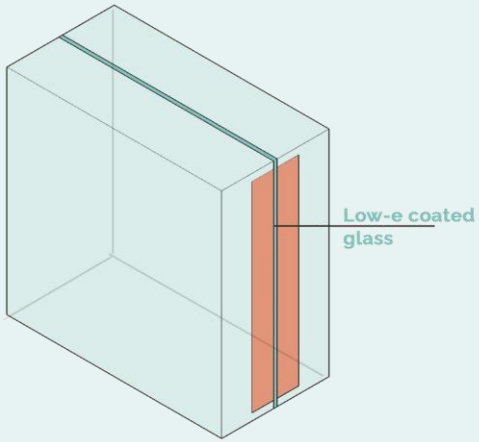
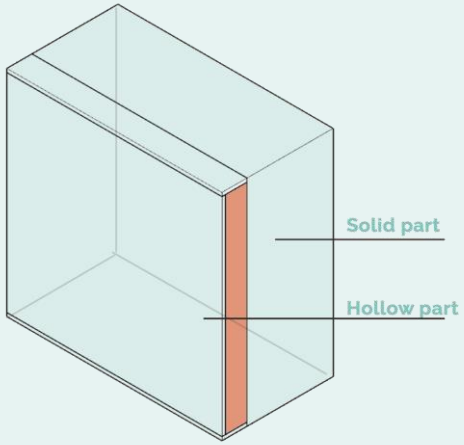
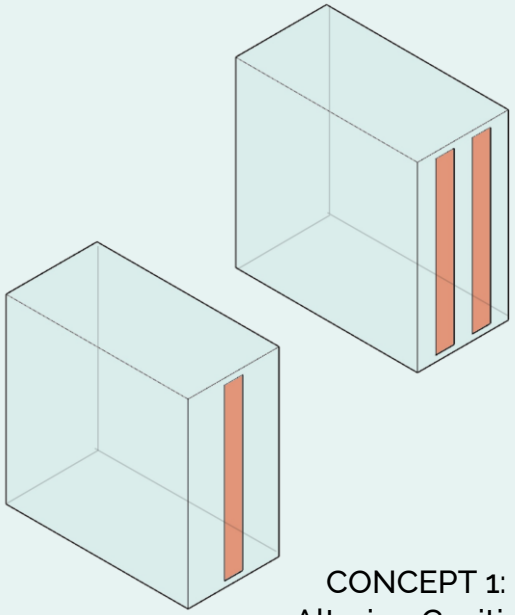


CONCEPT 2: Providing
coated glass in middle



CONCEPT 3: Merging
hollow block with solid

CONCEPTS



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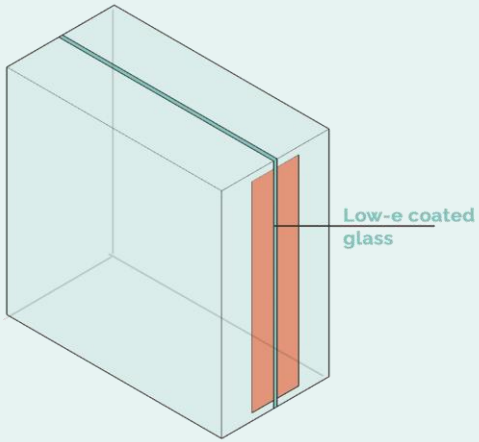

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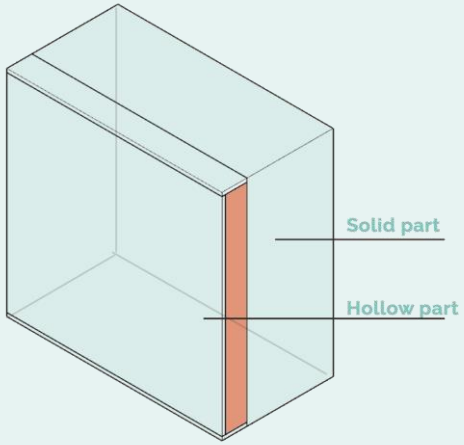
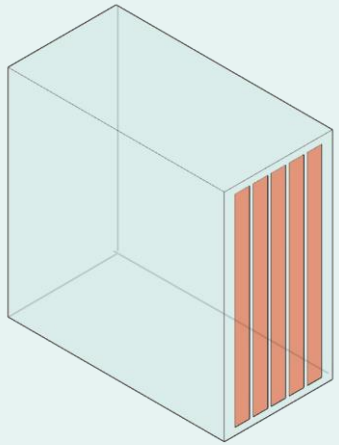
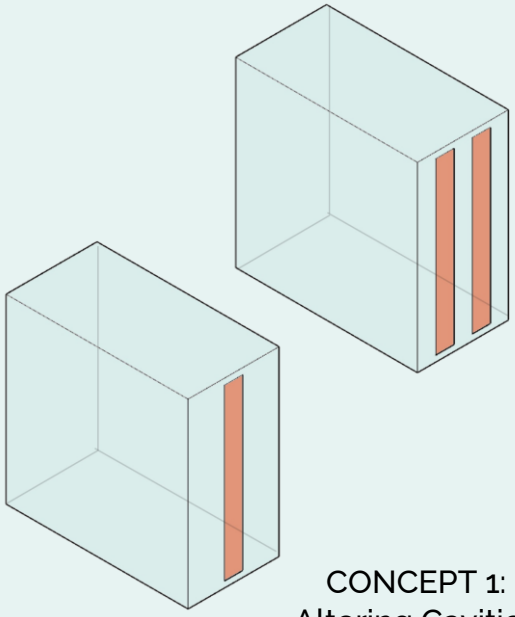


CONCEPT 3: Merging
hollow block with solid

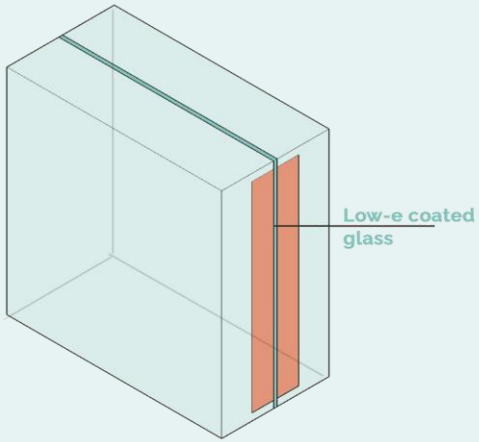


CONCEPT 4:
Honeycomb structure

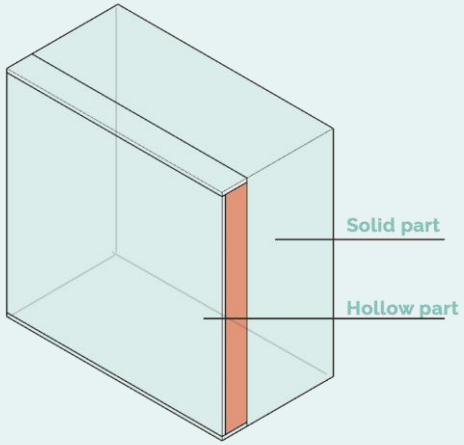
CONCEPTS



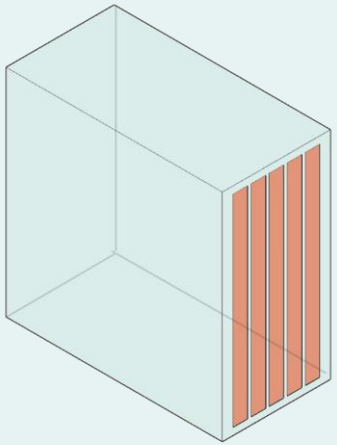
CONCEPT 1:
Altering Cavities



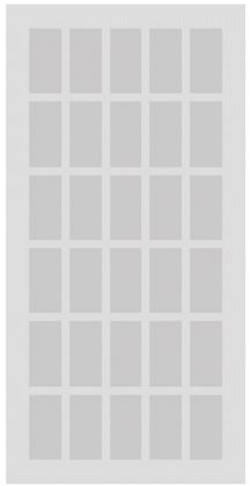
CONCEPT 2: Providing
coated glass in middle



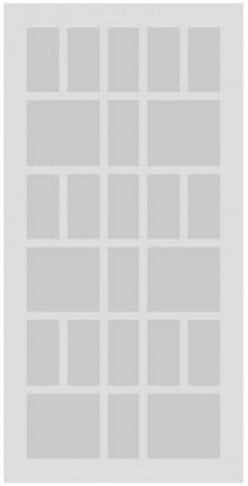
CONCEPT 3: Merging
hollow block with solid



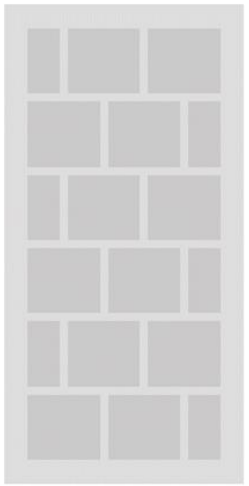
CONCEPT 4:
Honeycomb structure



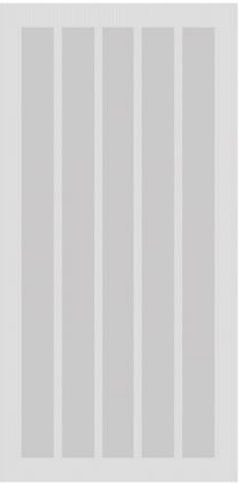
Pattern A



Pattern B

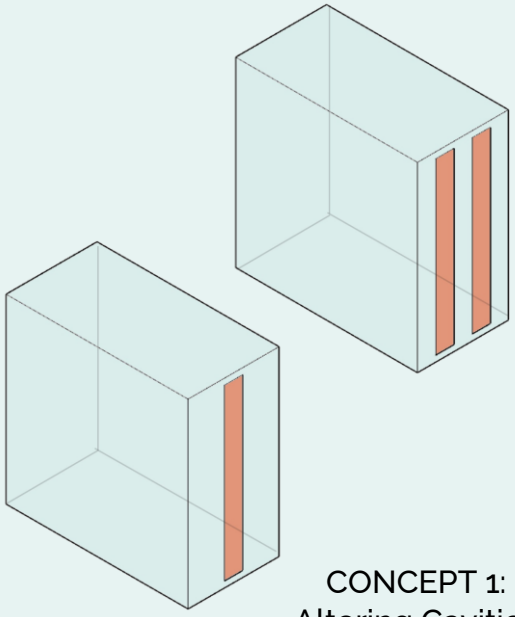


Pattern C

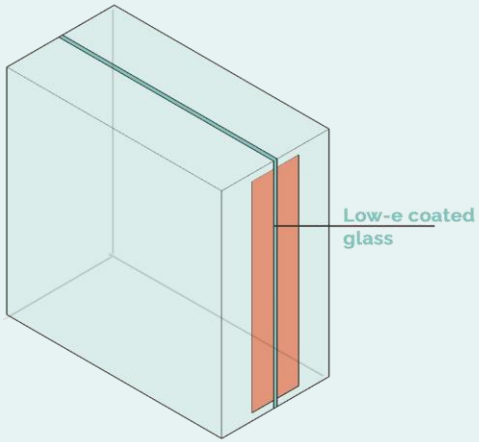


Pattern D

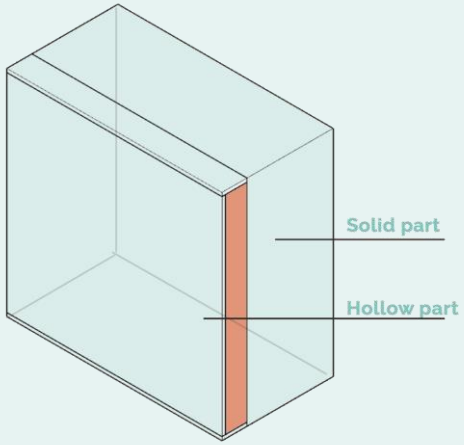
CONCEPTS



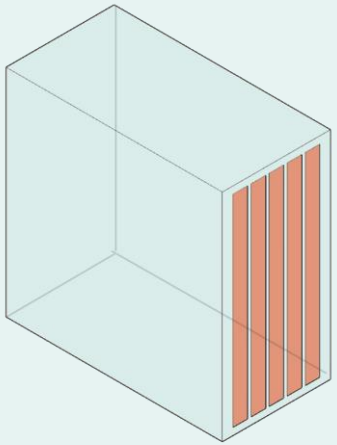
CONCEPT 1:
Altering Cavities



CONCEPT 2: Providing
coated glass in middle

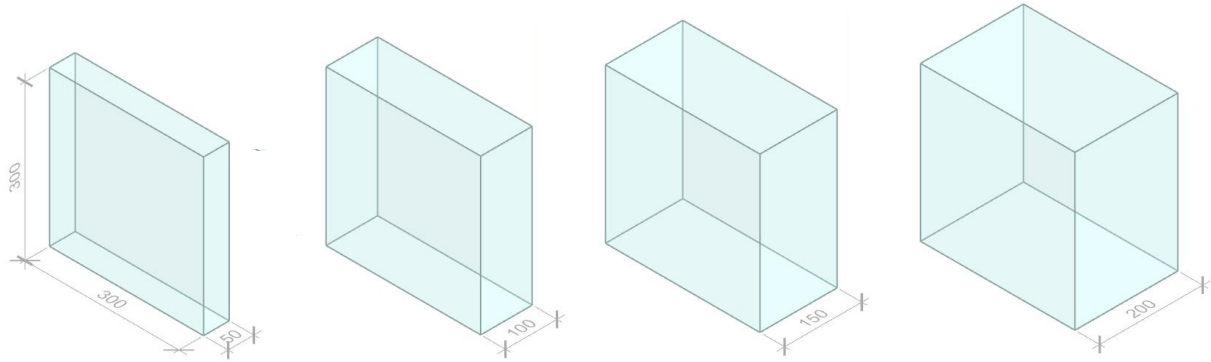


CONCEPT 3: Merging
hollow block with solid

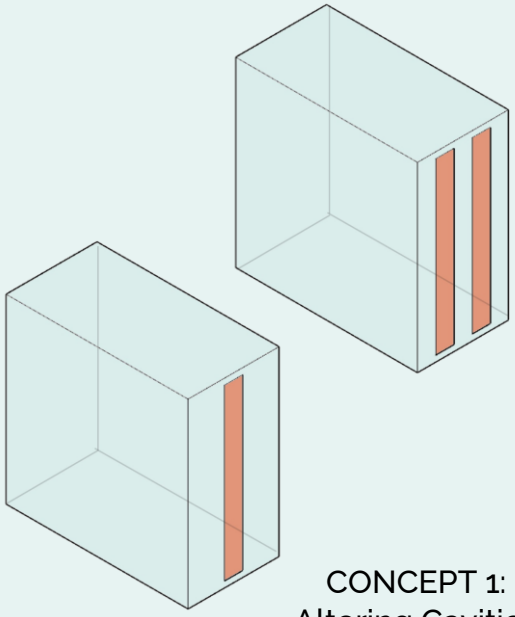


CONCEPT 4:
Honeycomb structure

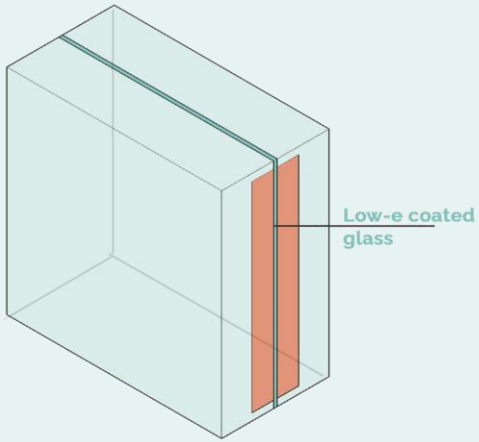
DIFFERENT SIZES OF BLOCK



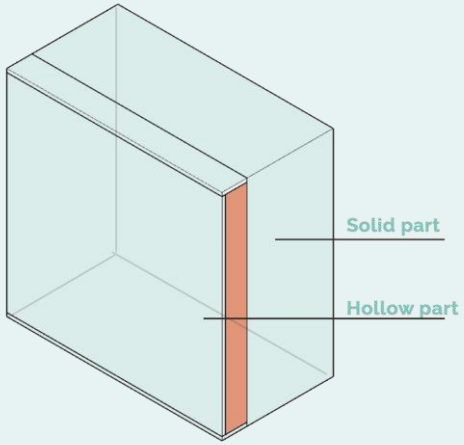
CONCEPTS



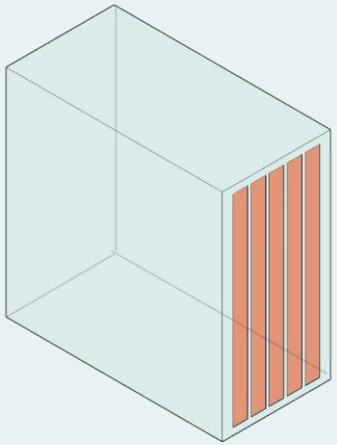
CONCEPT 1:
Altering Cavities



CONCEPT 2: Providing
coated glass in middle

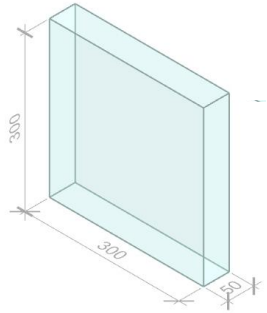


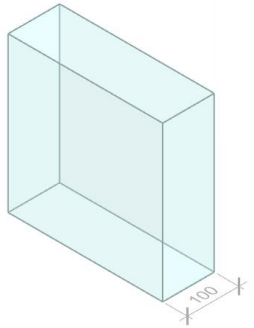
CONCEPT 3: Merging
hollow block with solid

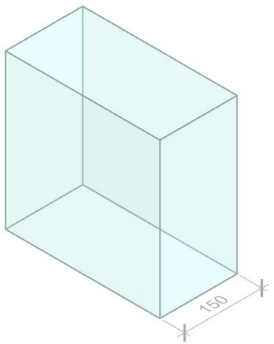


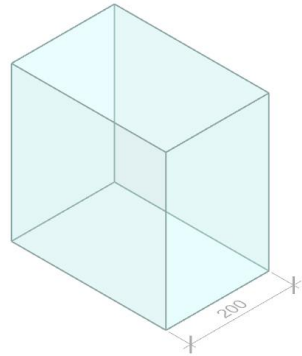
CONCEPT 4:
Honeycomb structure

DIFFERENT SIZES OF BLOCK





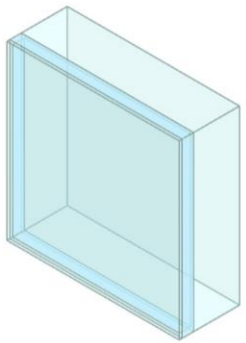




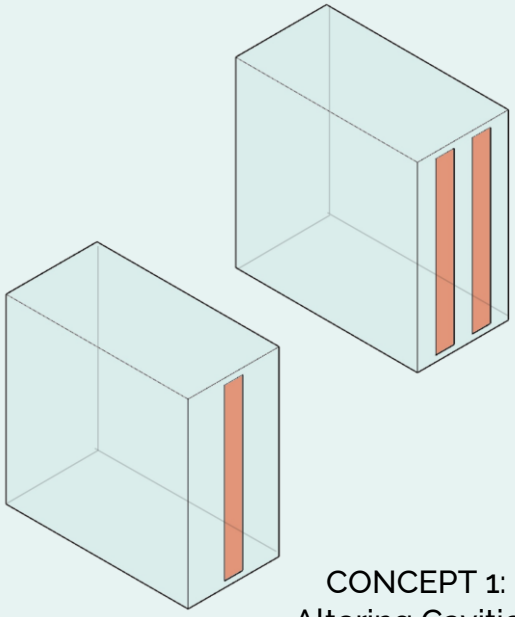
METHODOLOGY

STAGE 1

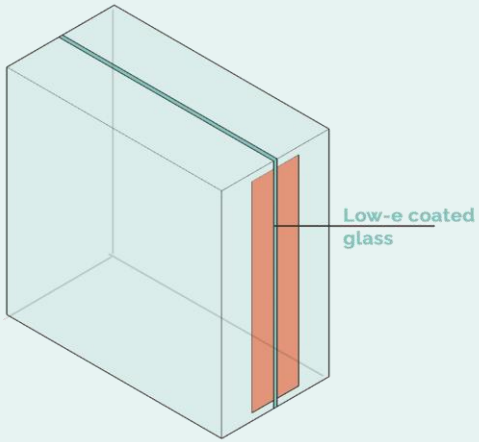
Analysis with air cavity and no coatings.



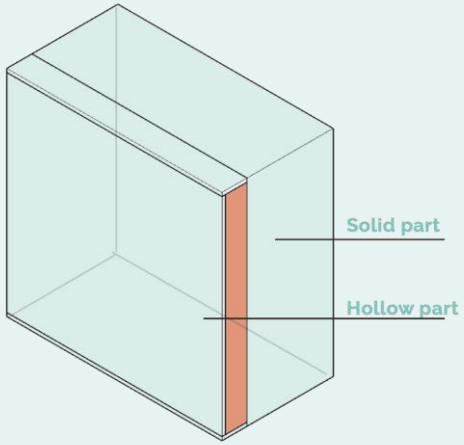
CONCEPTS



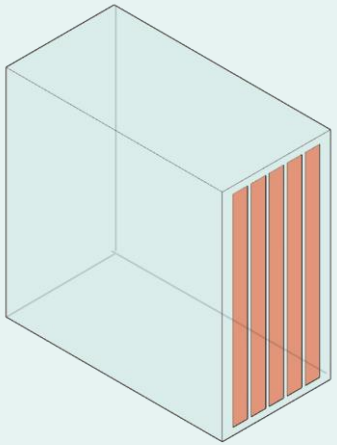
CONCEPT 1:
Altering Cavities



CONCEPT 2: Providing
coated glass in middle

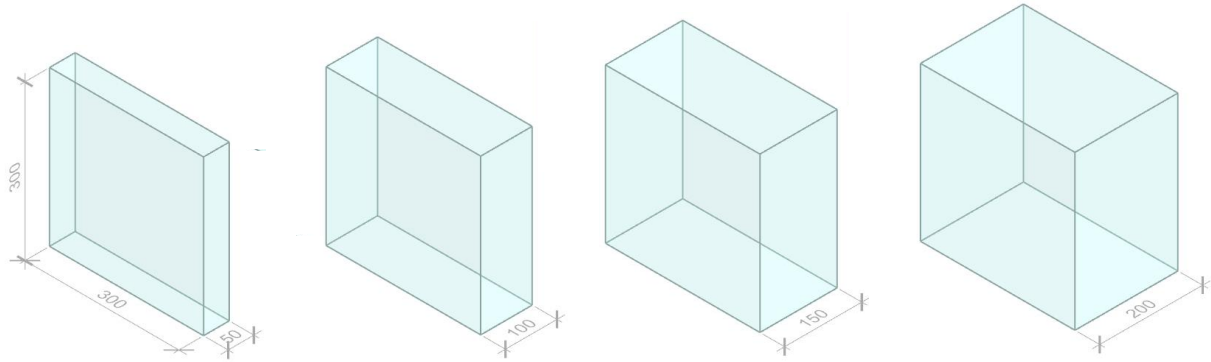


CONCEPT 3: Merging
hollow block with solid



CONCEPT 4:
Honeycomb structure

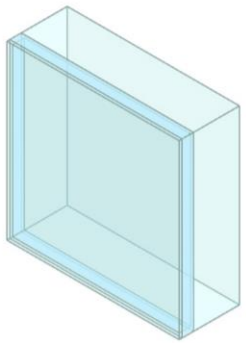
DIFFERENT SIZES OF BLOCK



METHODOLOGY

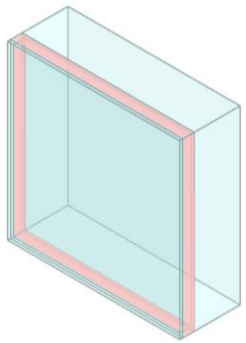
STAGE 1

Analysis with air cavity and no coatings.

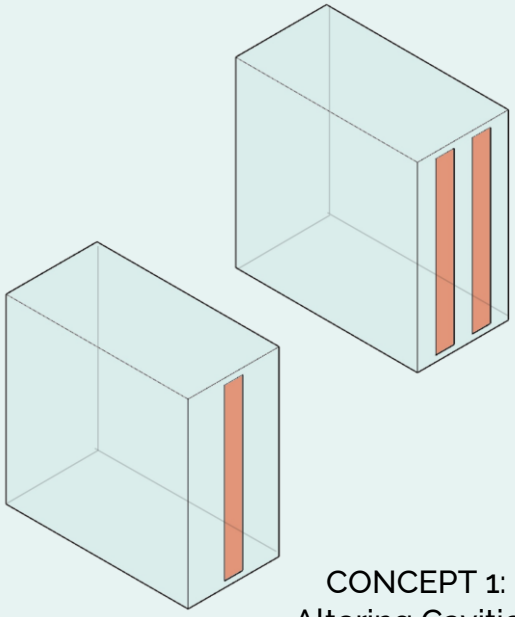


STAGE 2

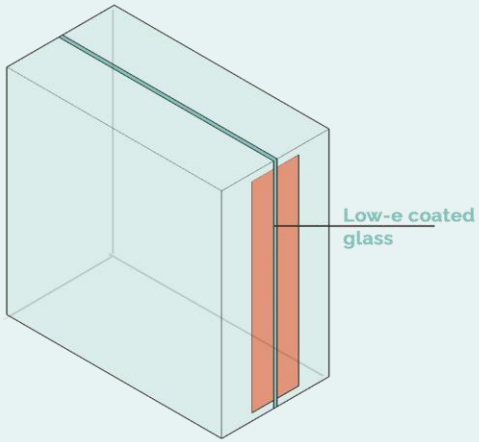
Analysis with argon cavity and no coatings.



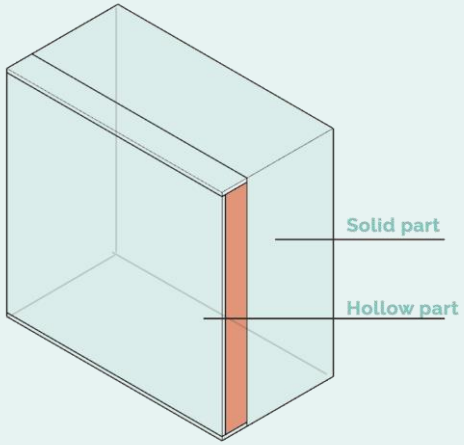
CONCEPTS



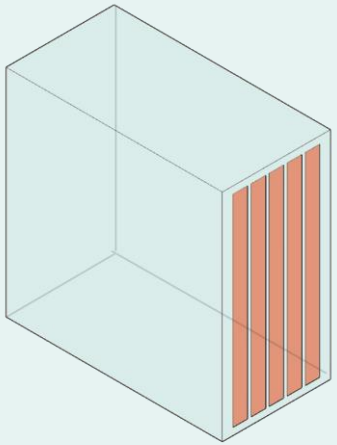
CONCEPT 1:
Altering Cavities



CONCEPT 2: Providing coated glass in middle

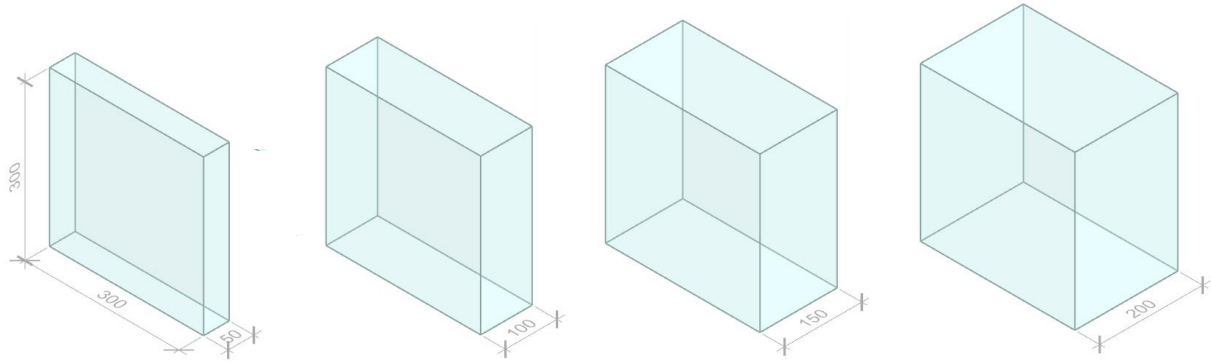


CONCEPT 3: Merging hollow block with solid



CONCEPT 4:
Honeycomb structure

DIFFERENT SIZES OF BLOCK

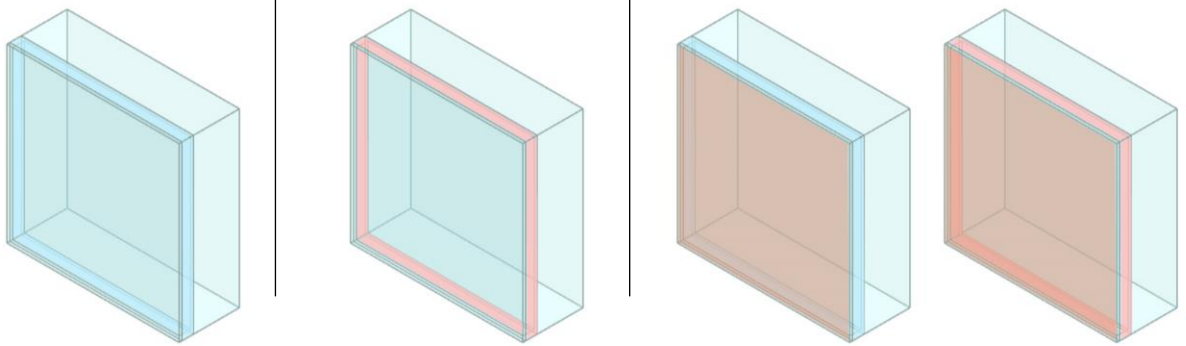


METHODOLOGY

STAGE 1
Analysis with air cavity and no coatings.

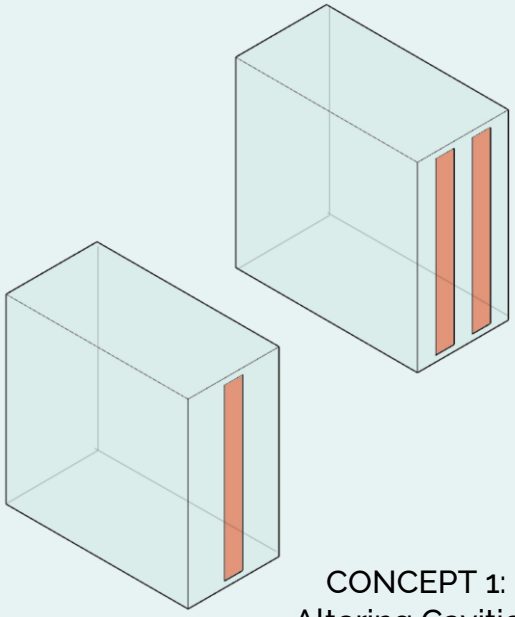
STAGE 2
Analysis with argon cavity and no coatings.

STAGE 3
Analysis with air and argon cavity and low emissivity coating.

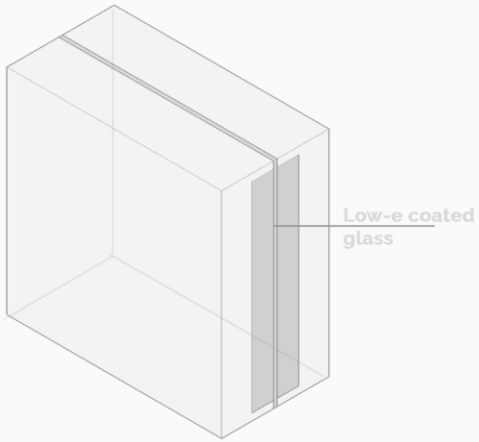


Air Cavity | Argon Cavity | Low-e coating | Glass

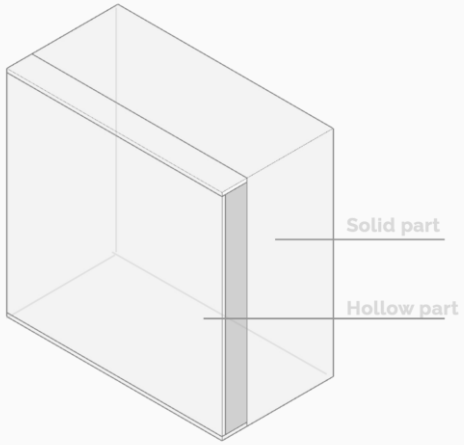
CONCEPTS



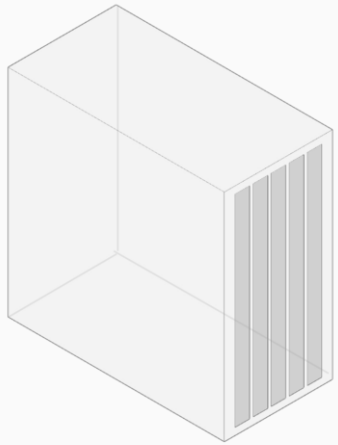
CONCEPT 1:
Altering Cavities



CONCEPT 2: Providing
coated glass in middle

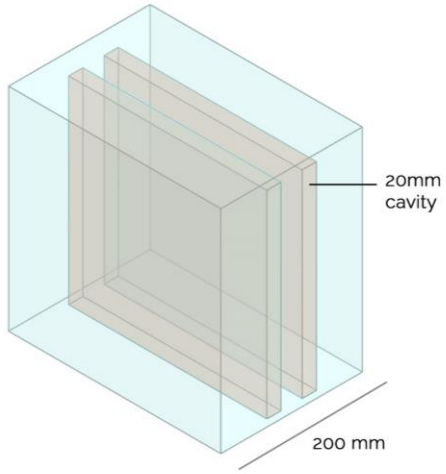


CONCEPT 3: Merging
hollow block with solid



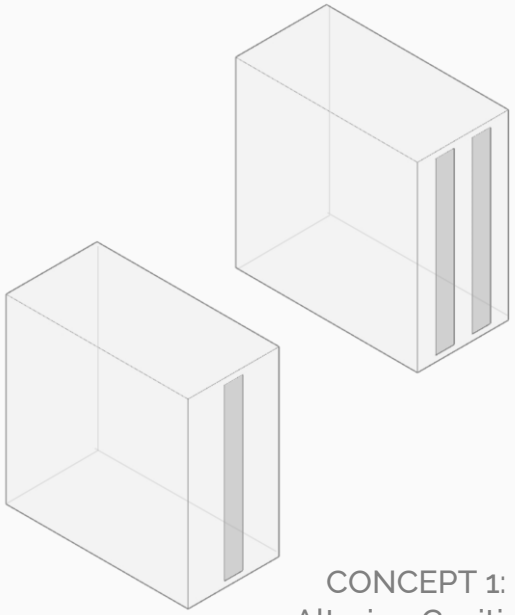
CONCEPT 4:
Honeycomb structure

FINAL DESIGN OPTIONS

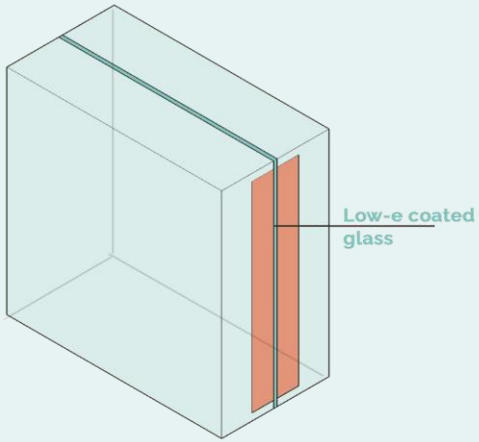


Design Option 1

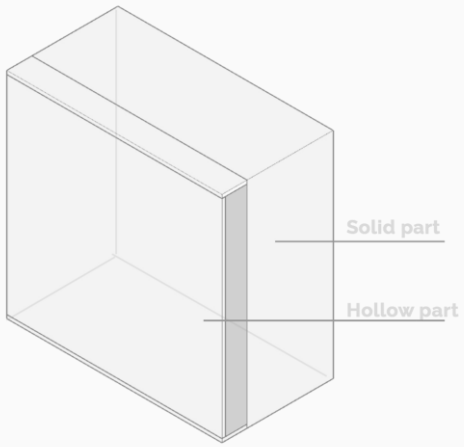
CONCEPTS



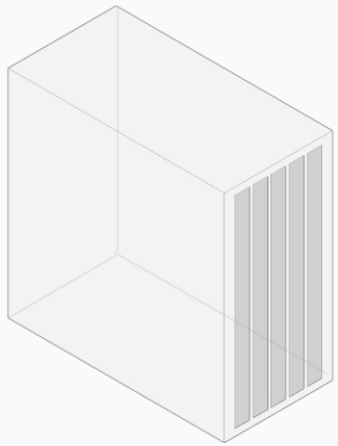
CONCEPT 1:
Altering Cavities



CONCEPT 2: Providing coated glass in middle

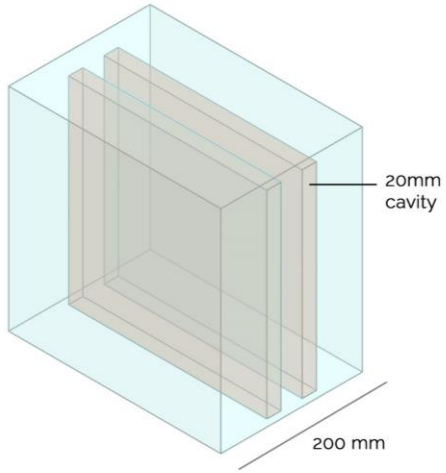


CONCEPT 3: Merging hollow block with solid

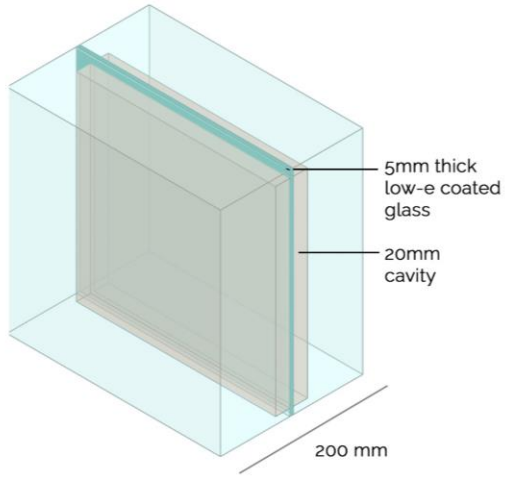


CONCEPT 4:
Honeycomb structure

FINAL DESIGN OPTIONS

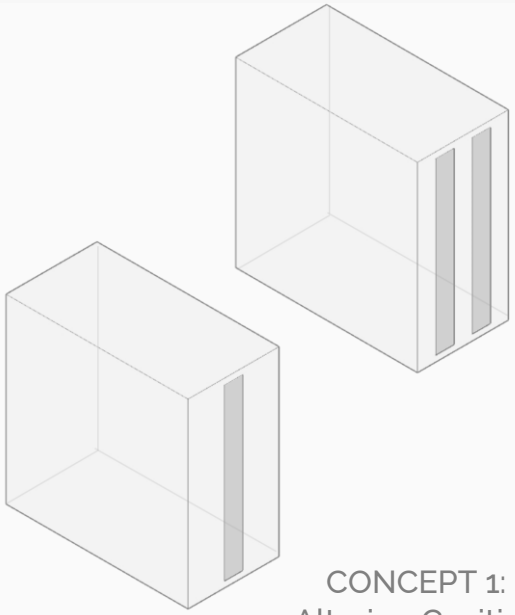


Design Option 1

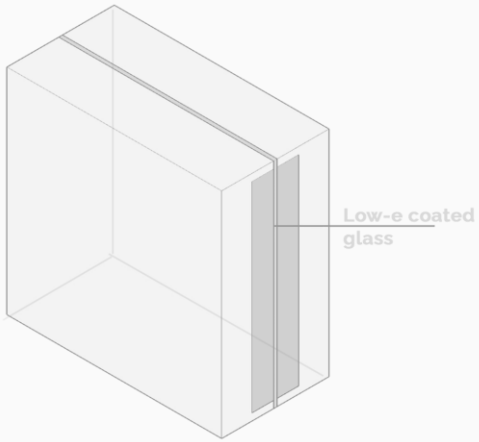


Design Option 2

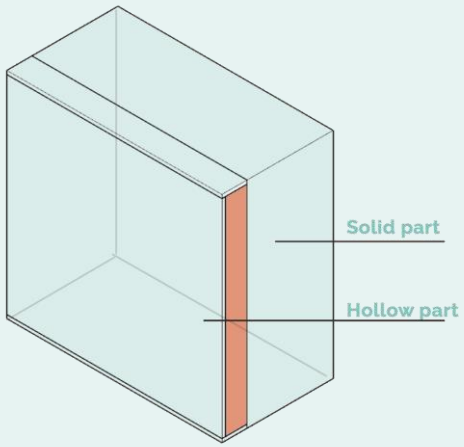
CONCEPTS



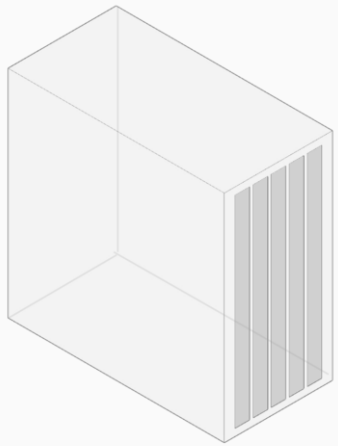
CONCEPT 1:
Altering Cavities



CONCEPT 2: Providing
coated glass in middle

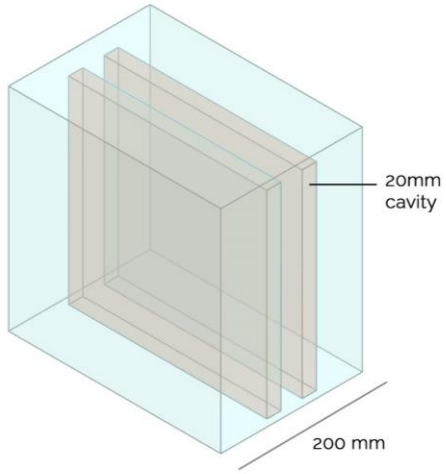


CONCEPT 3: Merging
hollow block with solid

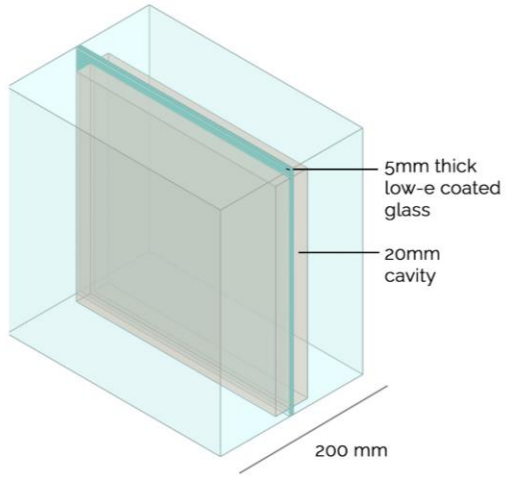


CONCEPT 4:
Honeycomb structure

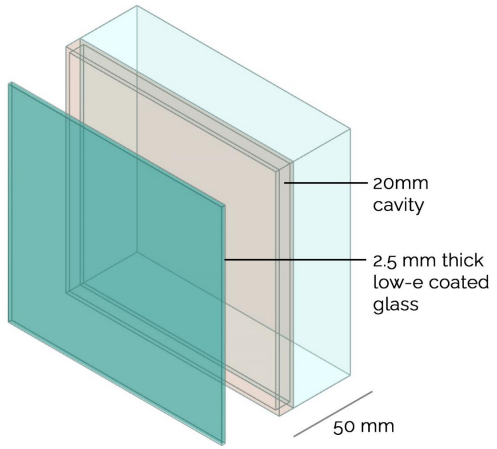
FINAL DESIGN OPTIONS



Design Option 1

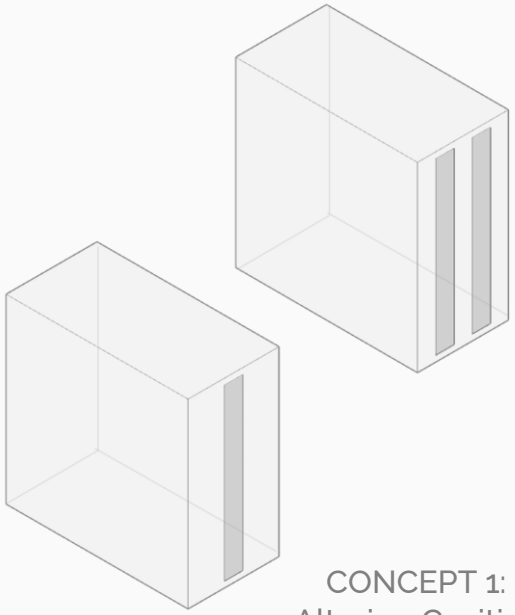


Design Option 2

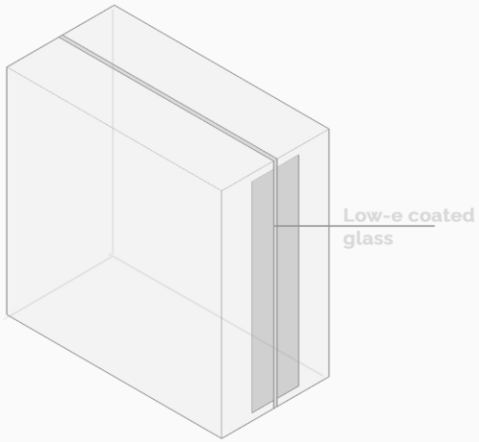


Design Option 3

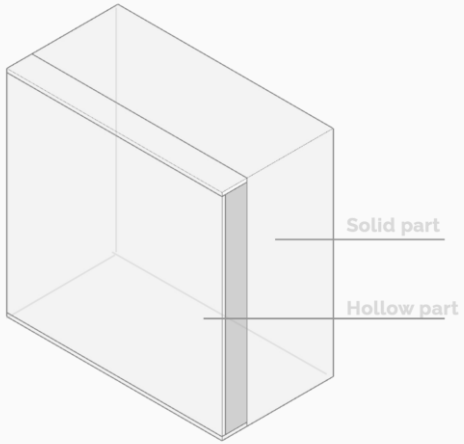
CONCEPTS



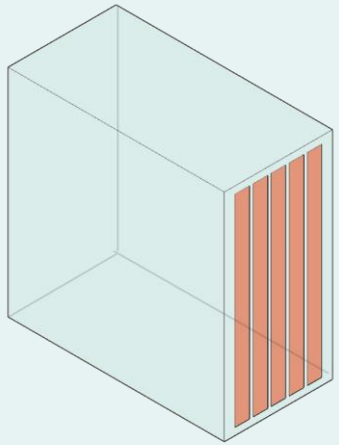
CONCEPT 1:
Altering Cavities



CONCEPT 2: Providing coated glass in middle

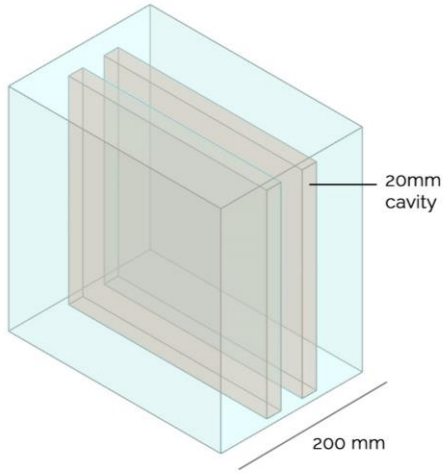


CONCEPT 3: Merging hollow block with solid

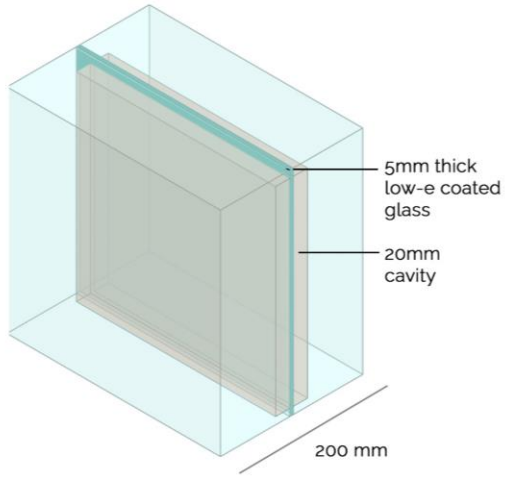


CONCEPT 4:
Honeycomb structure

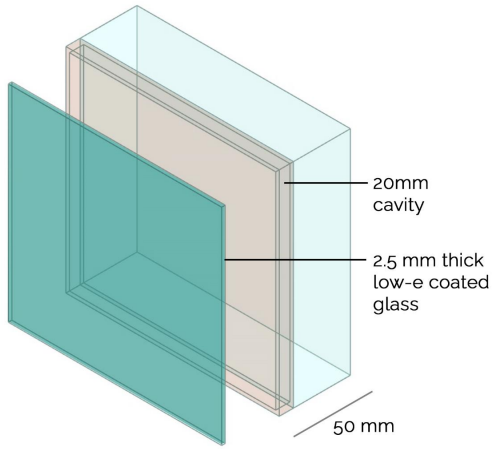
FINAL DESIGN OPTIONS



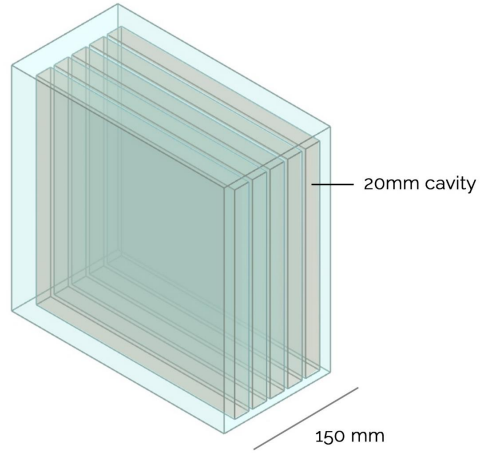
Design Option 1



Design Option 2



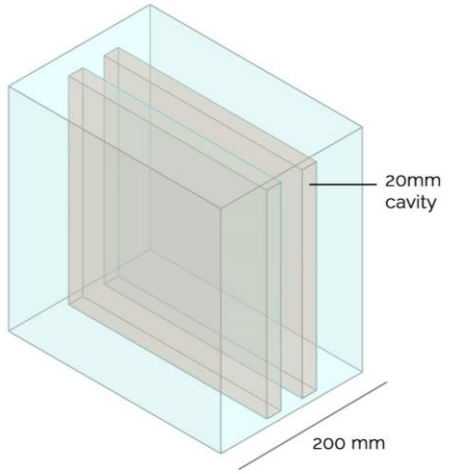
Design Option 3



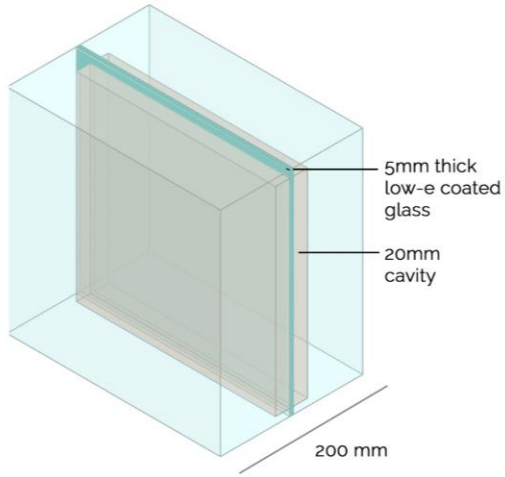
Design Option 4

	Design Option 1	Design Option 2	Design Option 3	Design Option 4
	++++	++++	++++	++++
	1.83 W/m2K	1.62 W/m2K	1.73 W/m2K	1.65 W/m2K
	++	++	++++	+++
	++++	+	++	++++
	+++	+++	++++	++

FINAL DESIGN OPTIONS



Design Option 1



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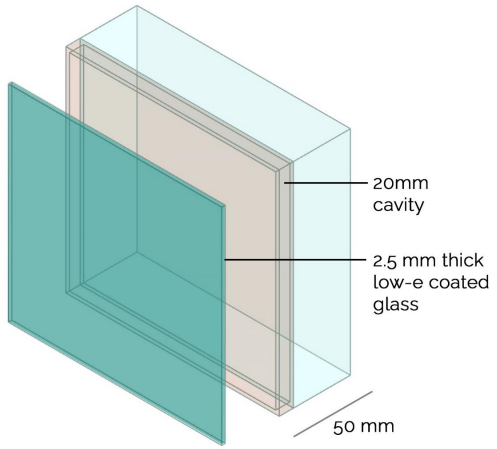
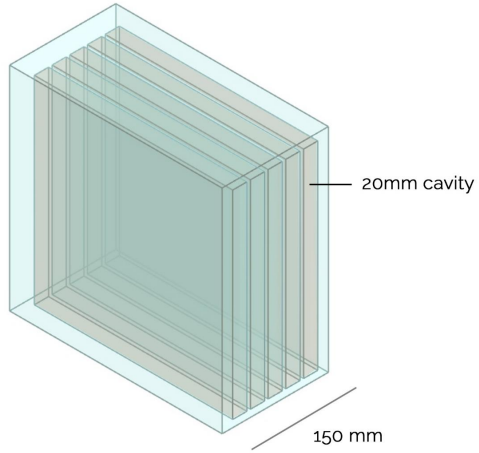


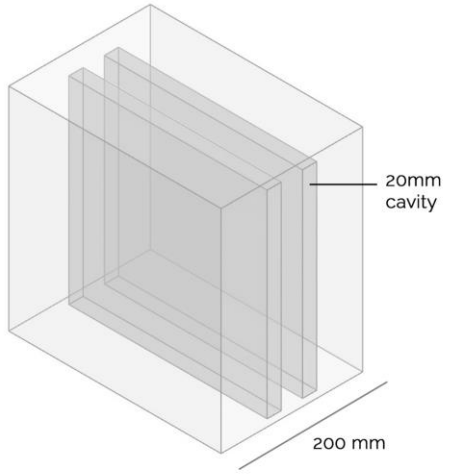
Design Option 3



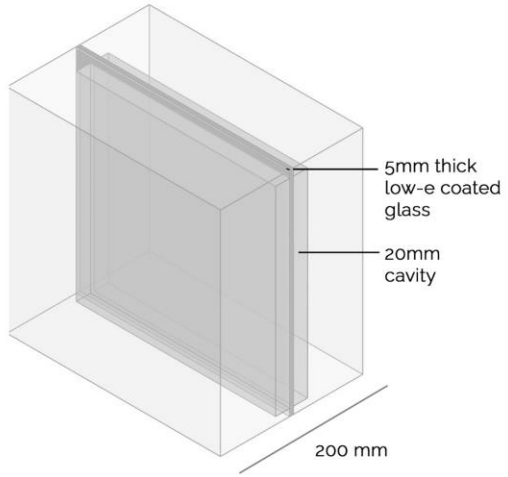
Design Option 4

	Design Option 1	Design Option 2	Design Option 3	Design Option 4
	++++	++++	++++	++++
	1.83 W/m2K	1.62 W/m2K	1.73 W/m2K	1.65 W/m2K
	++	++	++++	+++
	++++	+	++	++++
	+++	+++	++++	++

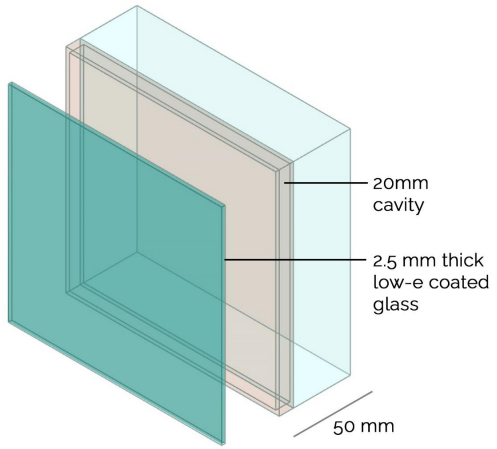
FINAL DESIGN OPTIONS



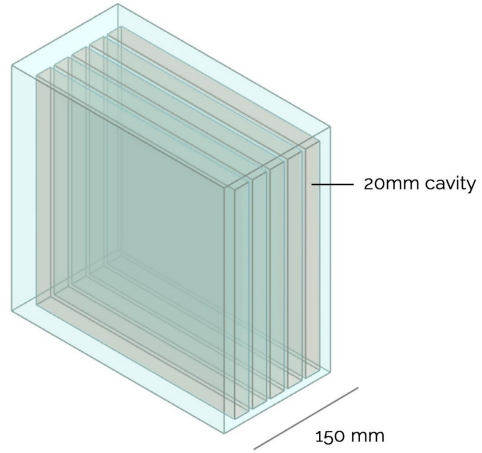
Design Option 1



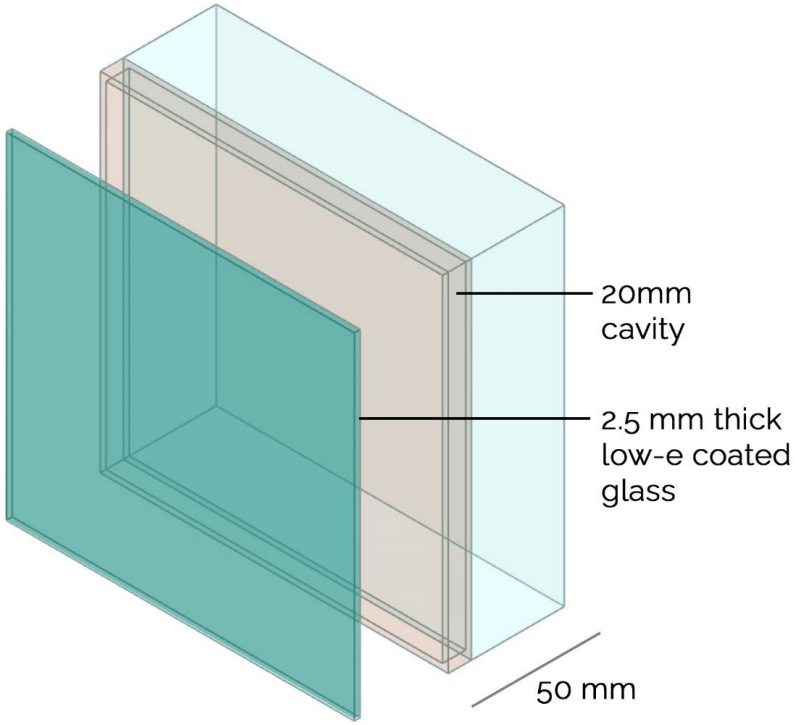
Design Option 2



Design Option 3

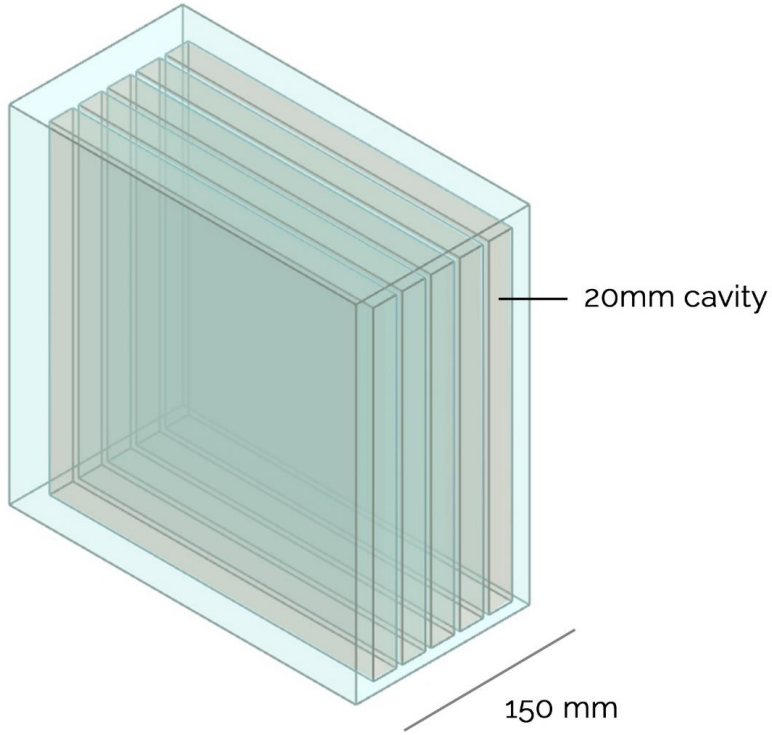


Design Option 4



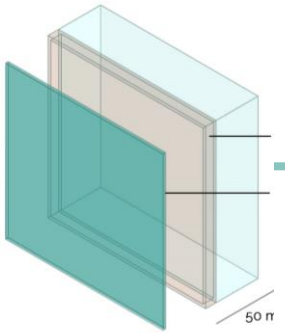
Design Option 3

FUSION BLOCK



Design Option 4

LATTICE BLOCK



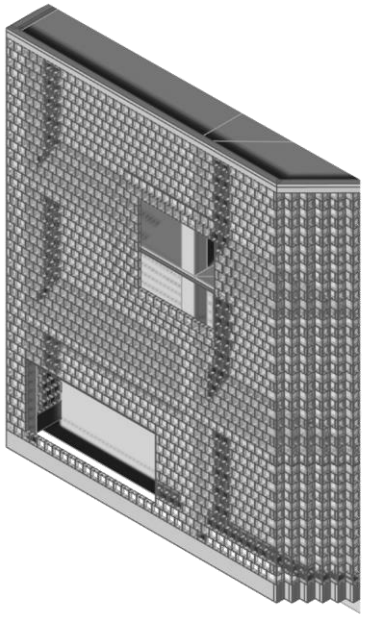
1 Detail Design

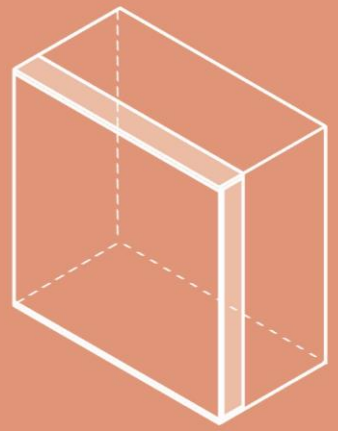
2 Connection System

3 Manufacturing

4 Installation

5 Thermal Performance





Fusion Block

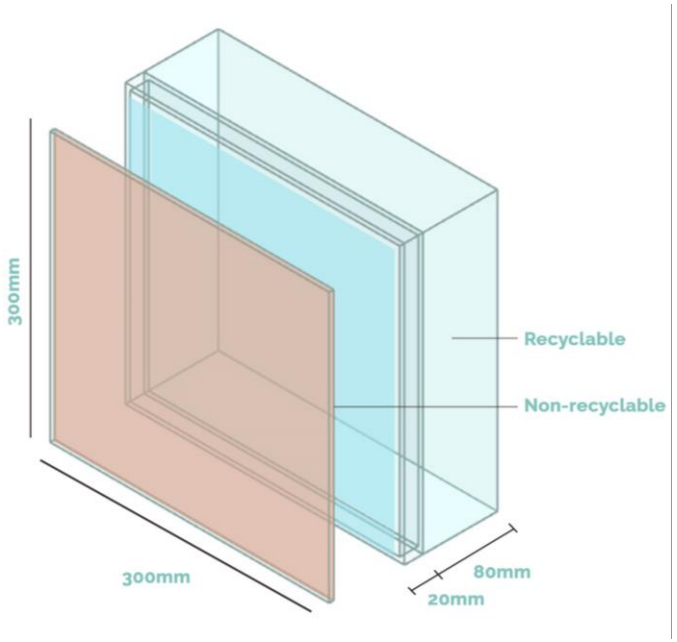
DETAIL DESIGN

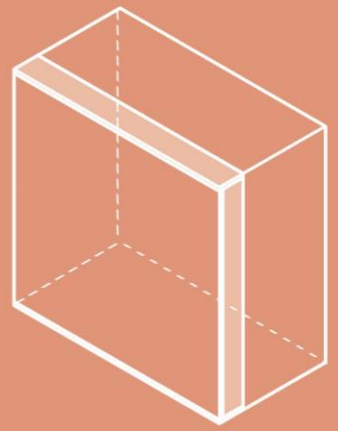
CONNECTION SYSTEM

MANUFACTURING

ASSEMBLY

THERMAL PERFORMANCE





Fusion Block

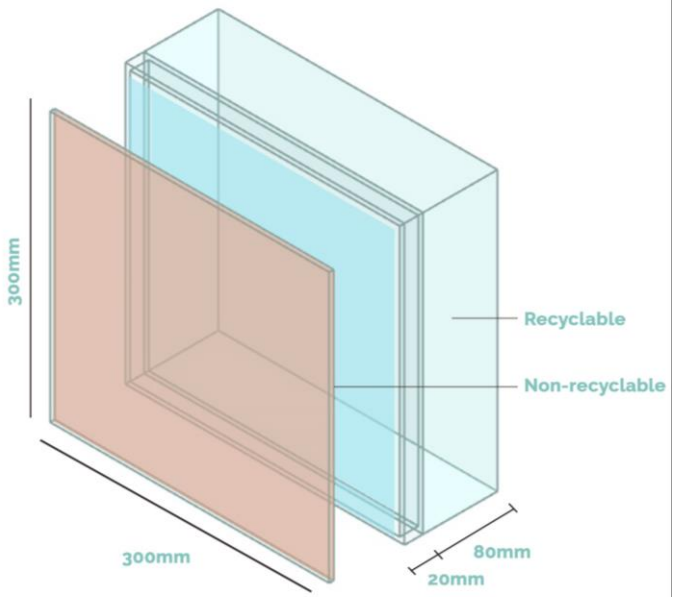
DETAIL DESIGN

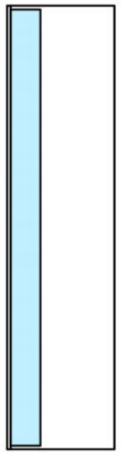
CONNECTION SYSTEM

MANUFACTURING

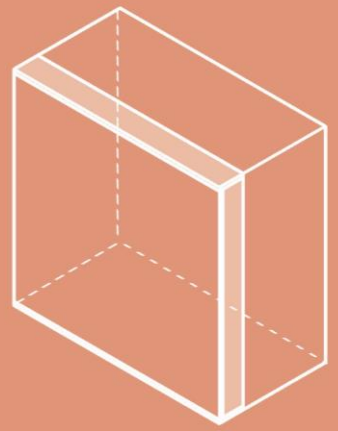
ASSEMBLY

THERMAL PERFORMANCE





U-value: 1.73 W/m2K
Block width: 50mm
Cavity width: 20mm



Fusion Block

DETAIL DESIGN

CONNECTION SYSTEM

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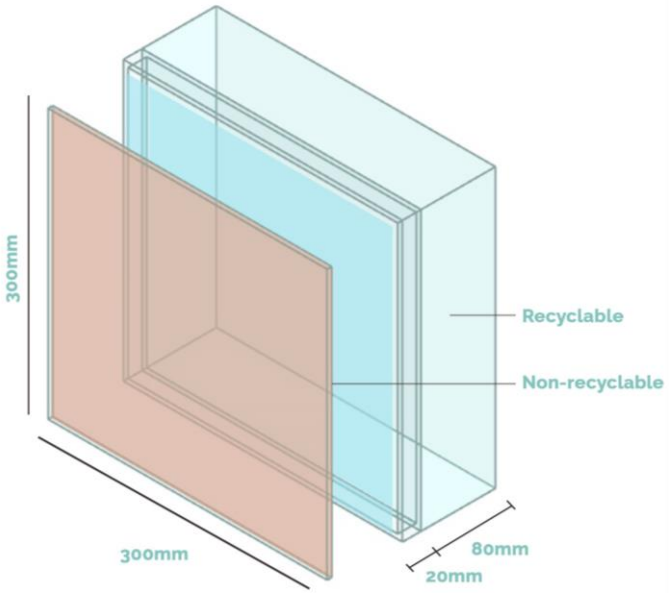
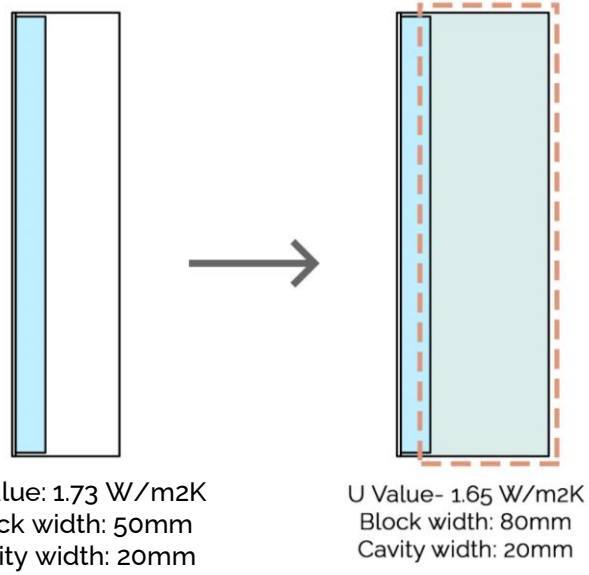
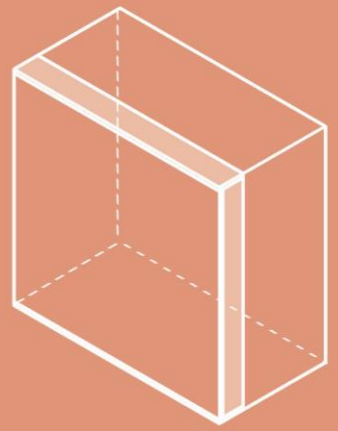
THERMAL PERFORMANCE





U-value: 1.73 W/m2K
Block width: 50mm
Cavity width: 20mm

U Value- 1.65 W/m2K
Block width: 80mm
Cavity width: 20mm



Fusion Block

DETAIL DESIGN

CONNECTION SYSTEM

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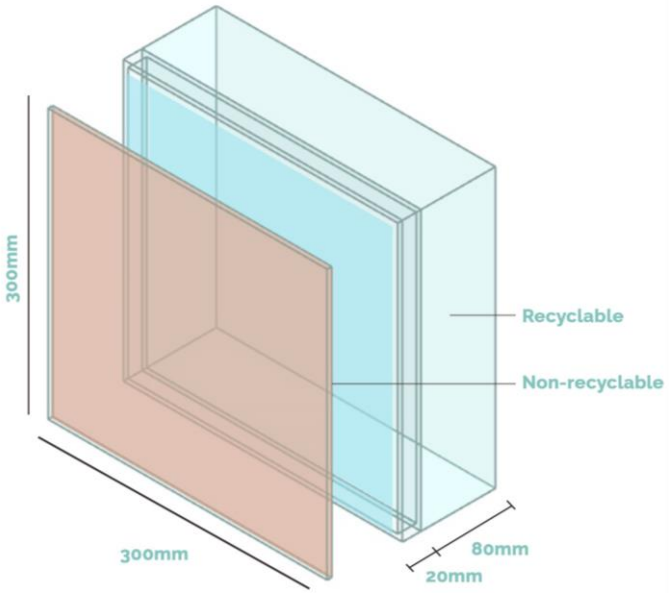
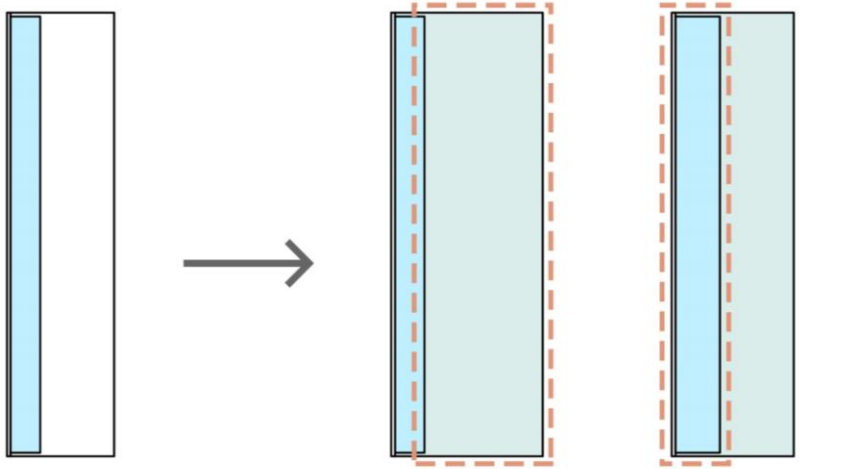
THERMAL PERFORMANCE

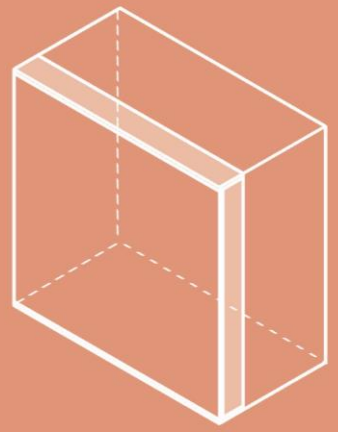




U-value: 1.73 W/m2K
Block width: 50mm
Cavity width: 20mm

U Value- 1.65 W/m2K
Block width: 80mm
Cavity width: 20mm

U Value- 1.64 W/m2K
Block width: 60mm
Cavity width: 30mm



Fusion Block

DETAIL DESIGN

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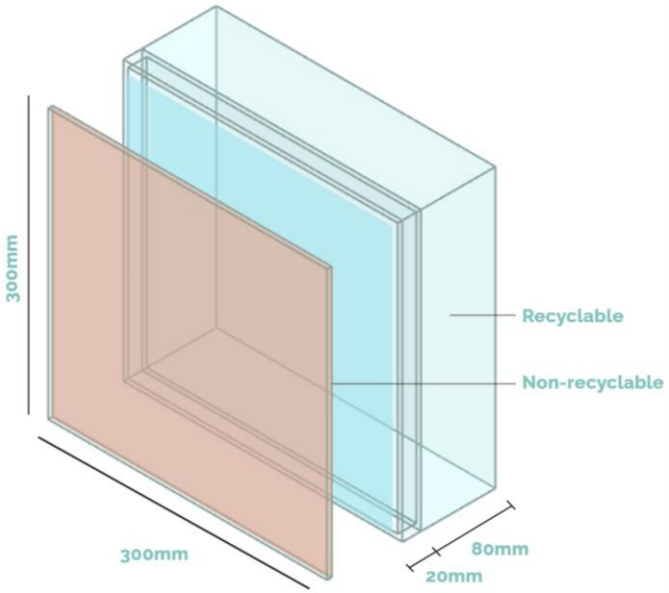
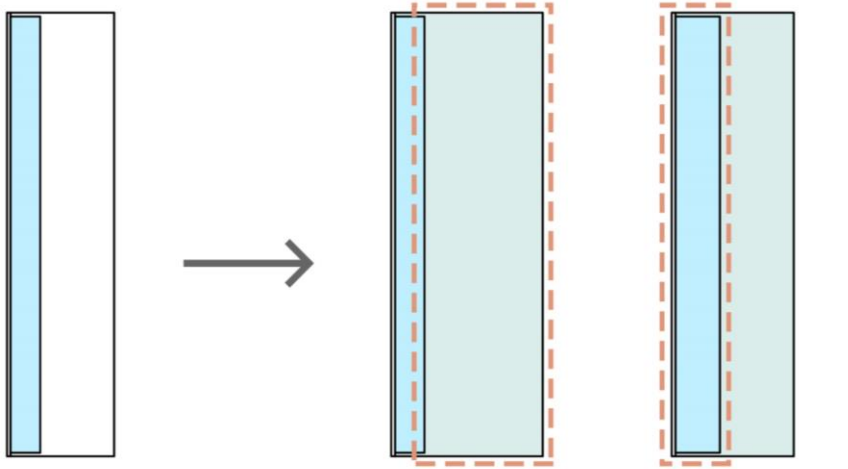
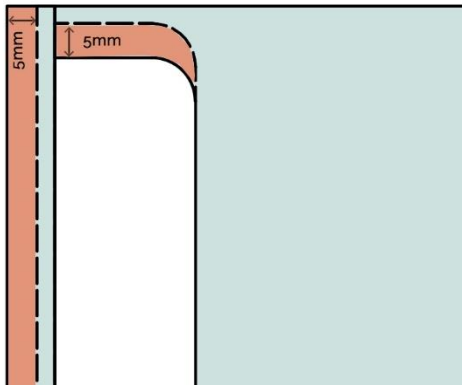


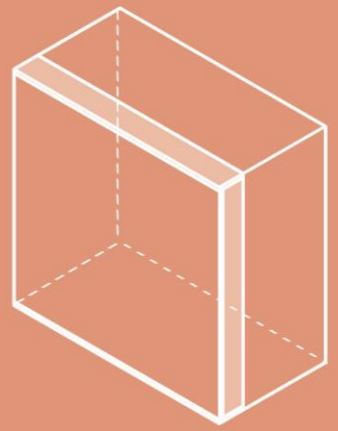


U-value: 1.73 W/m2K
Block width: 50mm
Cavity width: 20mm

U Value- 1.65 W/m2K
Block width: 80mm
Cavity width: 20mm

U Value- 1.64 W/m2K
Block width: 60mm
Cavity width: 30mm





Fusion Block

DETAIL DESIGN

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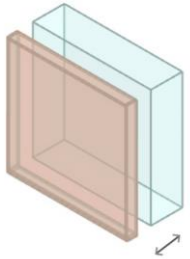
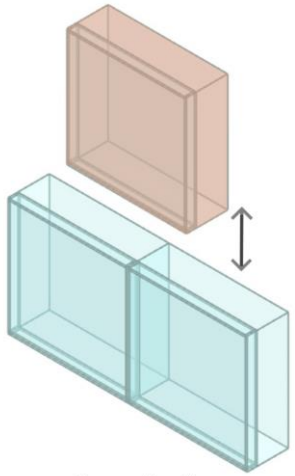
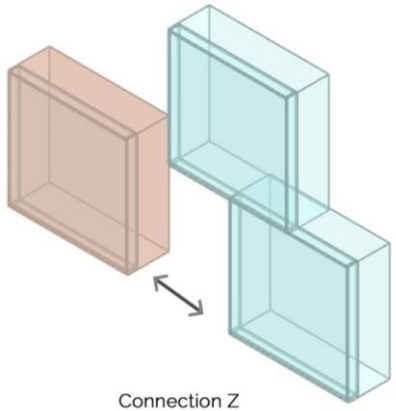


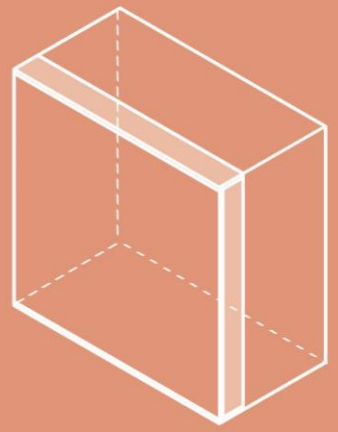
Connection X



Connection Y



Connection Z



Fusion Block

DETAIL DESIGN

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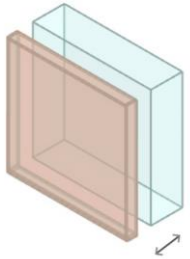
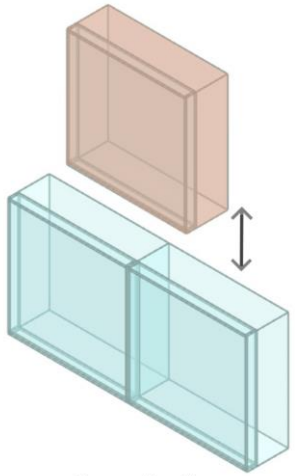


Connection X



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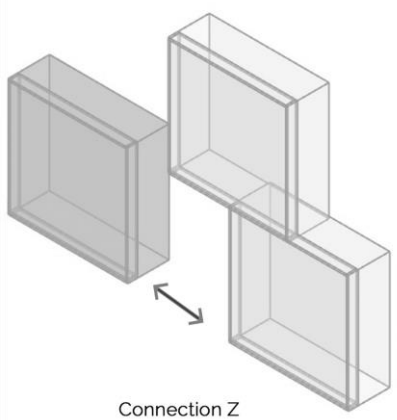
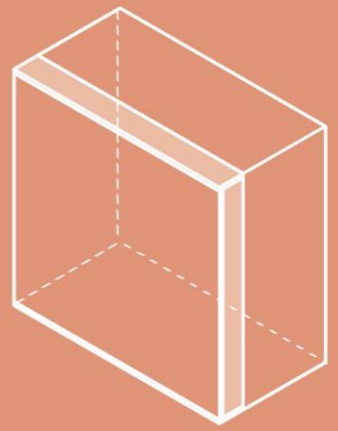


Connection Z



Fusion Block

DETAIL DESIGN

CONNECTION SYSTEM

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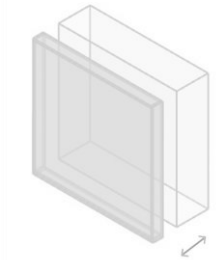
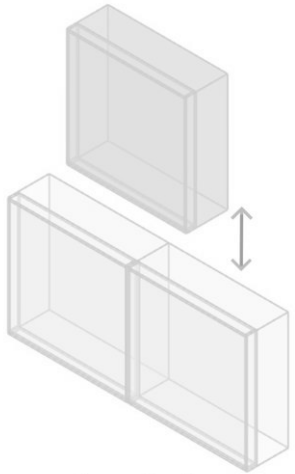
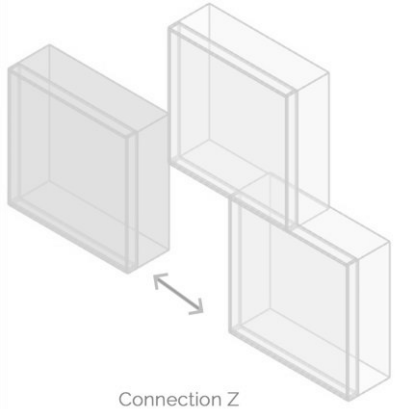


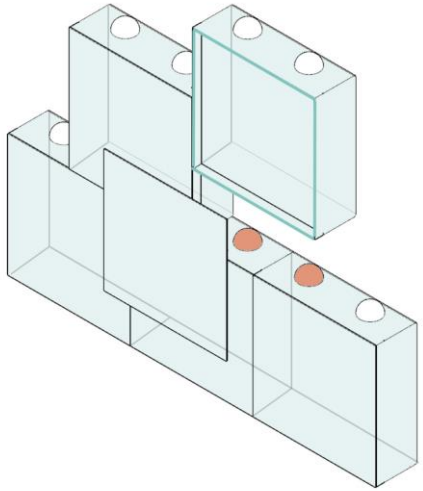
Connection X



Connection Y



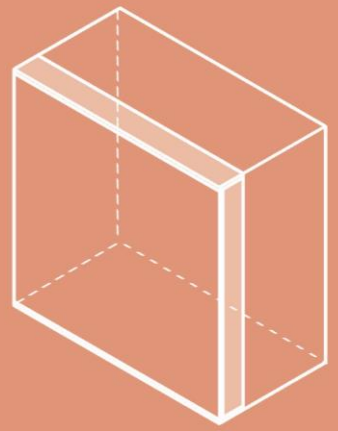
Connection Z



Option 1

Connection X: Glued

Connection Y: Interlocking



Fusion Block

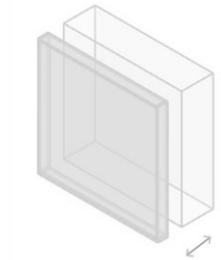
DETAIL DESIGN

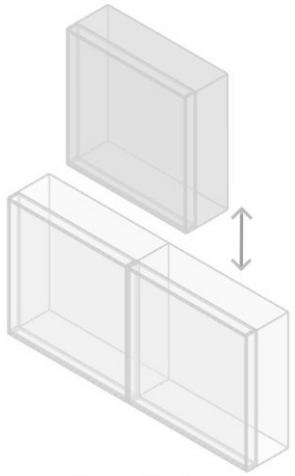
CONNECTION SYSTEM

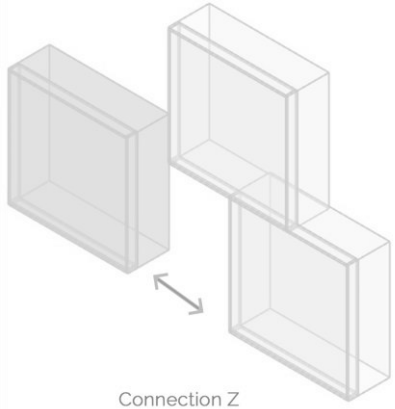
MANUFACTURING

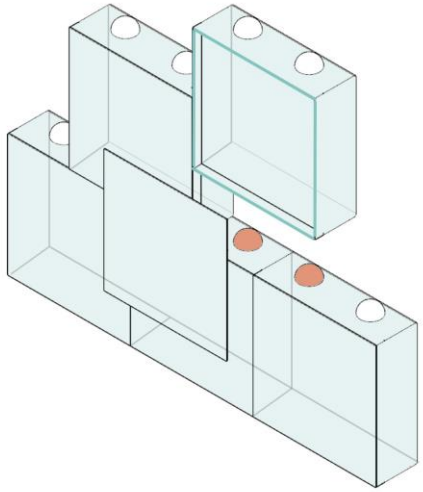
ASSEMBLY

THERMAL PERFORMANCE

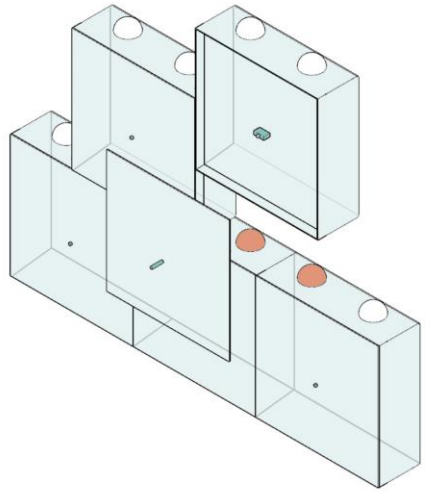




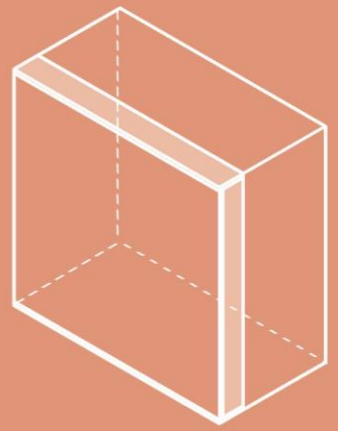




Option 1
Connection X: Glued
Connection Y: Interlocking



Option 2
Connection X: Bolted
Connection Y: Interlocking



Fusion Block

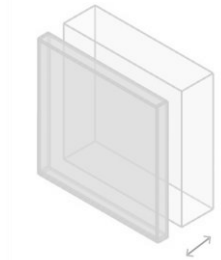
DETAIL DESIGN

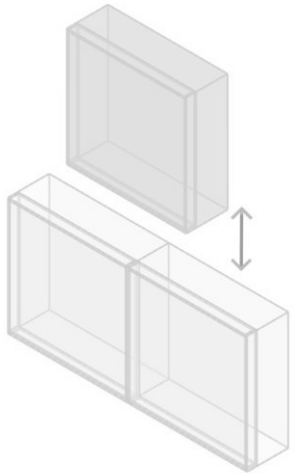
CONNECTION SYSTEM

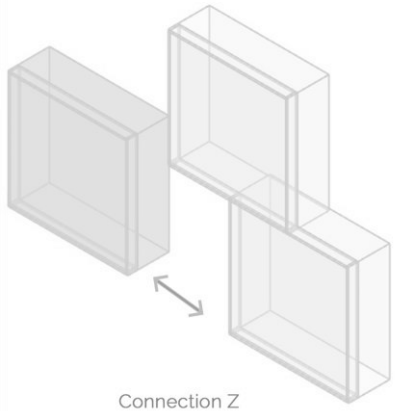
MANUFACTURING

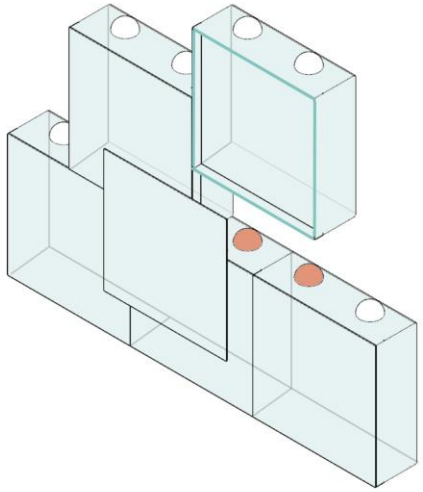
ASSEMBLY

THERMAL PERFORMANCE

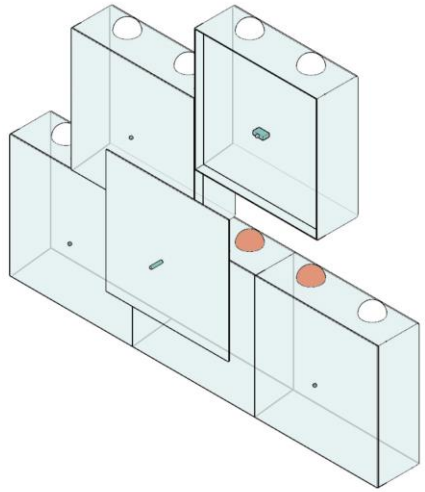




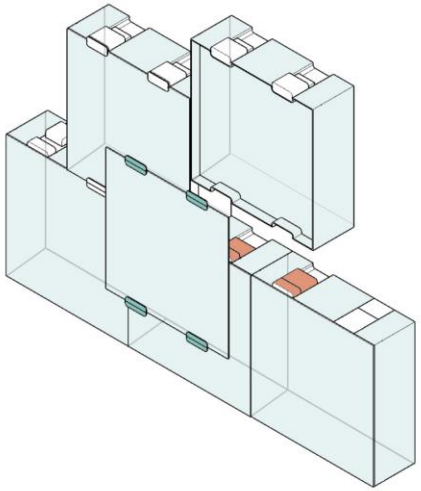




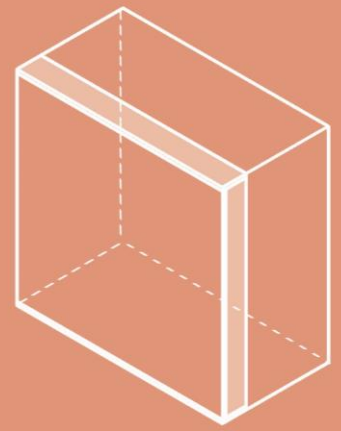
Option 1
Connection X: Glued
Connection Y: Interlocking



Option 2
Connection X: Bolted
Connection Y: Interlocking



Option 3
Connection X: Clamped
Connection Y: Interlocking



Fusion Block

DETAIL DESIGN

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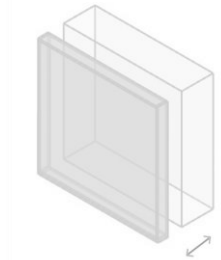
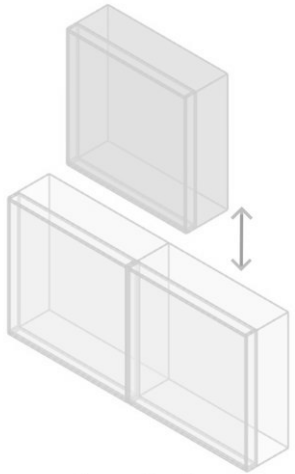
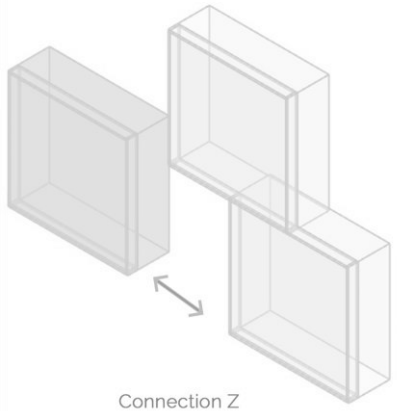
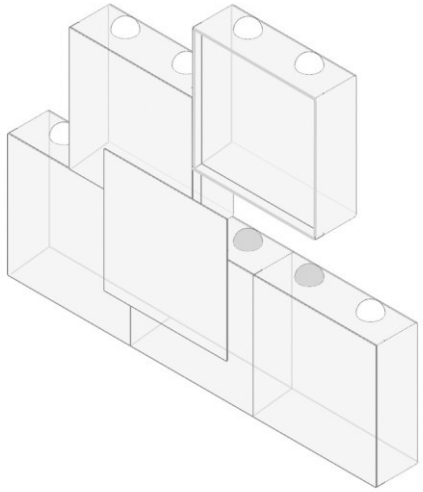
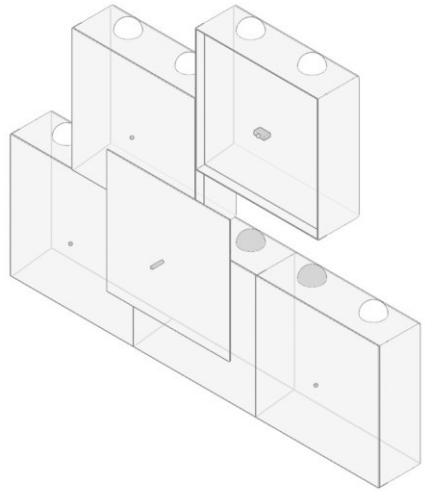




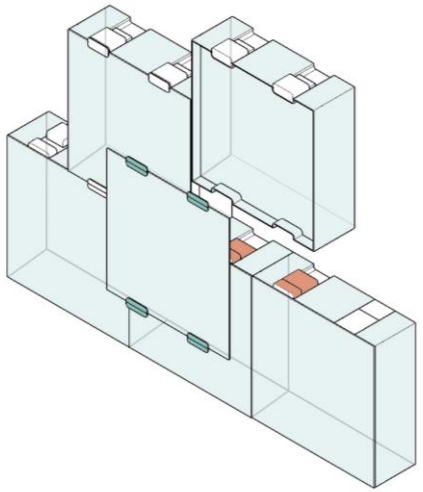




Option 1
Connection X: Glued
Connection Y: Interlocking

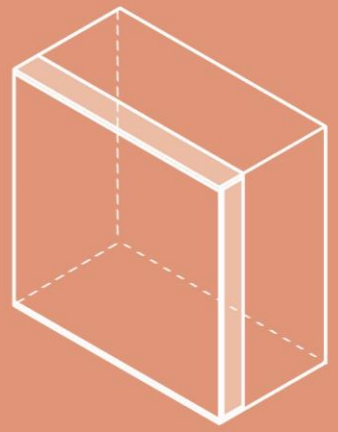


Option 2
Connection X: Bolted
Connection Y: Interlocking



Option 3
Connection X: Clamped
Connection Y: Interlocking

Connection Type		Unobstructed view	Reversibility	Ease of assembly	Load Distribution	Overall
Fusion Block	Glued + Interlock	++++	++	+++	+++	+++
	Clamped + Interlock	++	++++	+++	++	+++
	Embeded Connection	+++	++++	++++	++++	++++



Fusion Block

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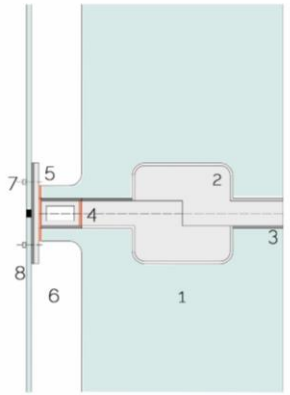
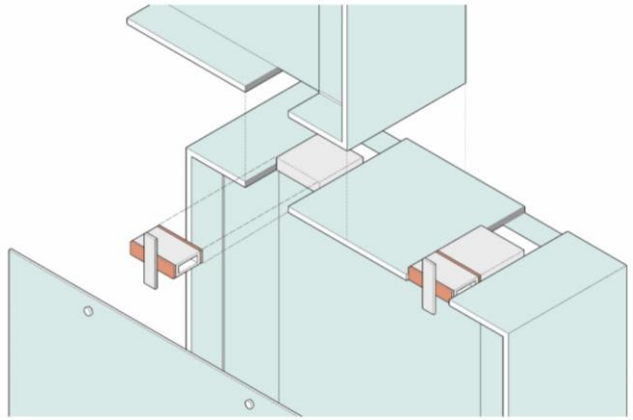
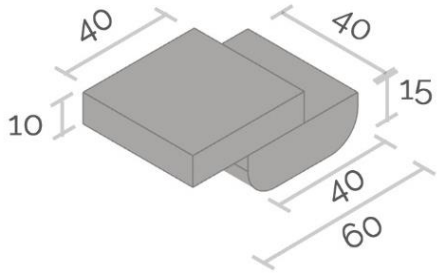
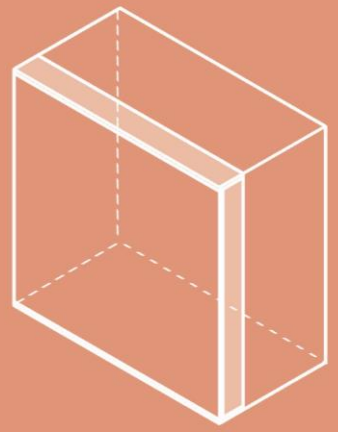




1. Glass Block
2. Tungsten embed
3. Rubber to separate direct contact of glass and metal
4. Thermal Break – Neoprene
5. Glass block to float glass connector piece: 40mm x 18mm x 10mm
6. Cavity 20mm
7. Bolts
8. Float glass piece





Fusion Block

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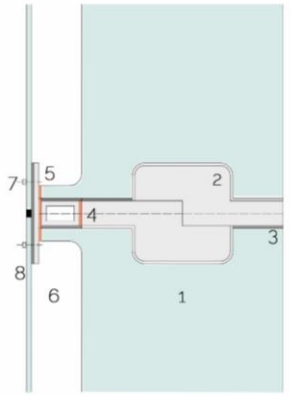

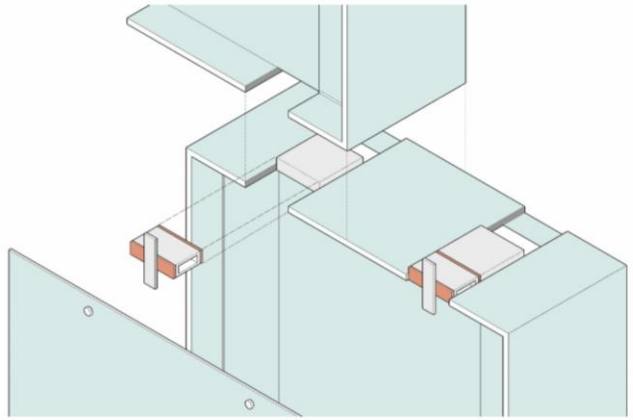

1. Glass Block
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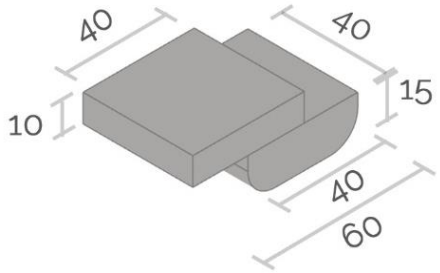
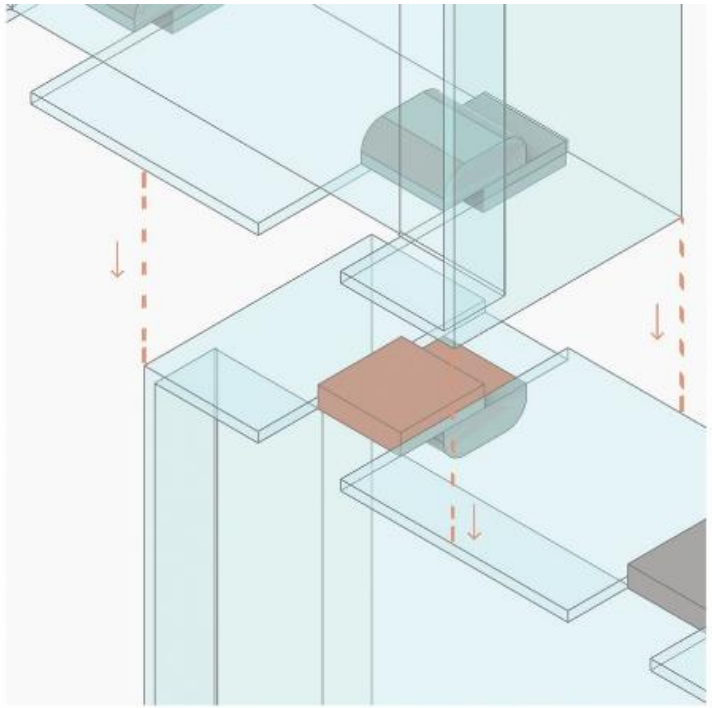
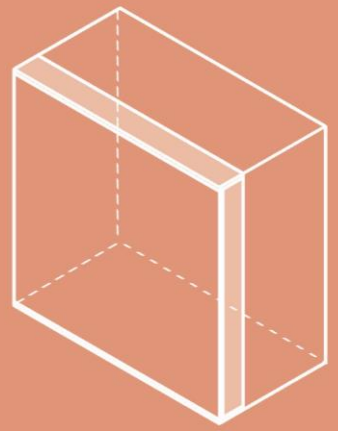
7. Bolts
8. Float glass piece





Step 1



Fusion Block

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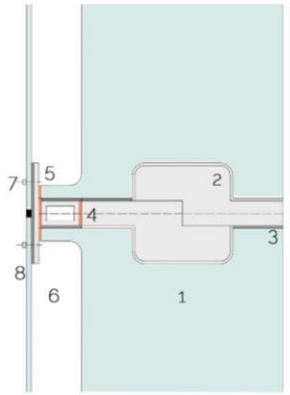
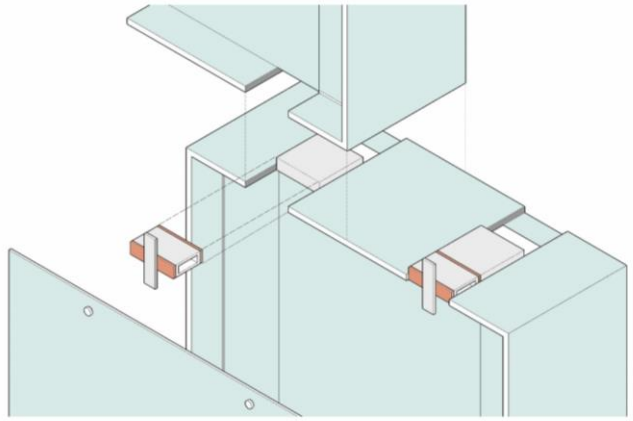
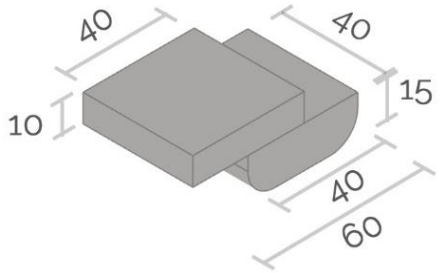
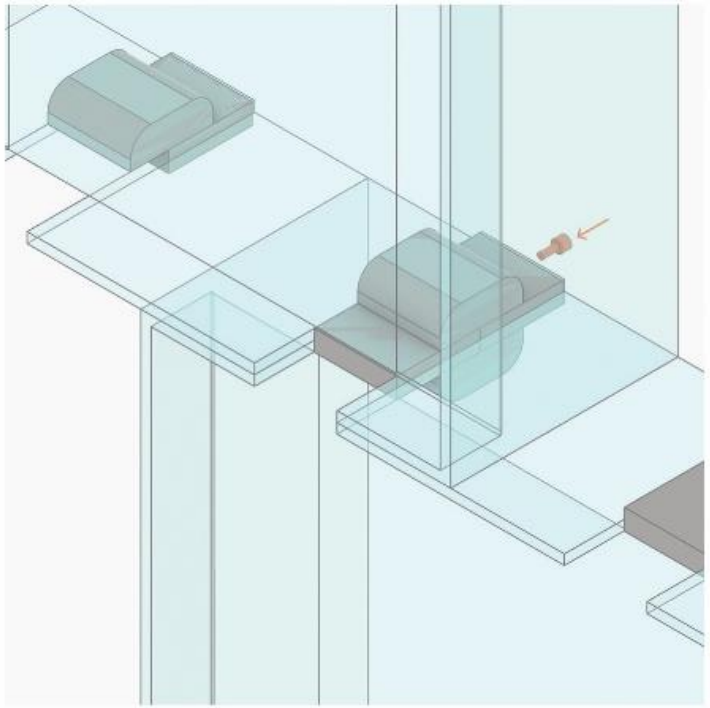


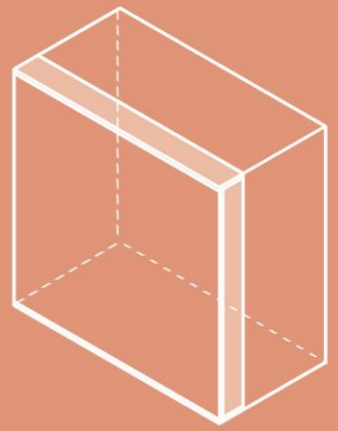


1. Glass Block
2. Tungsten embed
3. Rubber to separate direct contact of glass and metal
4. Thermal Break – Neoprene
5. Glass block to float glass connector piece: 40mm x 18mm x 10mm
6. Cavity 20mm
7. Bolts
8. Float glass piece





Step 2



Fusion Block

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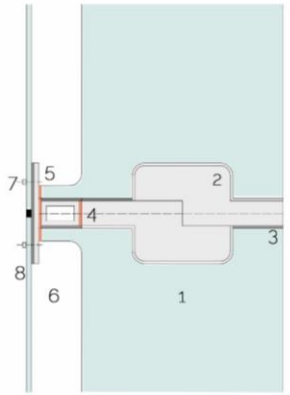

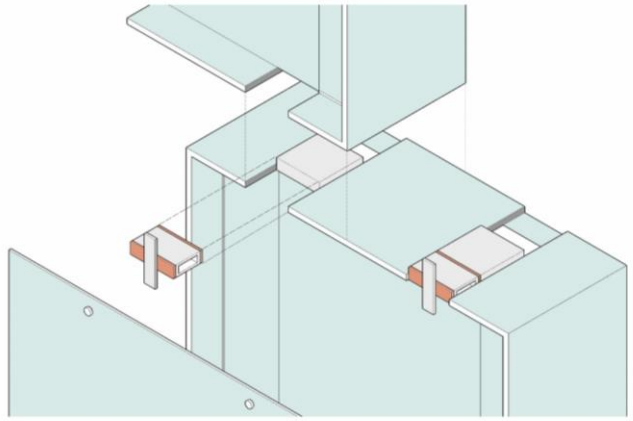

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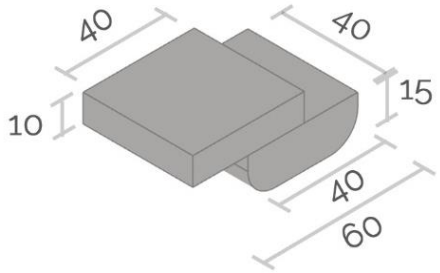
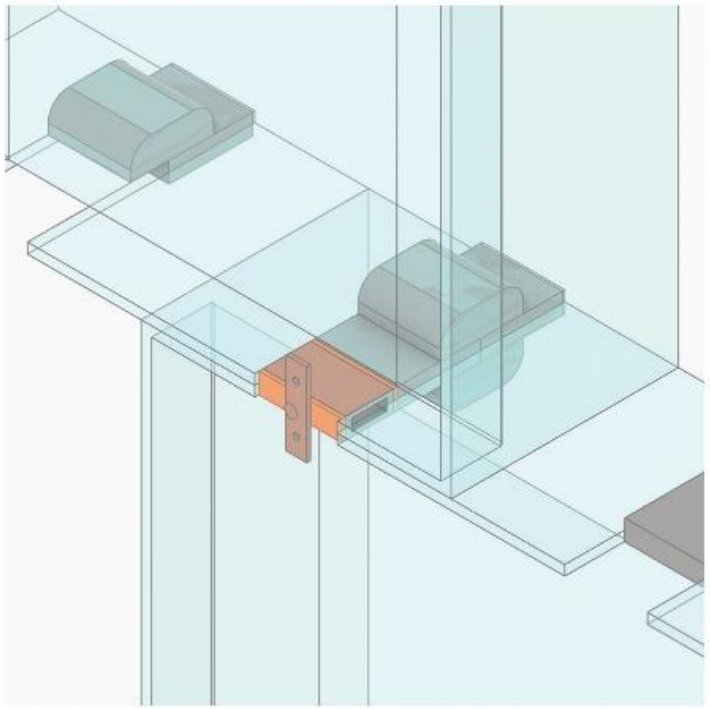
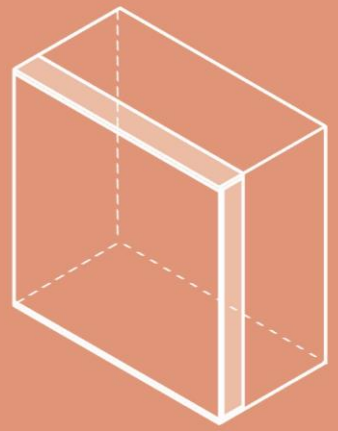
7. Bolts
8. Float glass piece





Step 3



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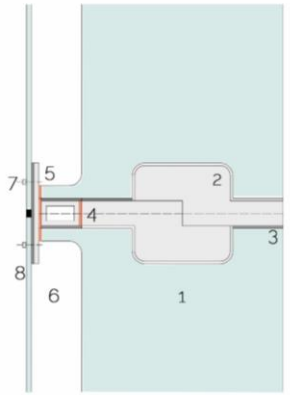

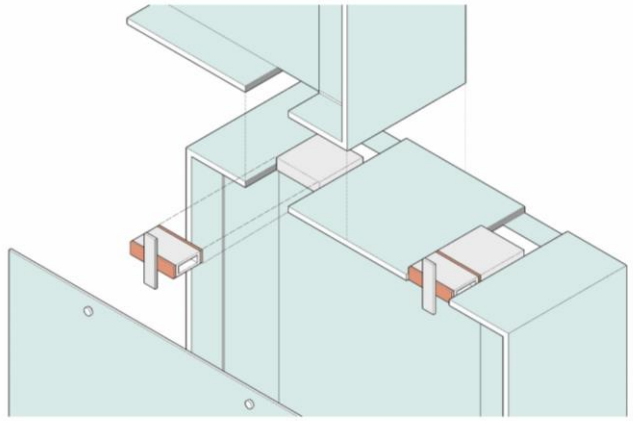

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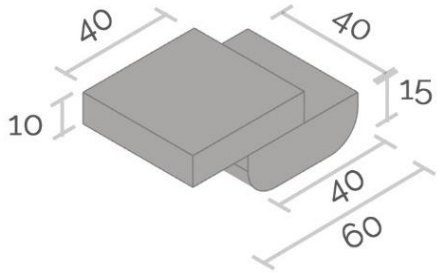
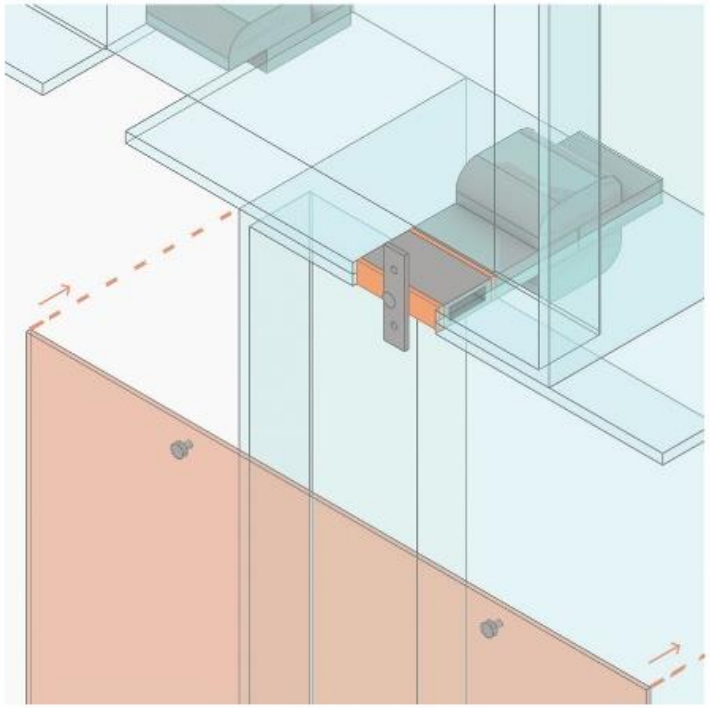
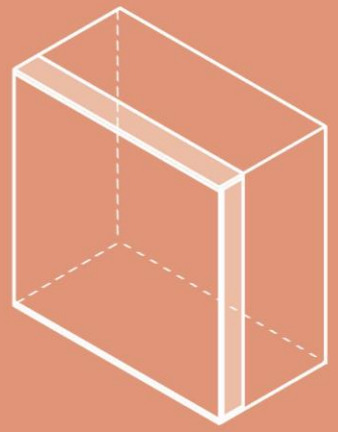
7. Bolts
8. Float glass piece





Step 4



Fusion Block

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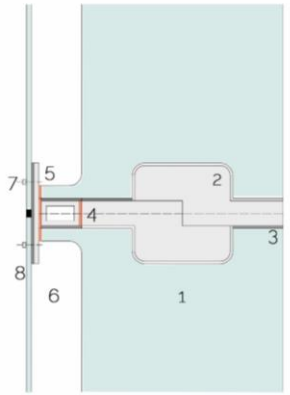

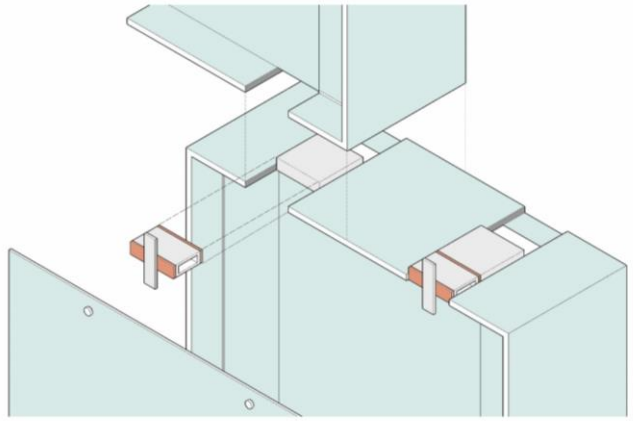

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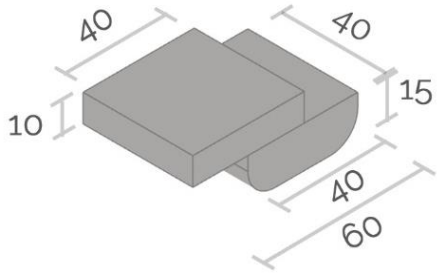
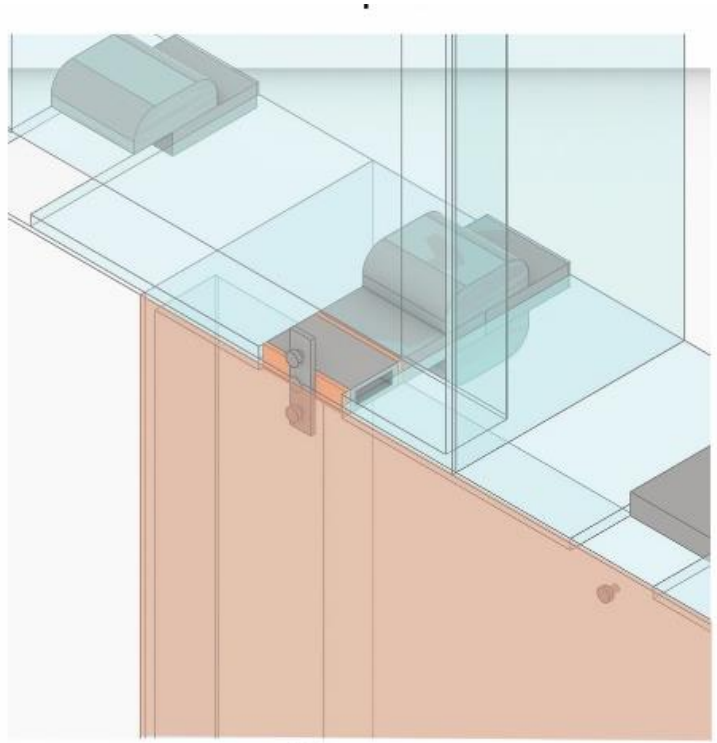
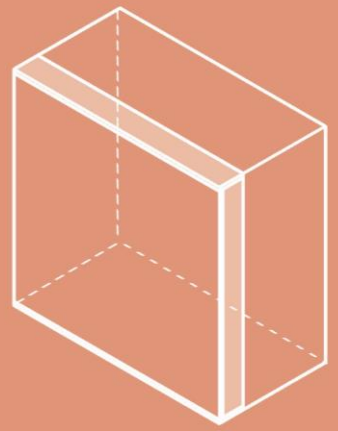
7. Bolts
8. Float glass piece





Step 5



Fusion Block

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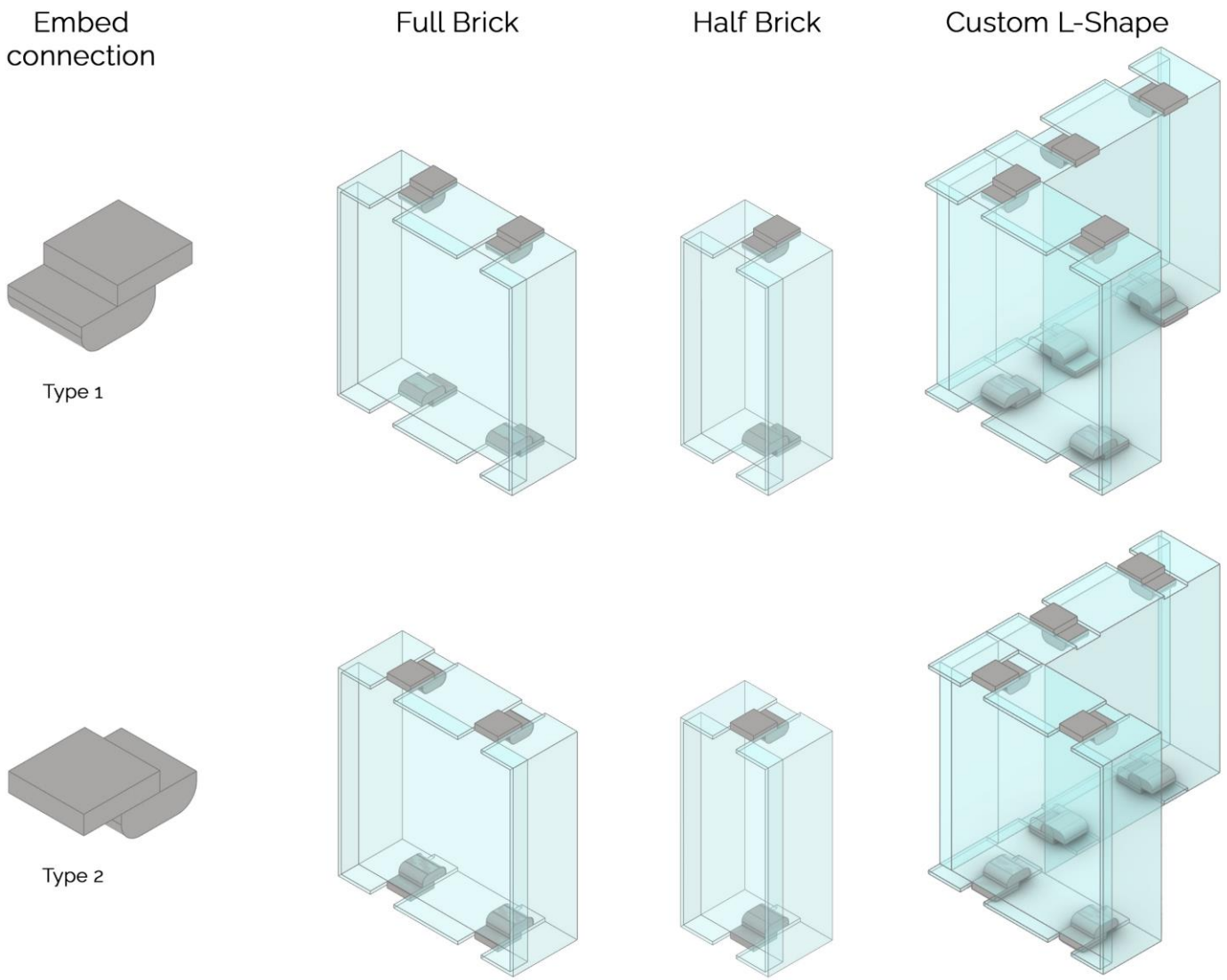
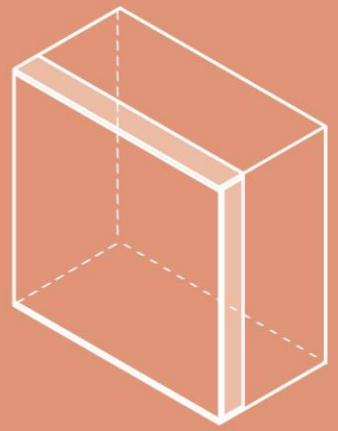


Total number of blocks: 1168
Full Brick: 1106
Half Brick: 40
L-Shape: 22



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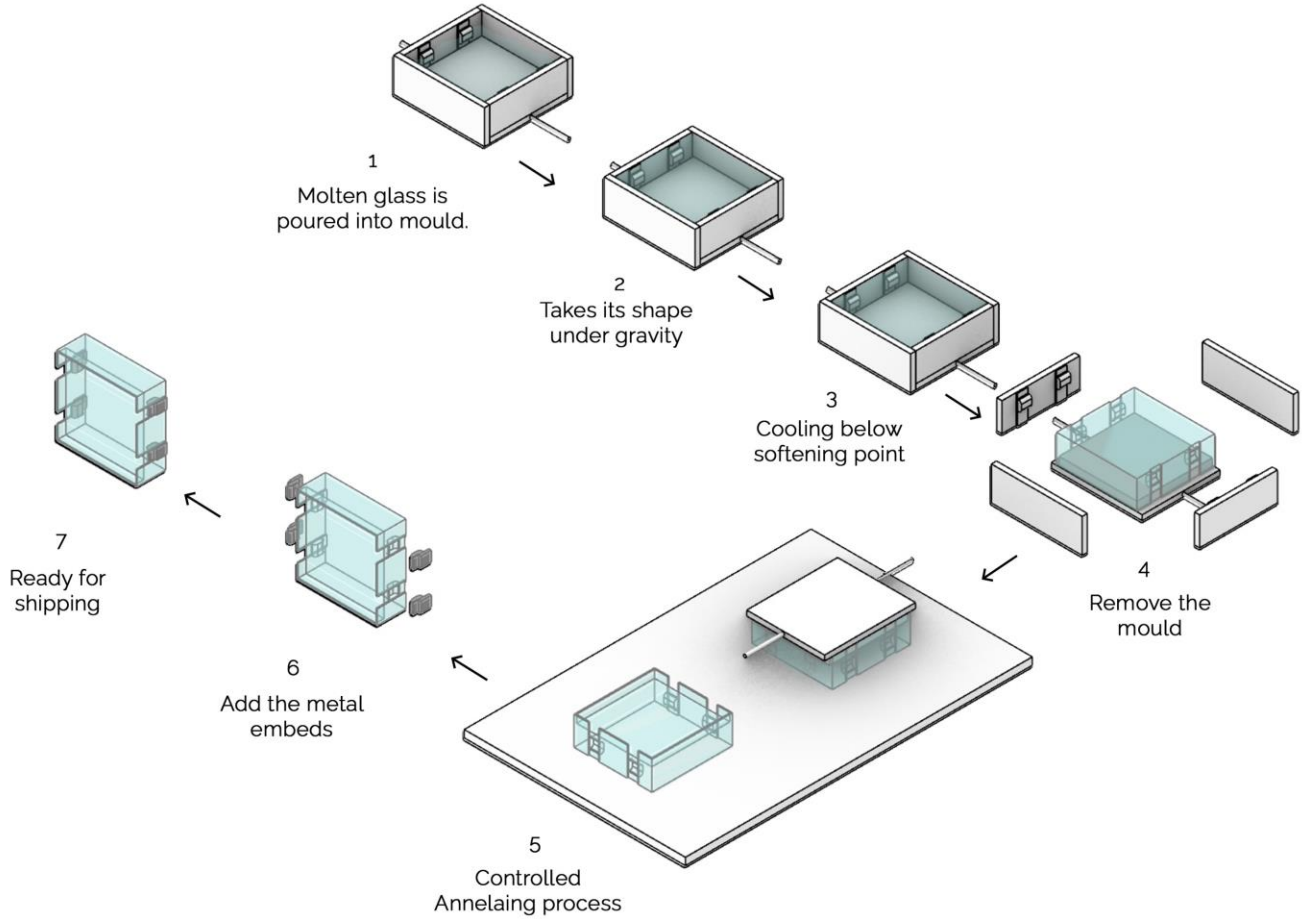
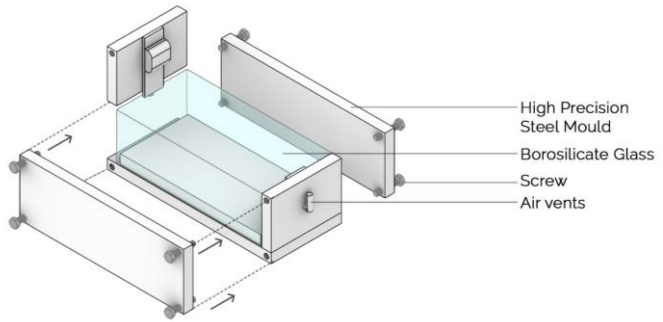
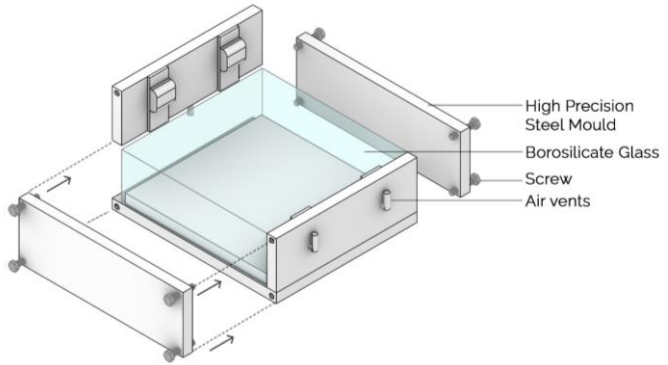
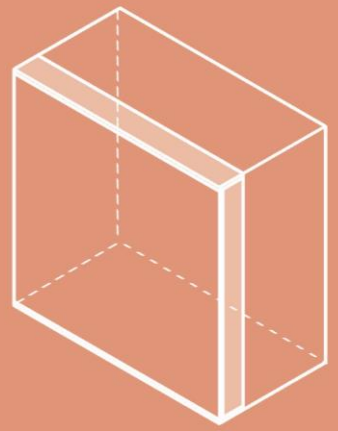






MANUFACTURING PROCESS OF FULL AND HALF BRICK



Fusion Block

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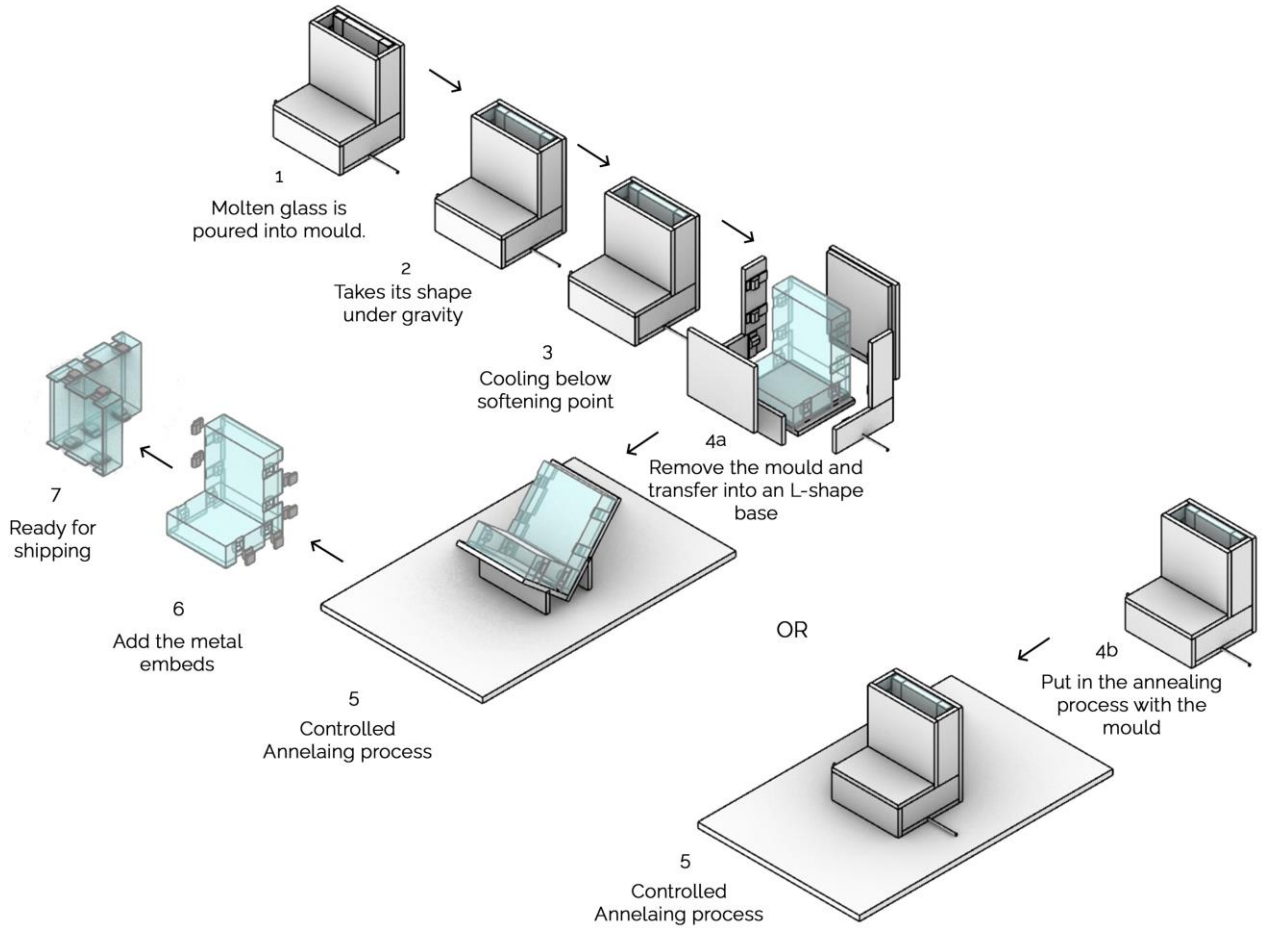
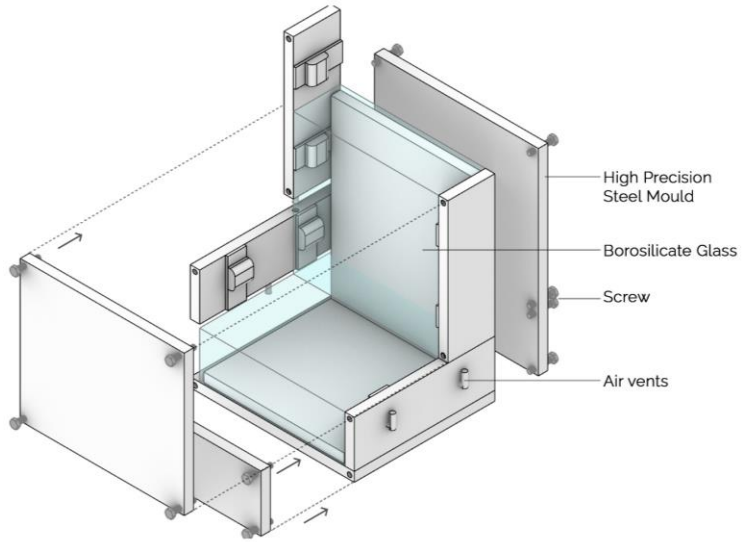


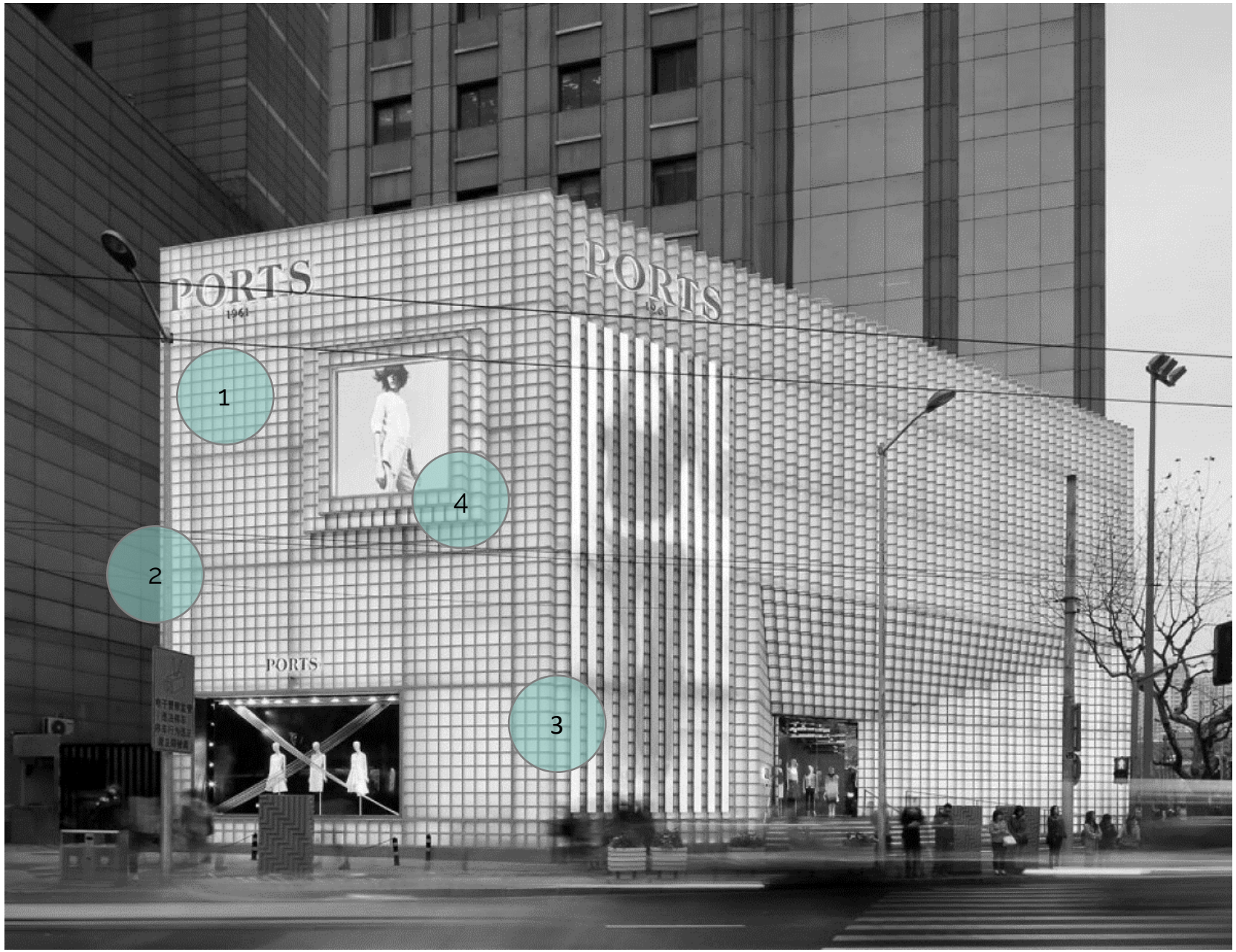


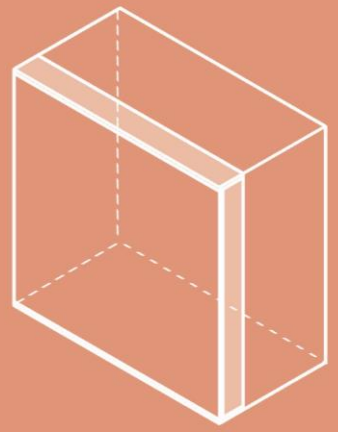
MANUFACTURING PROCESS OF L-SHAPE BRICK

PORTS 1961, SHANGHAI

Design Aspects for Assembly:

1. Straight façade
2. L-Junction
3. Corbel Junction
4. Corbel Window





Fusion Block

DETAIL DESIGN

CONNECTION SYSTEM

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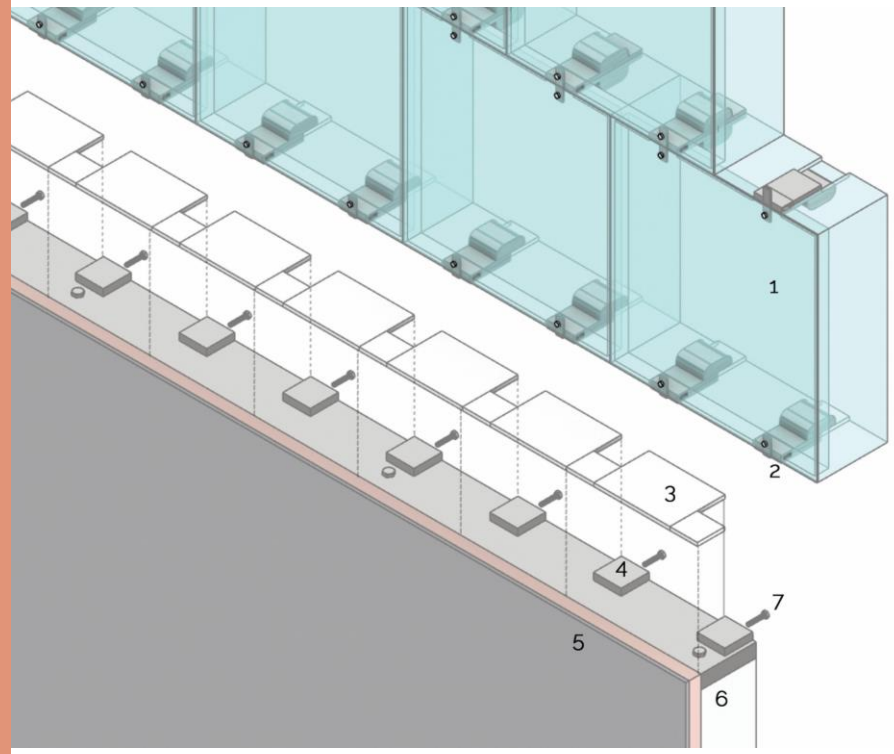
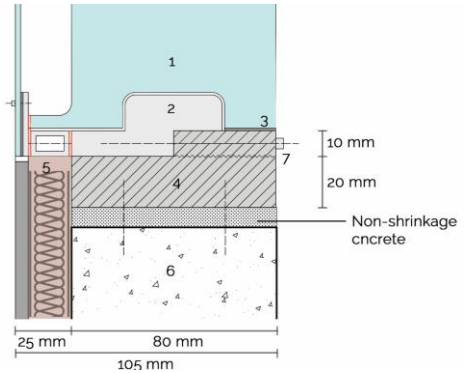
ASSEMBLY

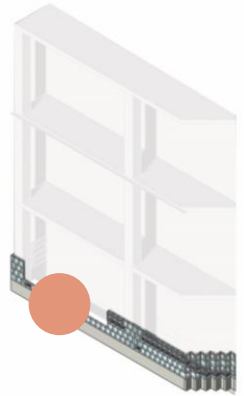
THERMAL PERFORMANCE

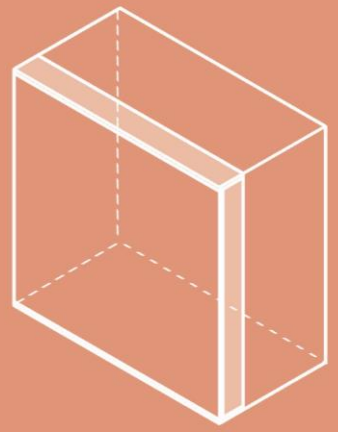
BOTTOM CONNECTION



1. Glass Block
2. Tungsten embed
3. Rubber to separate direct contact of glass and metal
4. Tungsten rectangular block
5. Insulation with wall finish
6. Concrete base







Fusion Block

DETAIL DESIGN

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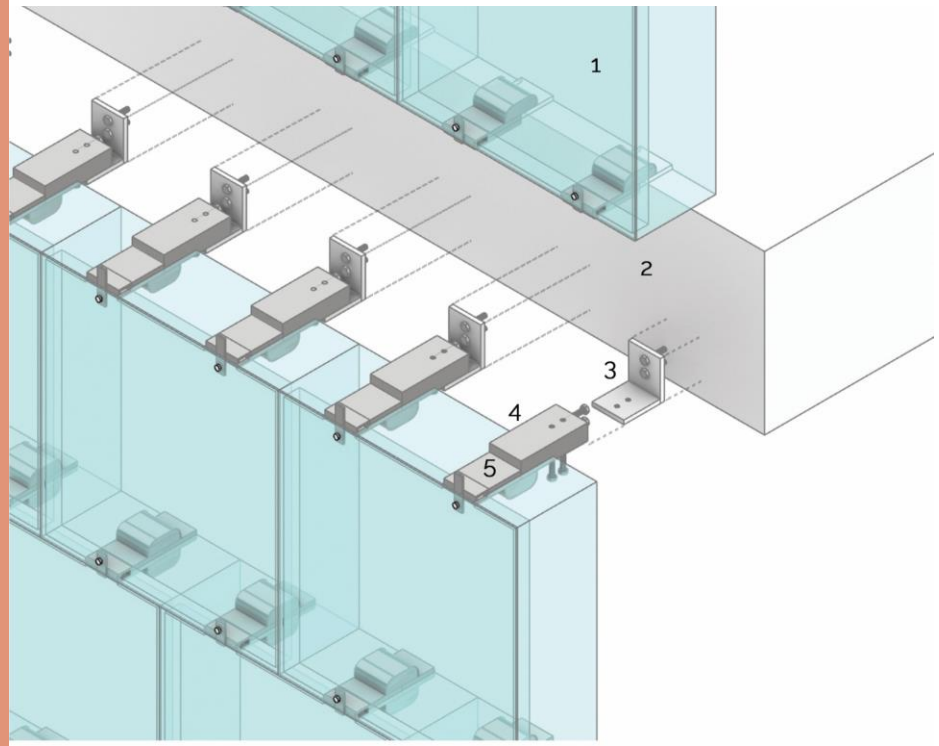
MANUFACTURING

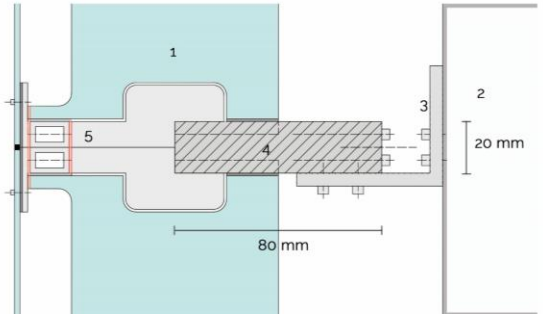
ASSEMBLY

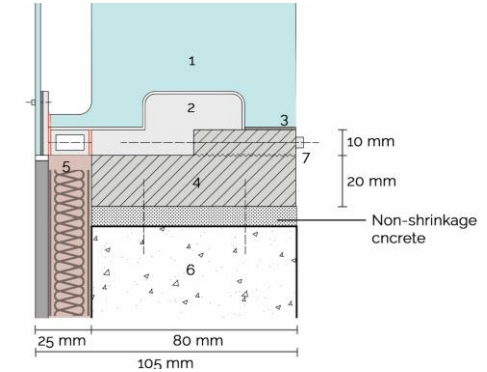
THERMAL PERFORMANCE

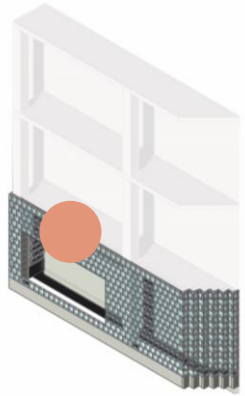
INTERMEDIATE FLOOR CONNECTION

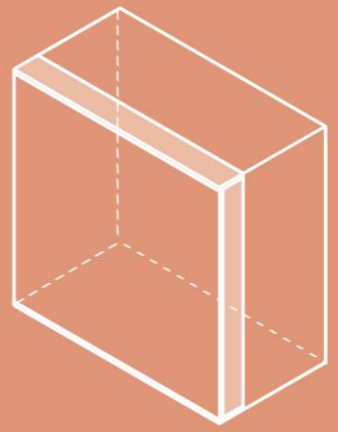


1. Glass Block
2. Floor slab
3. Steel angle-section
4. Tungsten rectangular block
5. Tungsten embedded connection









Fusion Block

DETAIL DESIGN

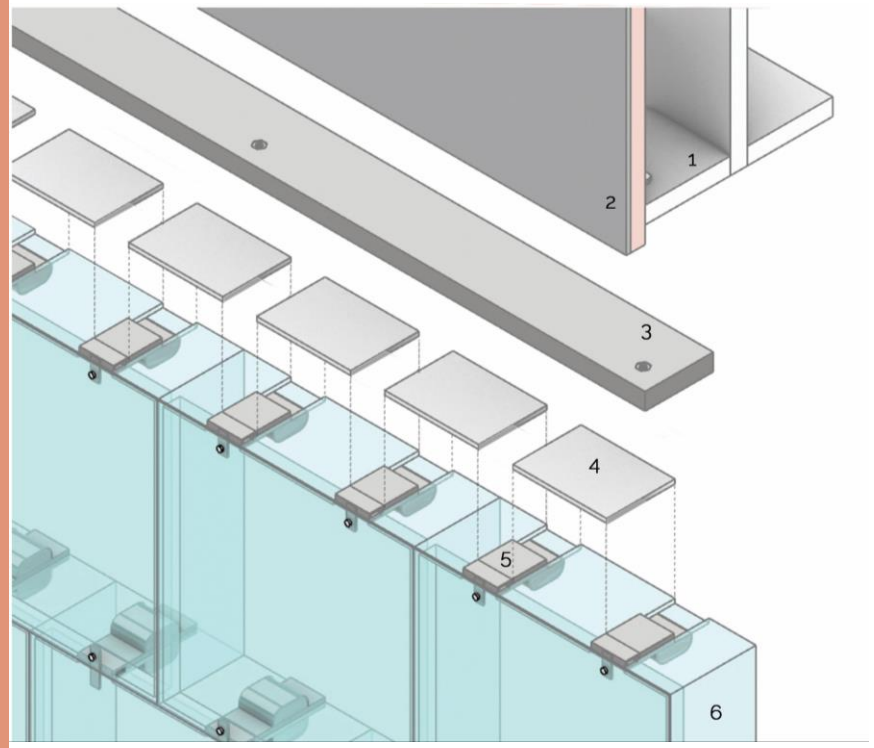
CONNECTION SYSTEM

MANUFACTURING

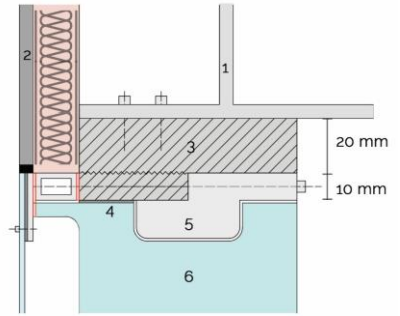
ASSEMBLY

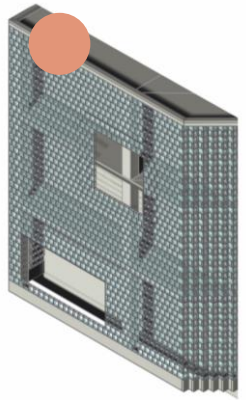
THERMAL PERFORMANCE

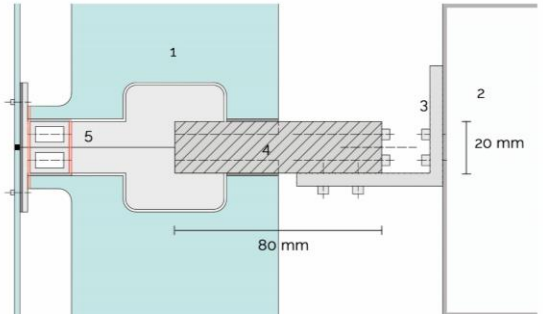
TOP CONNECTION

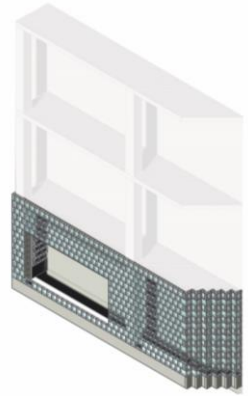


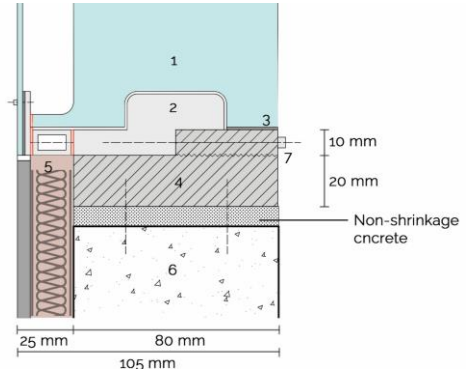
1. I-beam
2. Insulation with wall finish
3. Steel plate with tungsten coating
4. Rubber to separate direct contact of glass and metal
5. Tungsten embedded connection
6. Glass Block

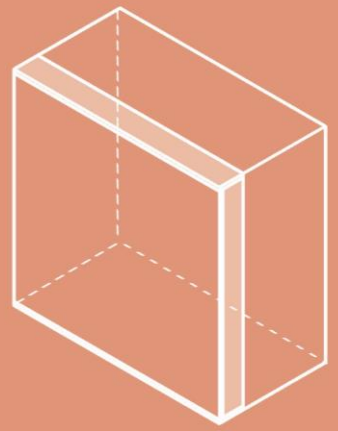












Fusion Block

DETAIL DESIGN

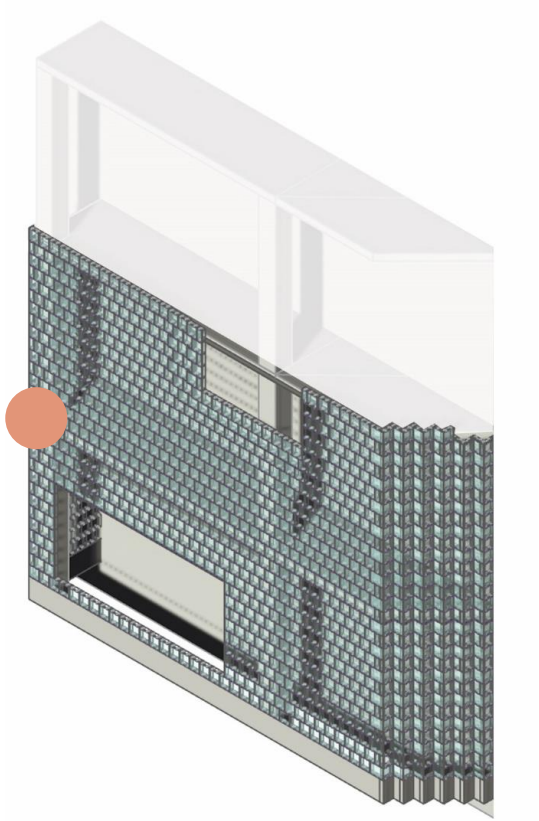
CONNECTION SYSTEM

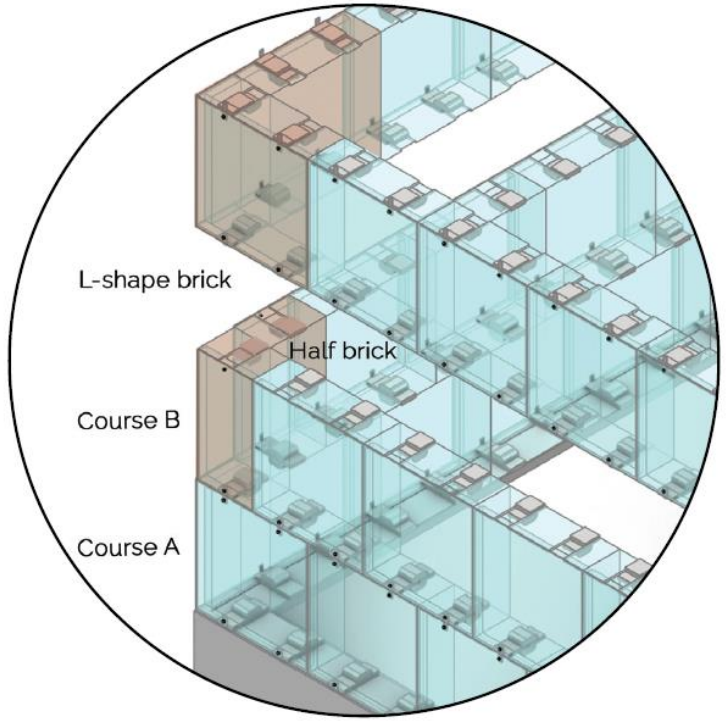
MANUFACTURING

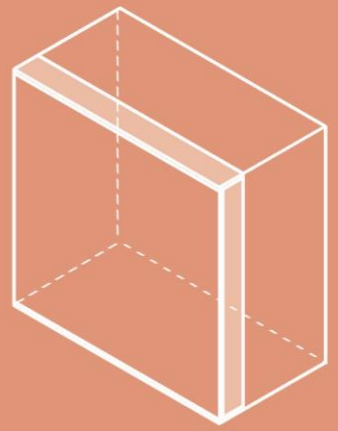
ASSEMBLY

THERMAL PERFORMANCE

L-JUNCTION







Fusion Block

DETAIL DESIGN

CONNECTION SYSTEM

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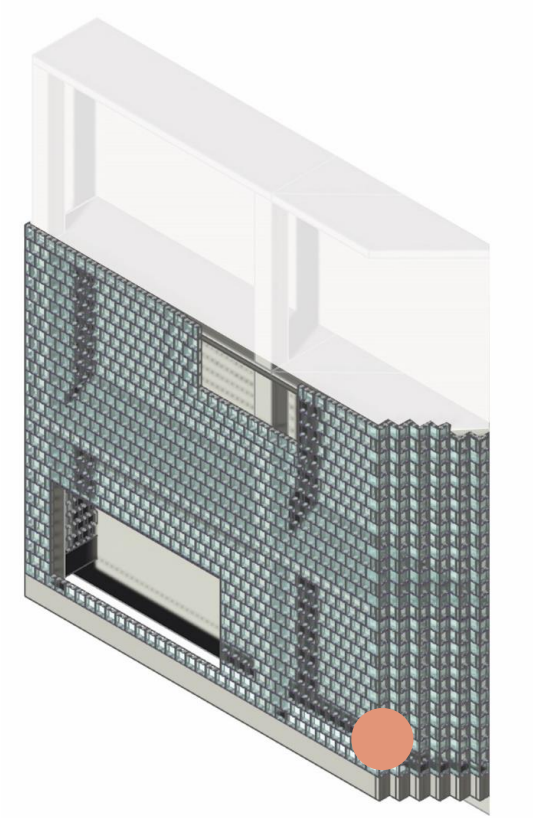
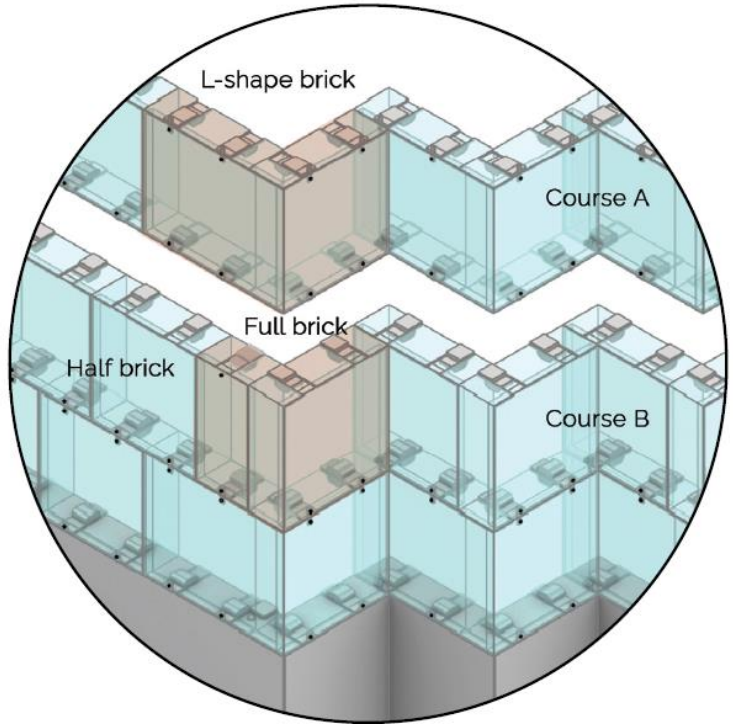
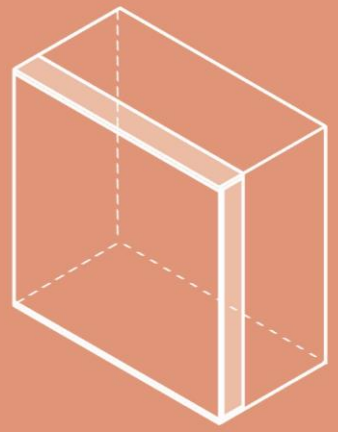
CORBEL JUNCTION







Fusion Block

DETAIL DESIGN

CONNECTION SYSTEM

MANUFACTURING

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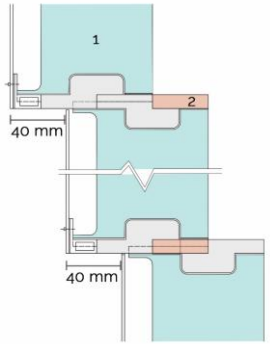
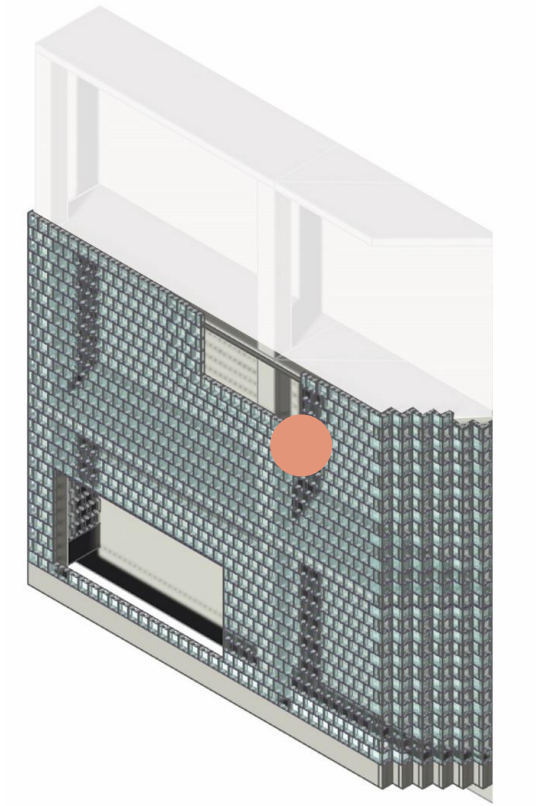
THERMAL PERFORMANCE

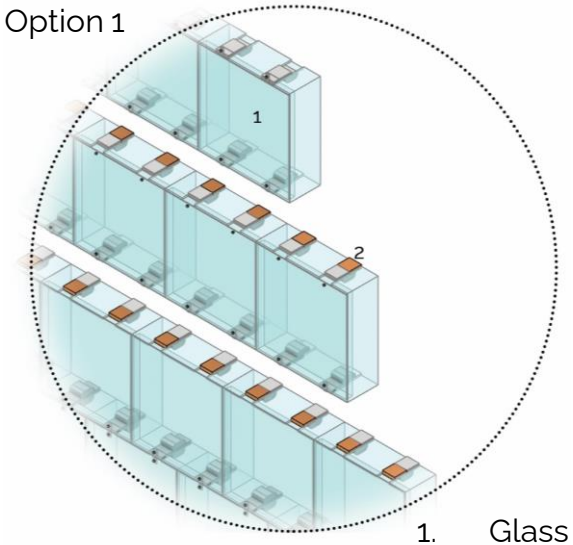
CORBEL WINDOW OPTIONS

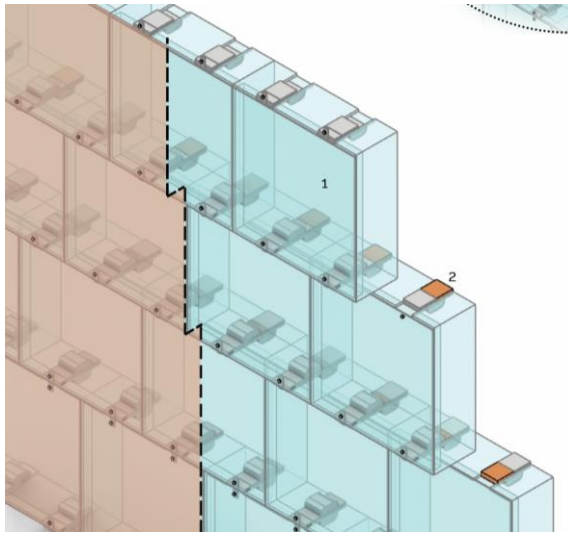


Option 1

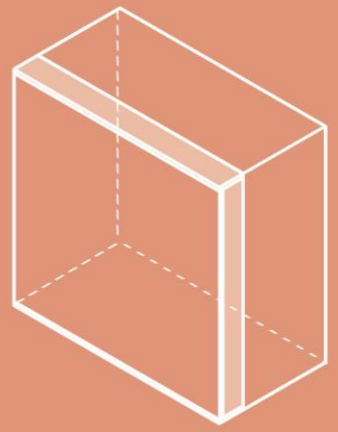


Option 1





1. Glass Block
2. Tungsten rectangular block



Fusion Block

DETAIL DESIGN

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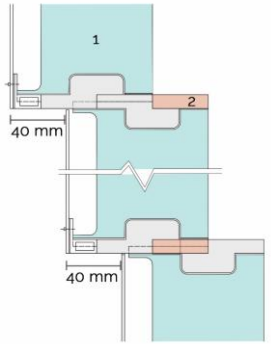
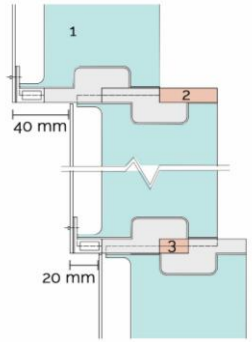
THERMAL PERFORMANCE

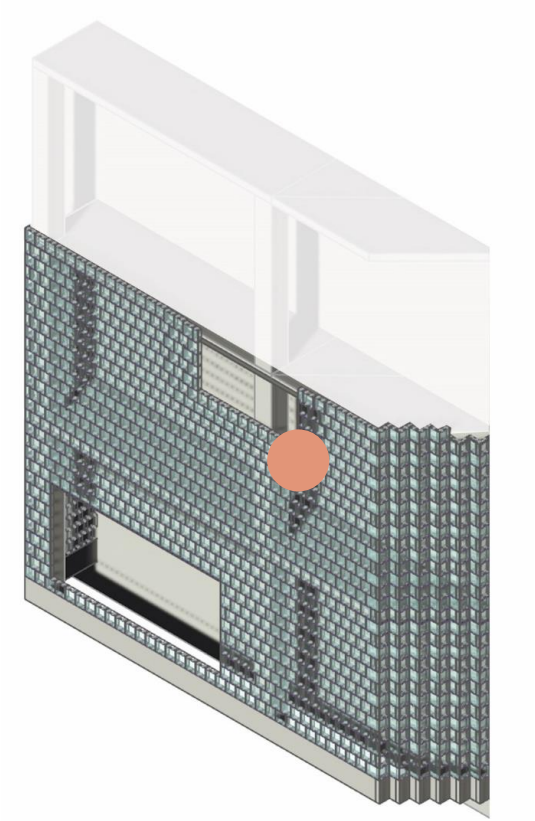
CORBEL WINDOW OPTIONS



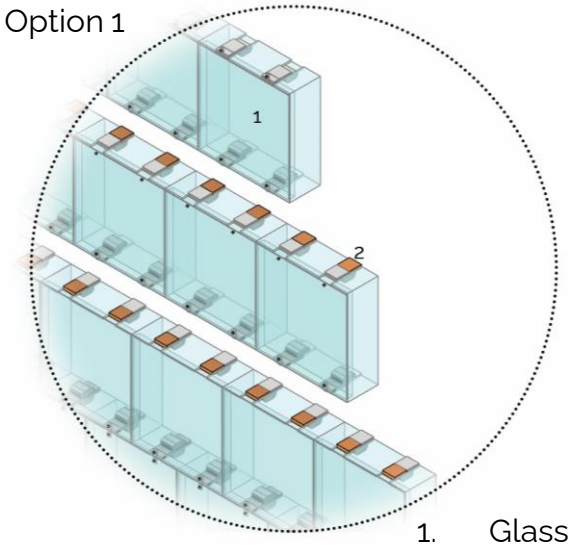
Option 1

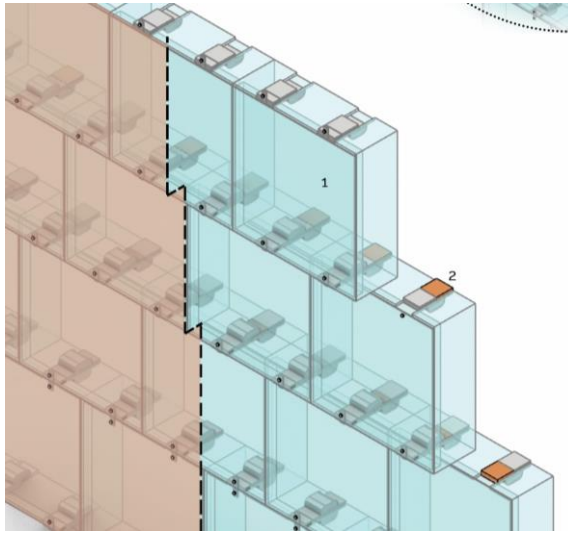


Option 2



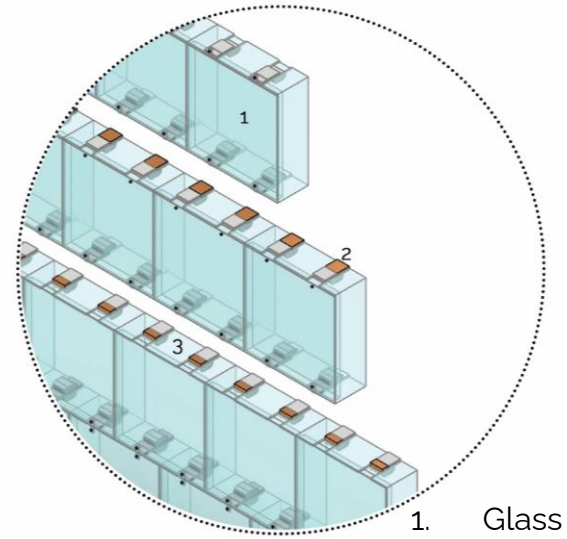
Option 1



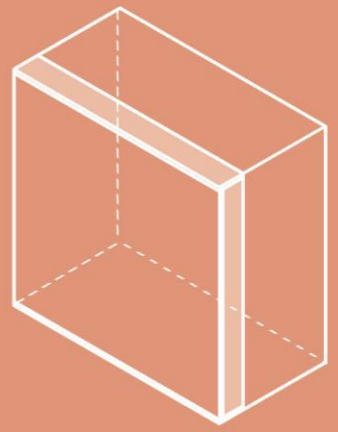


1. Glass Block
2. Tungsten rectangular block

Option 2



1. Glass Block
2. Tungsten rectangular block 40mm
3. Tungsten rectangular block 20mm



Fusion Block

DETAIL DESIGN

CONNECTION SYSTEM

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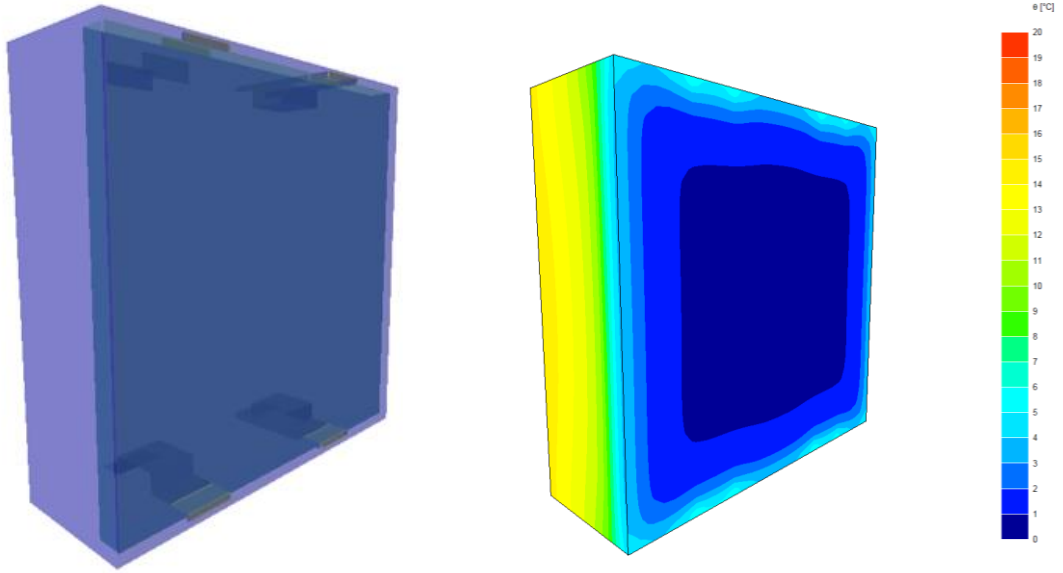
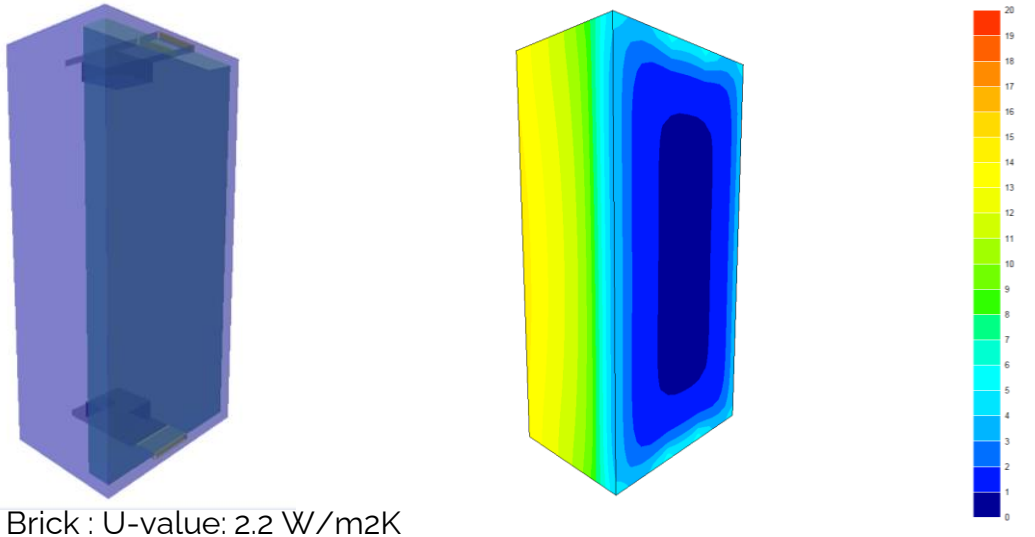


Full Brick : U-value: 2 W/m2K



Half Brick : U-value: 2.2 W/m2K

The total thermal transmittance of the facade with these block can be calculated as following:

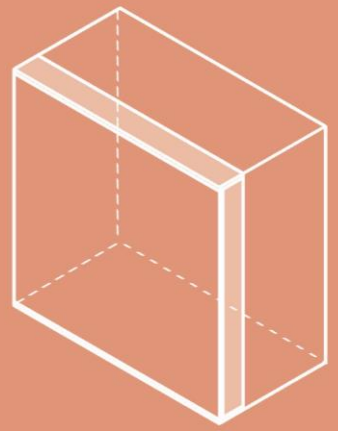
$$U_{fac} = \frac{U_{full}S_{full} + U_{half}S_{half}}{S_{total}}$$

here,

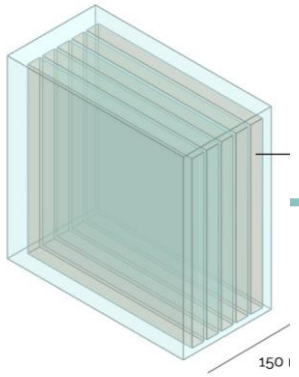
U_{fac}	W/m²K	Thermal transmittance of facade
U_{full}, U_{half}	W/m²K	Thermal transmittance of full and half bricks
S_{full}, S_{half}	m²	Surface of full and half bricks
S_{total}	m²	Total surface area

The total thermal transmittance of the facade is:

$$U_{fac} = \frac{2.0 \times 101.52 + 2.2 \times 1.8}{103.32} = \mathbf{2.0\ W/m^2K}$$



Fusion Block



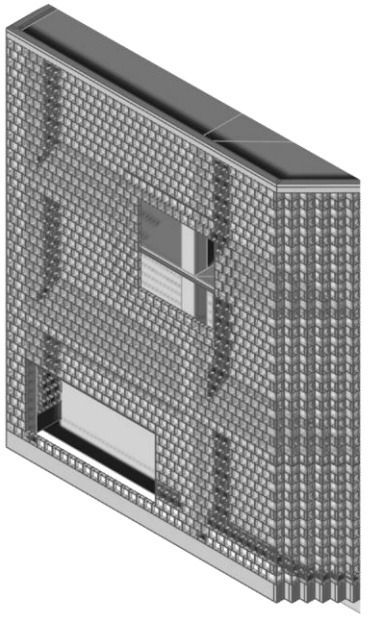
1 Detail Design

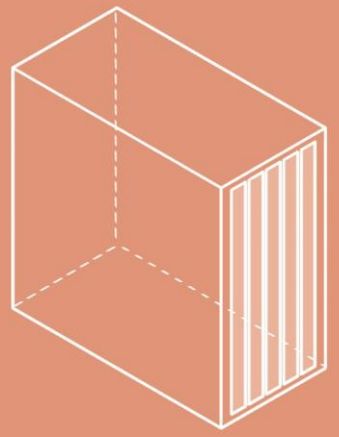
2 Connection System

3 Manufacturing

4 Installation

5 Thermal Performance





Lattice Block

DETAIL DESIGN

CONNECTION SYSTEM

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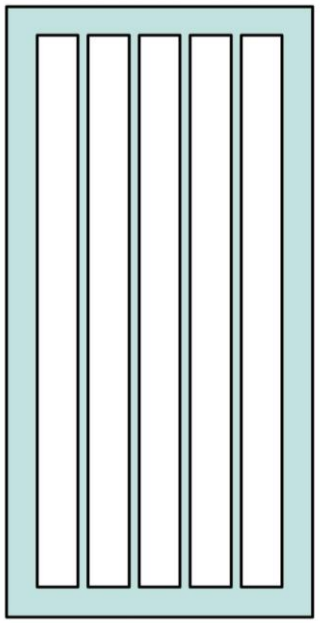
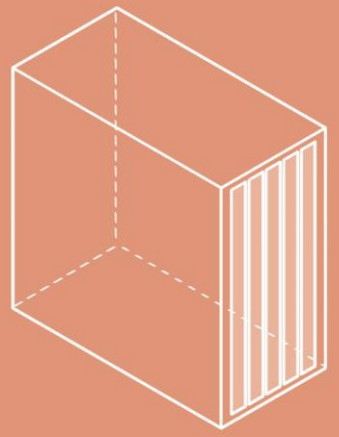
THERMAL PERFORMANCE



U-value: 1.65 W/m2K
Block width: 150mm
Cavity width: 20mm



Lattice Block

DETAIL DESIGN

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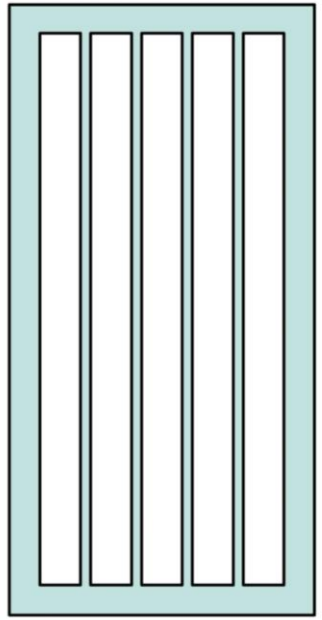
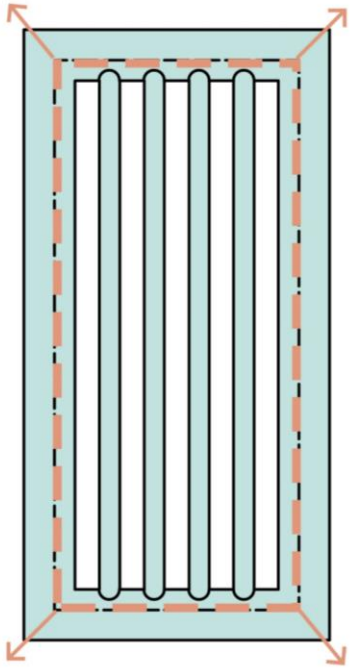
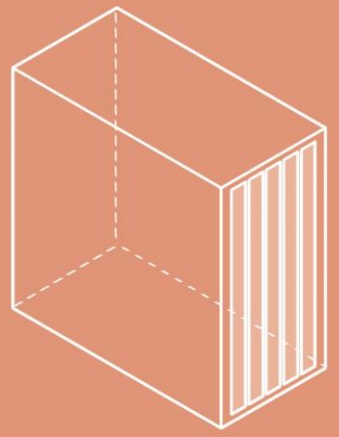


U-value: 1.65 W/m2K
Block width: 150mm
Cavity width: 20mm



U-value: 1.8 W/m2K
Block width: 150mm
Cavity width: 20mm



Lattice Block

DETAIL DESIGN

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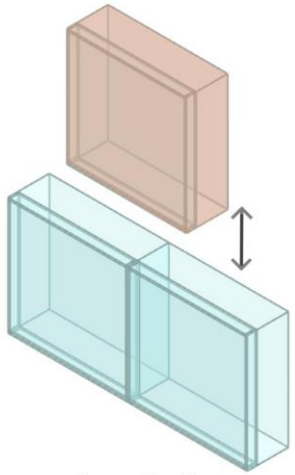
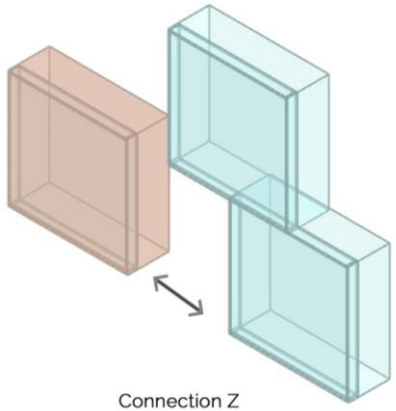
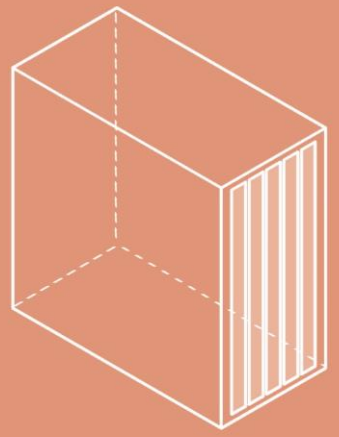


Connection Y



Connection Z



Lattice Block

DETAIL DESIGN

CONNECTION SYSTEM

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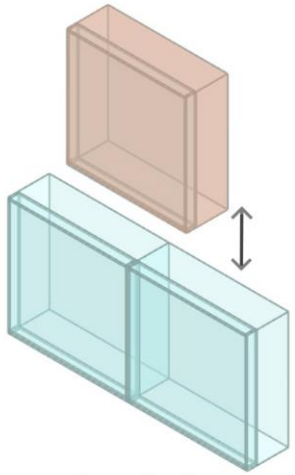
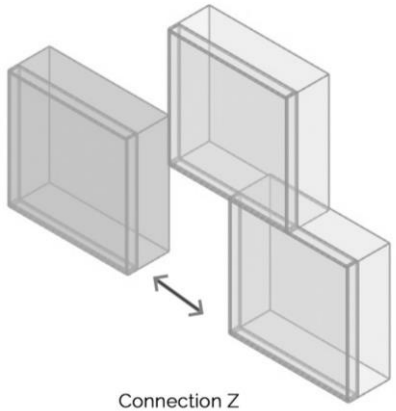
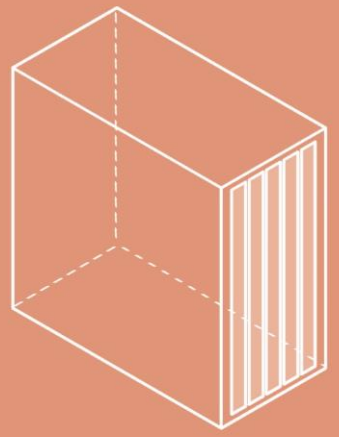
THERMAL PERFORMANCE



Connection Y



Connection Z



Lattice Block

DETAIL DESIGN

CONNECTION SYSTEM

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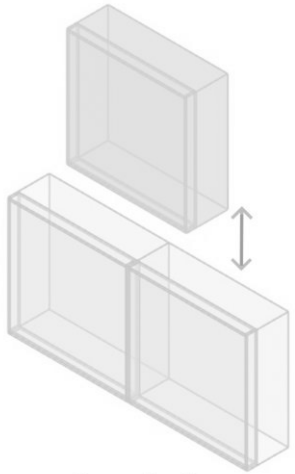
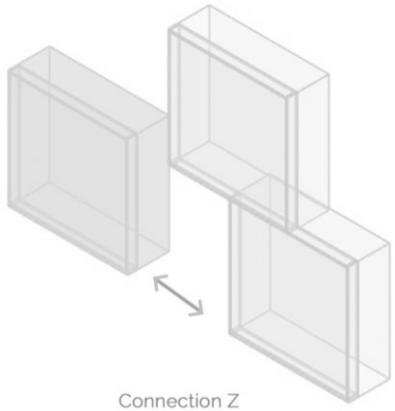
ASSEMBLY

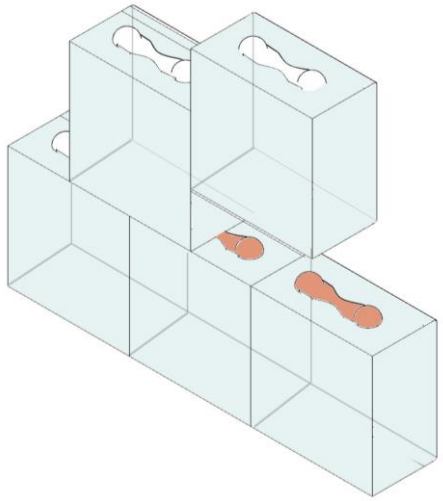
THERMAL PERFORMANCE



Connection Y

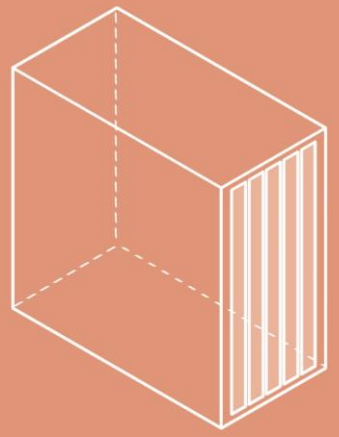


Connection Z



Option 1

Connection Y: King-Queen Interlocking



Lattice Block

DETAIL DESIGN

CONNECTION SYSTEM

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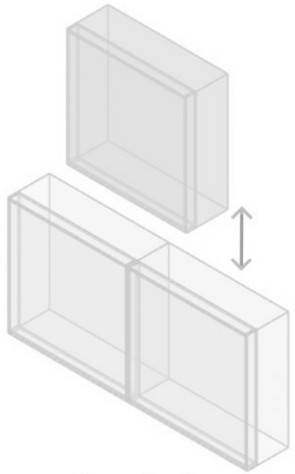
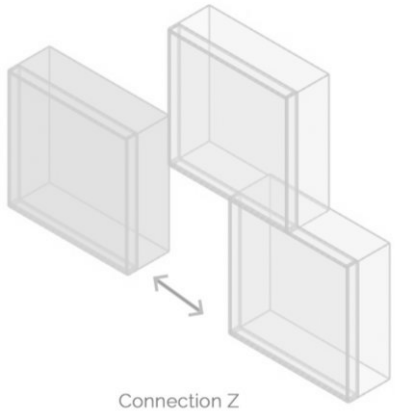
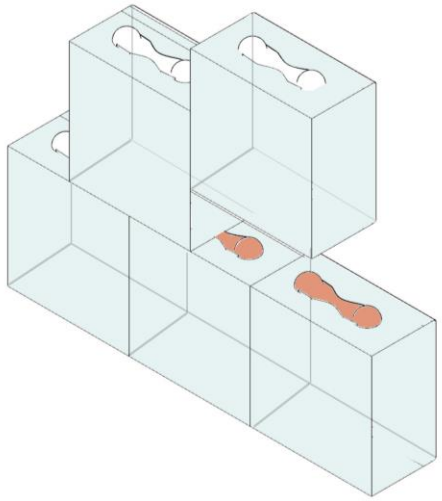
THERMAL PERFORMANCE



Connection Y

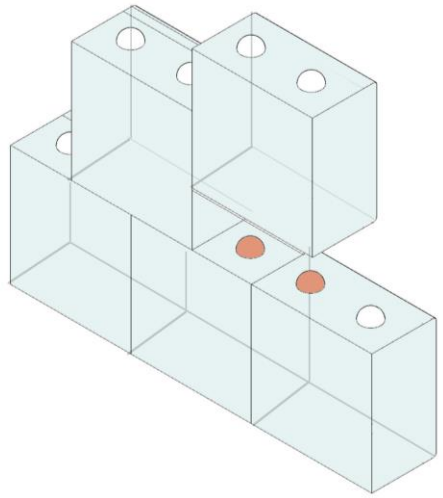


Connection Z



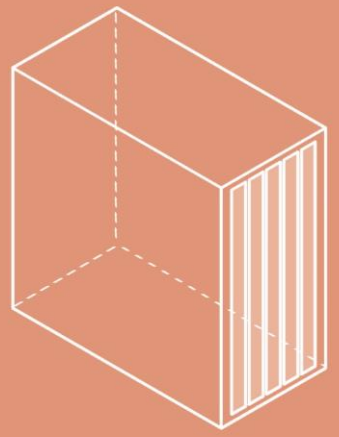
Option 1

Connection Y: King-Queen Interlocking



Option 2

Connection Y: Hemispherical Interlock



Lattice Block

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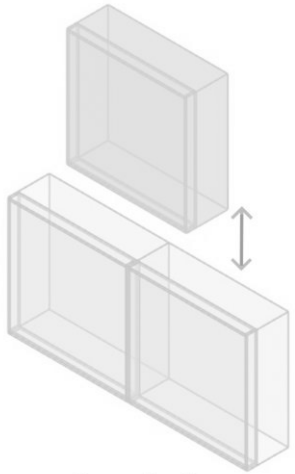
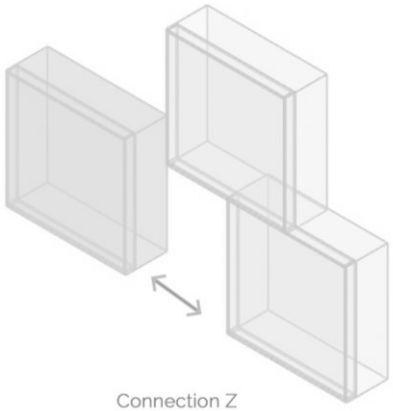
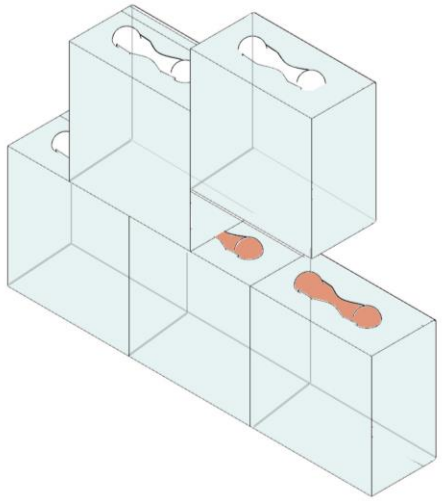


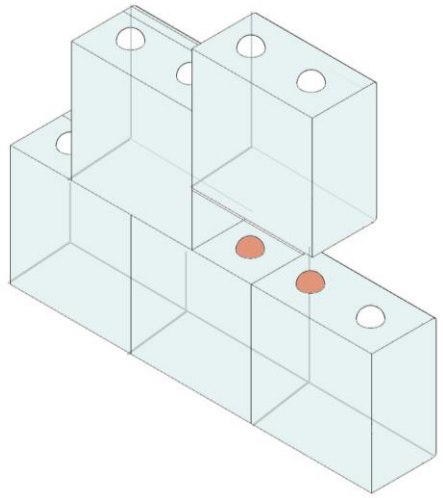
Connection Y



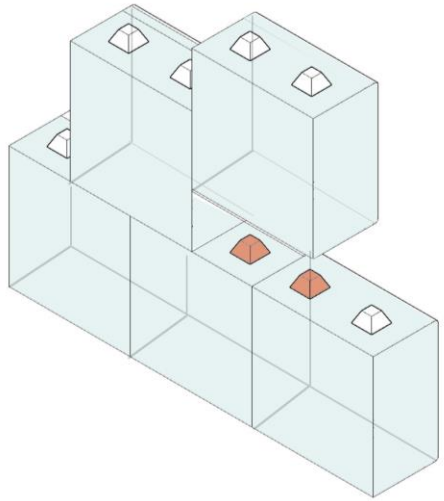
Connection Z



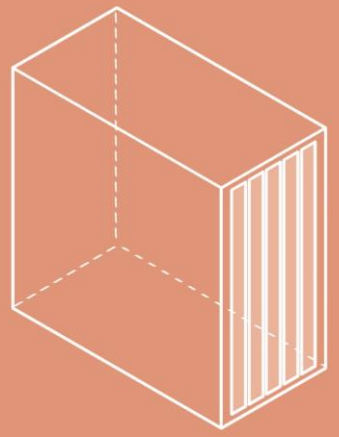
Option 1
Connection Y: King-Queen Interlocking



Option 2
Connection Y: Hemispherical Interlock



Option 3
Connection Y: Lego Type Interlock



Lattice Block

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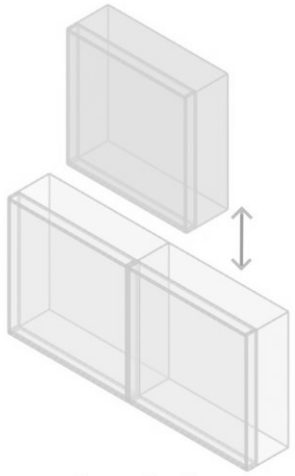
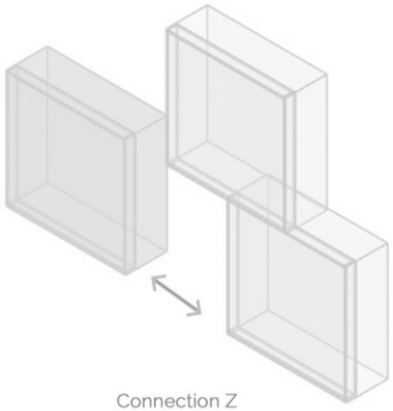
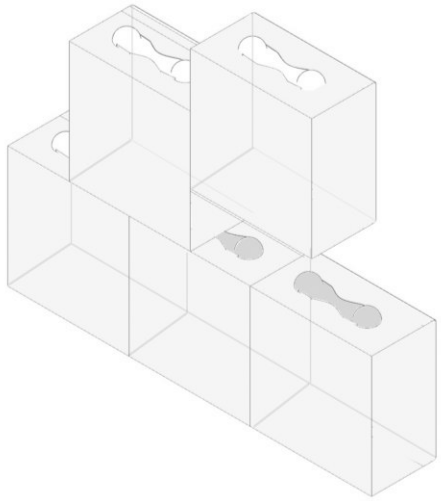


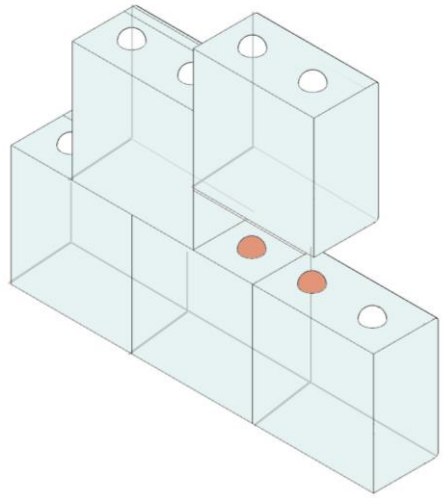
Connection Y



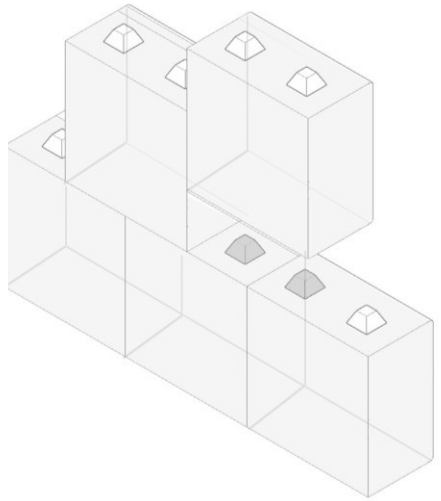
Connection Z



Option 1
Connection Y: King-Queen Interlocking

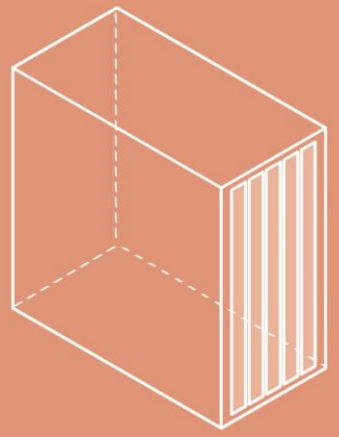


Option 2
Connection Y: Hemispherical Interlock



Option 3
Connection Y: Lego Type Interlock

Connection Type		Unobstructed view	Reversibility	Ease of assembly	Load Distribution	Overall
Lattice Block	King-Queen Block interlock	++++	++++	++	++	+++
	Hemispherical Interlock	++++	++++	++++	++++	++++
	Lego type Interlock	+++	++++	++++	+++	+++



Lattice Block

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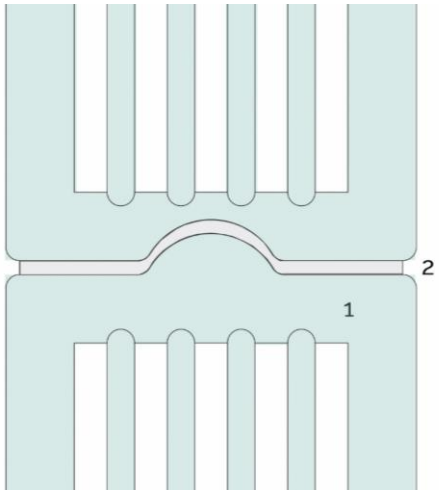
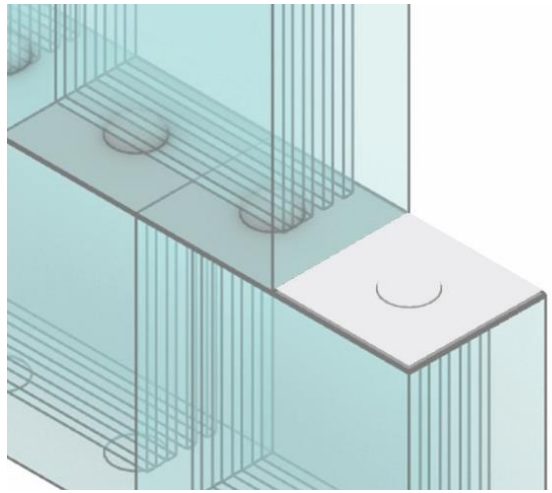
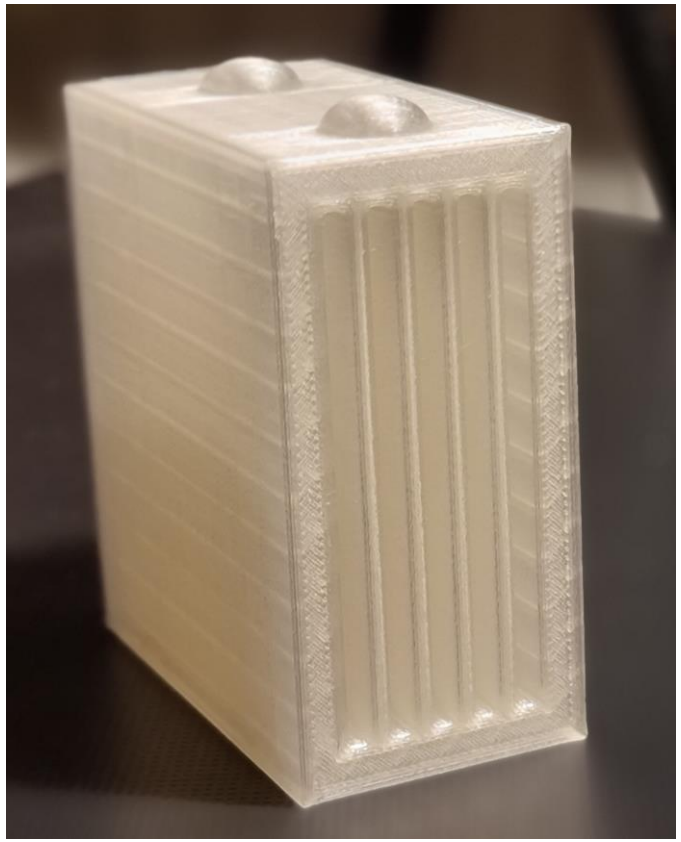
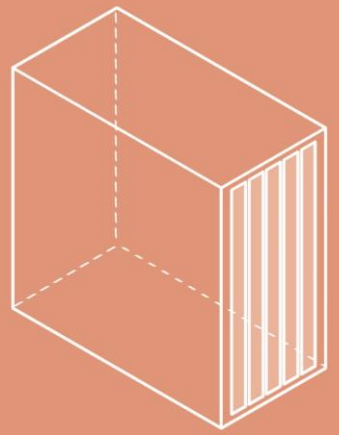


1. Glass Block
2. Neoprene Interlayer







Lattice Block

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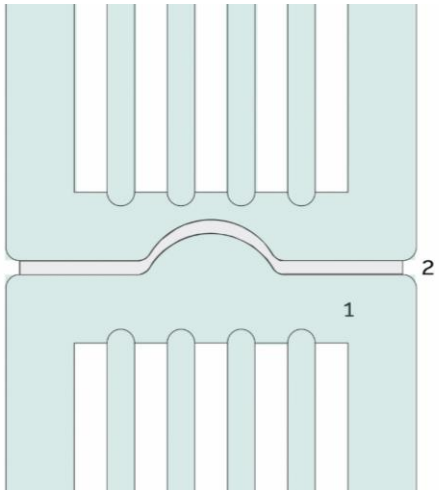
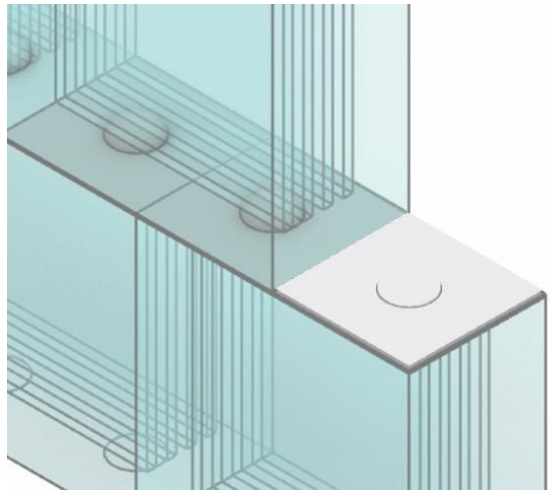
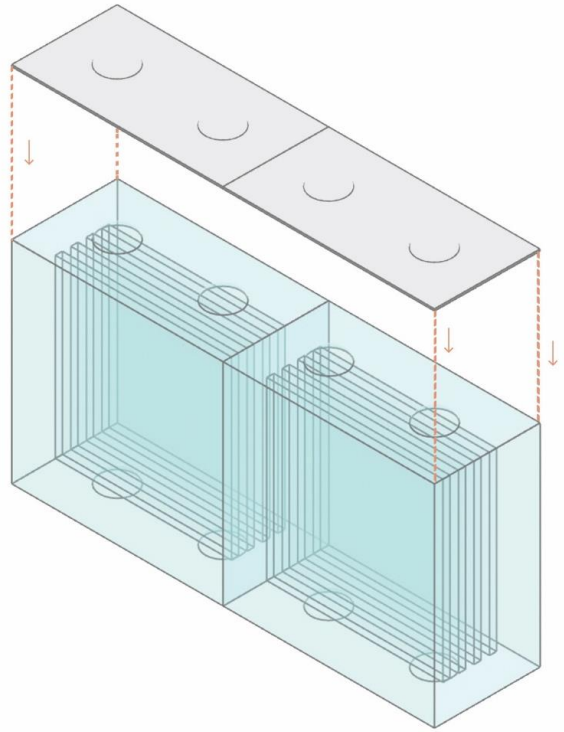
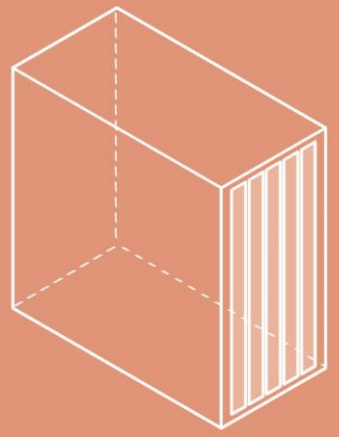


1. Glass Block
2. Neoprene Interlayer





Step 1



Lattice Block

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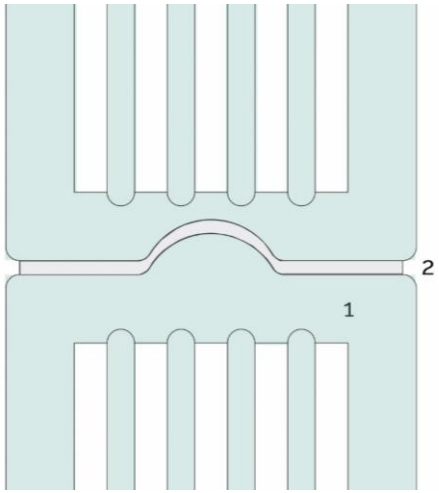

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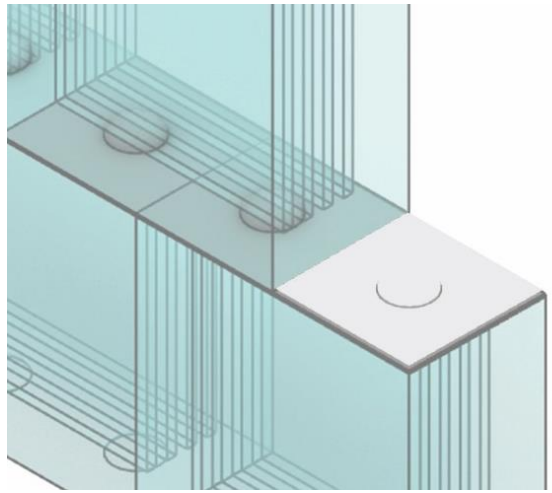

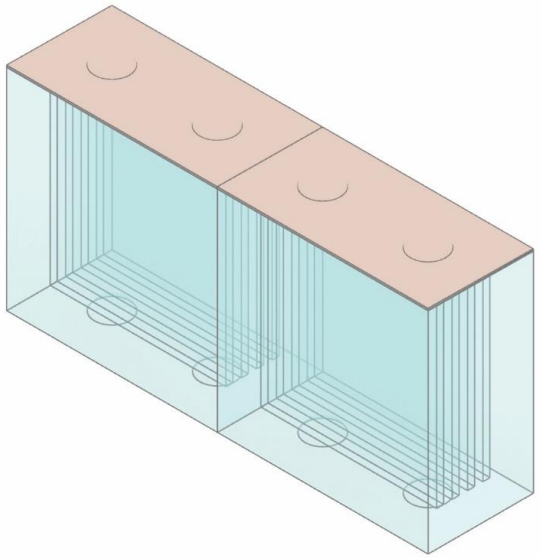

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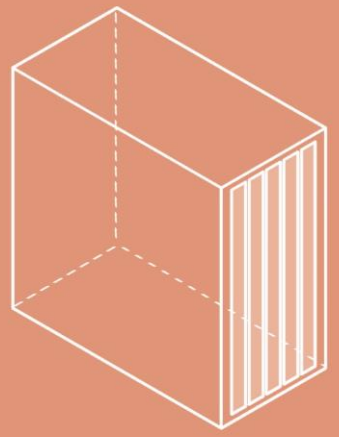

Lattice Block

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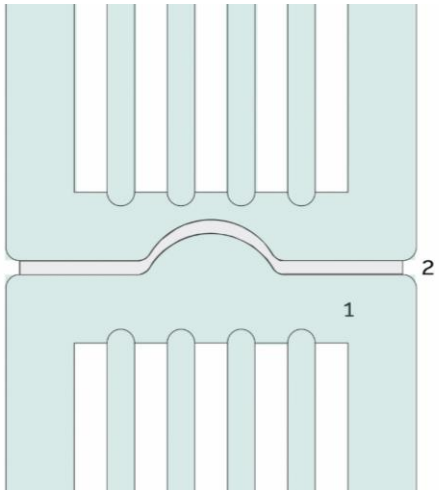
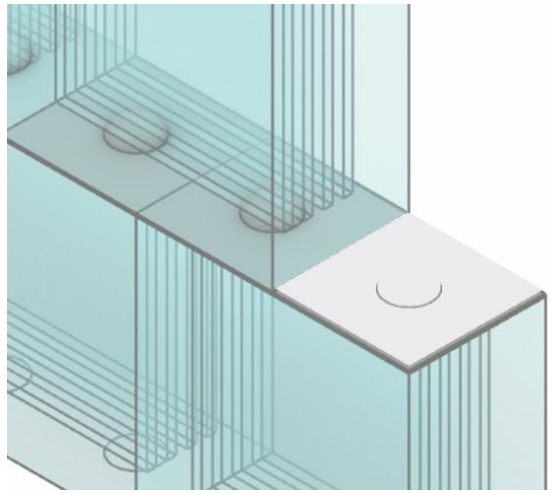
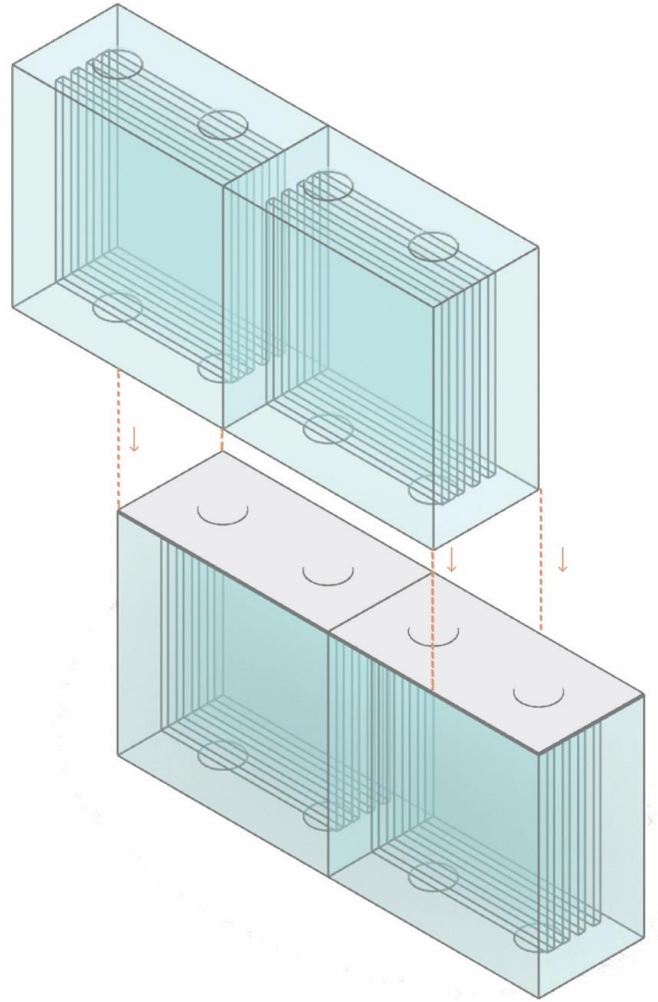
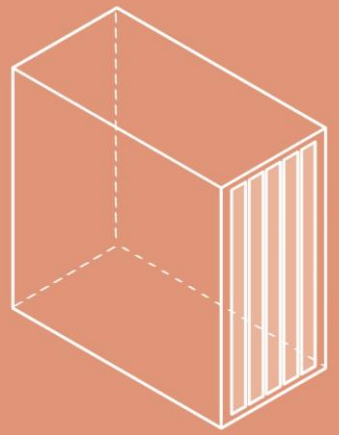


1. Glass Block
2. Neoprene Interlayer





Step 3



Lattice Block

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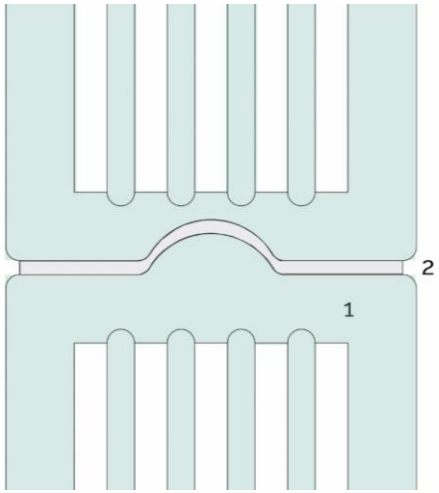

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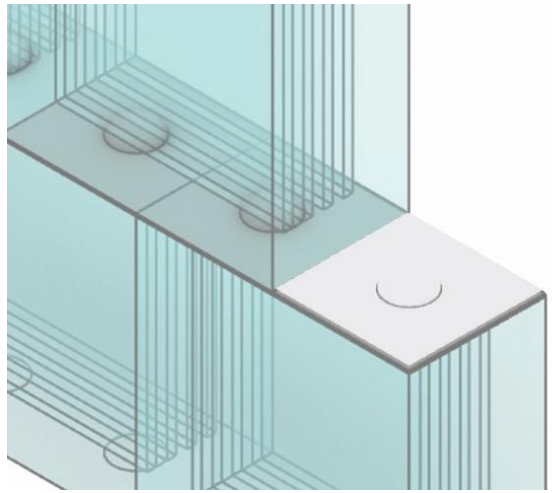
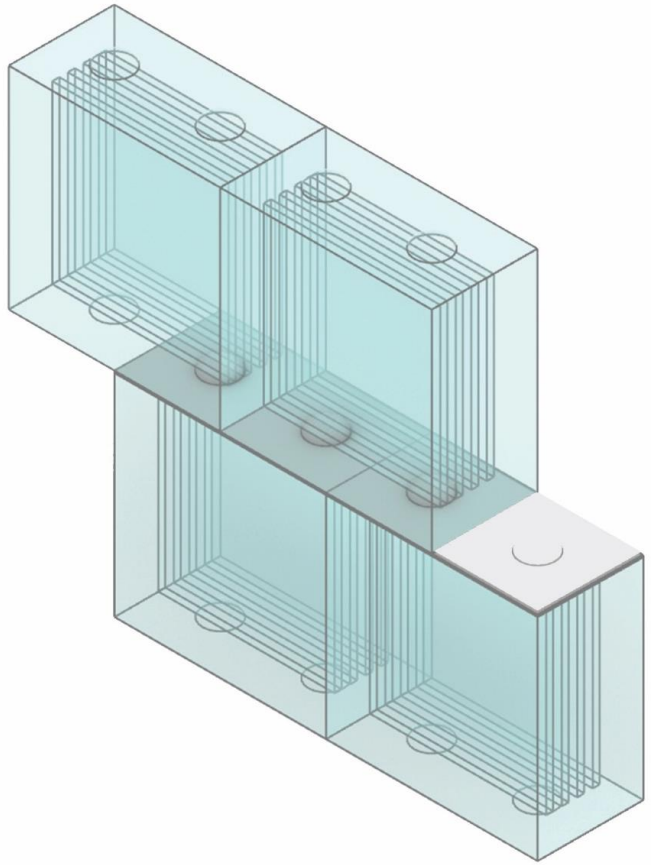
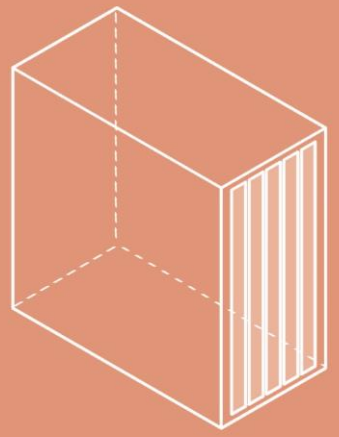
2. Neoprene Interlayer





Step 4



Lattice Block

DETAIL DESIGN

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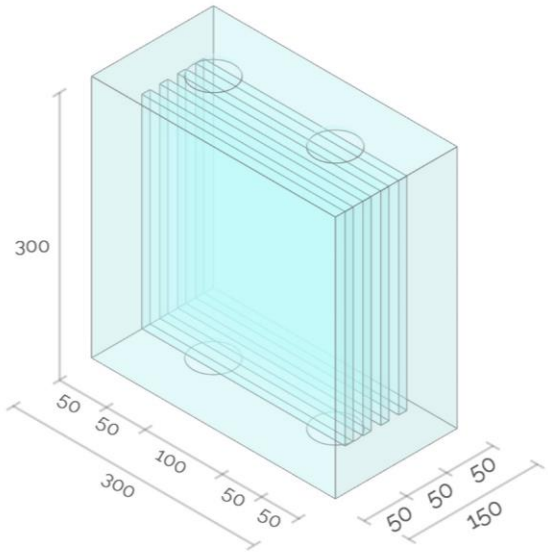
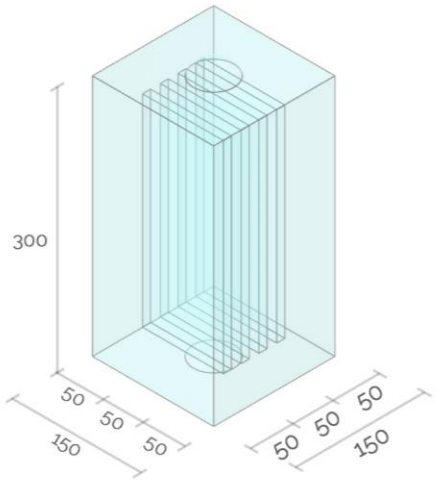
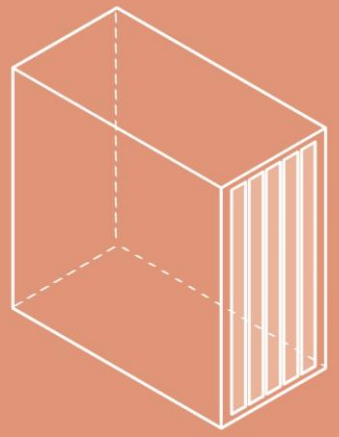
Full Brick



Half Brick



Total number of blocks: 1266
Full Brick: 1246
Half Brick: 20



Lattice Block

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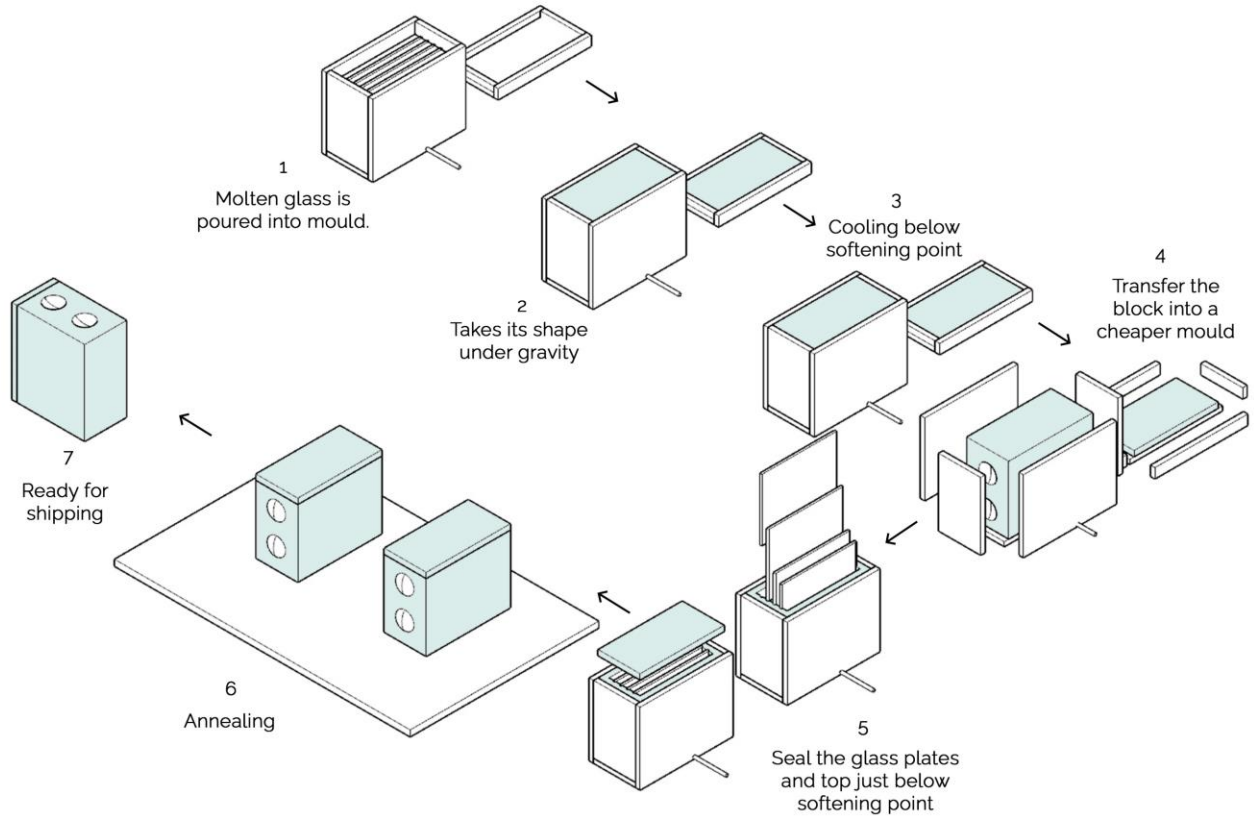
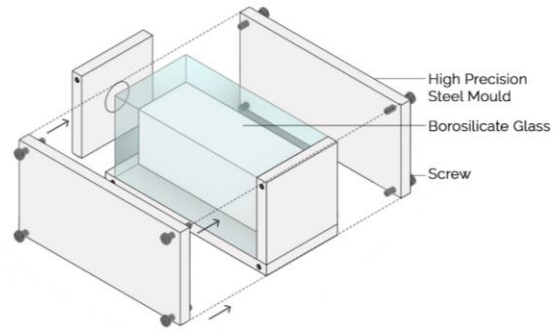
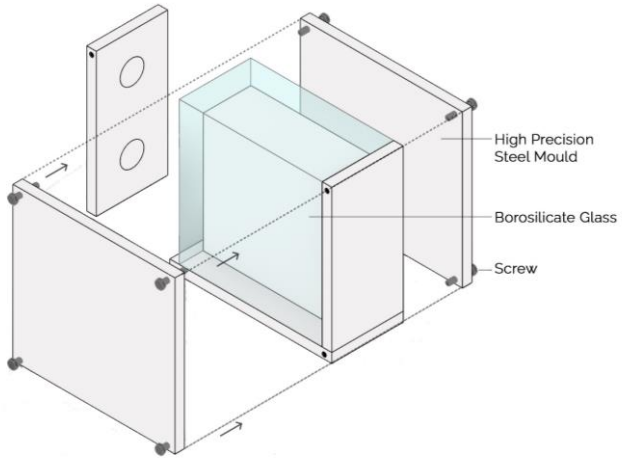
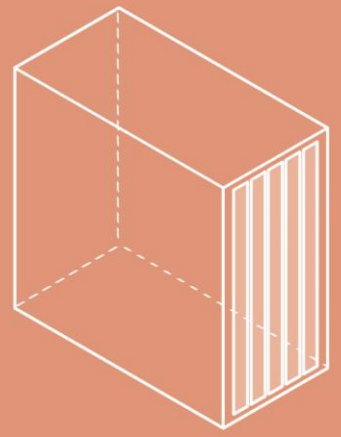






MANUFACTURING PROCESS OF FULL AND HALF BRICK – OP 1



Lattice Block

DETAIL DESIGN

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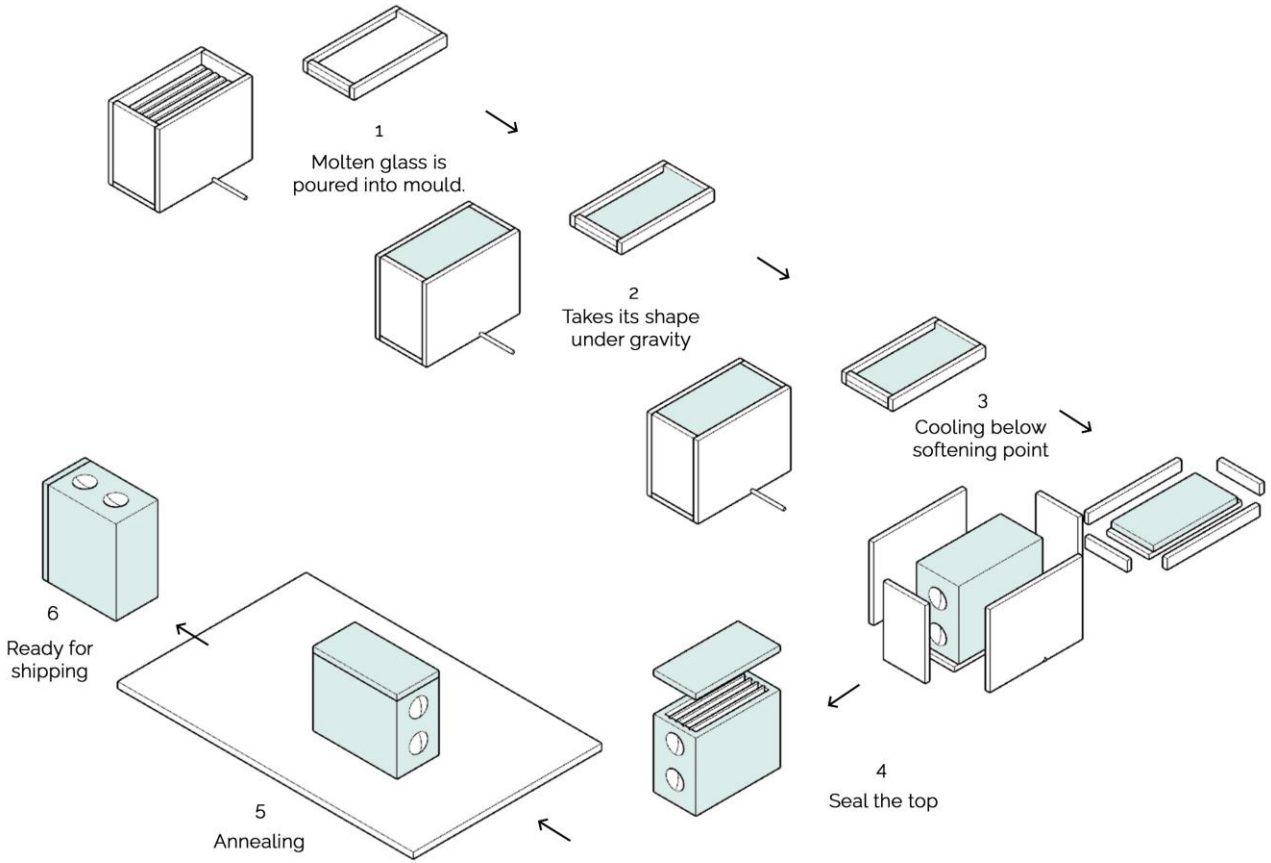
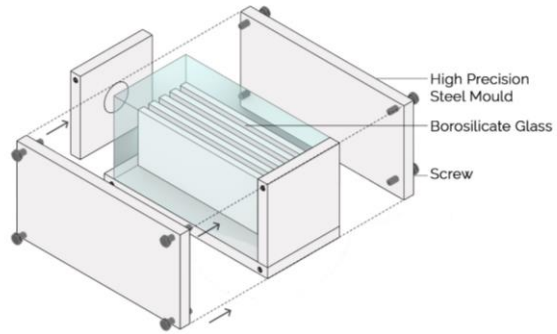
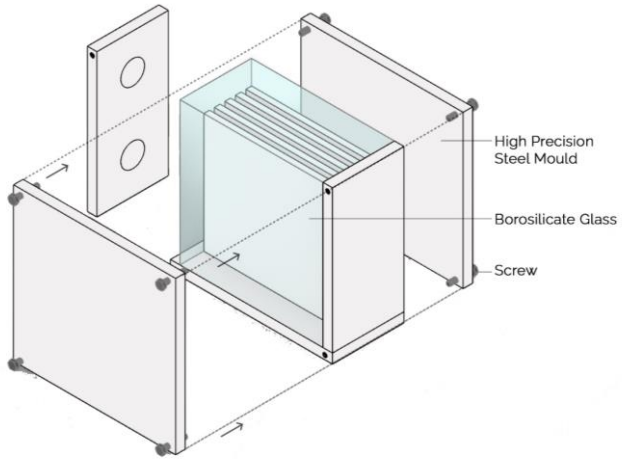
THERMAL PERFORMANCE





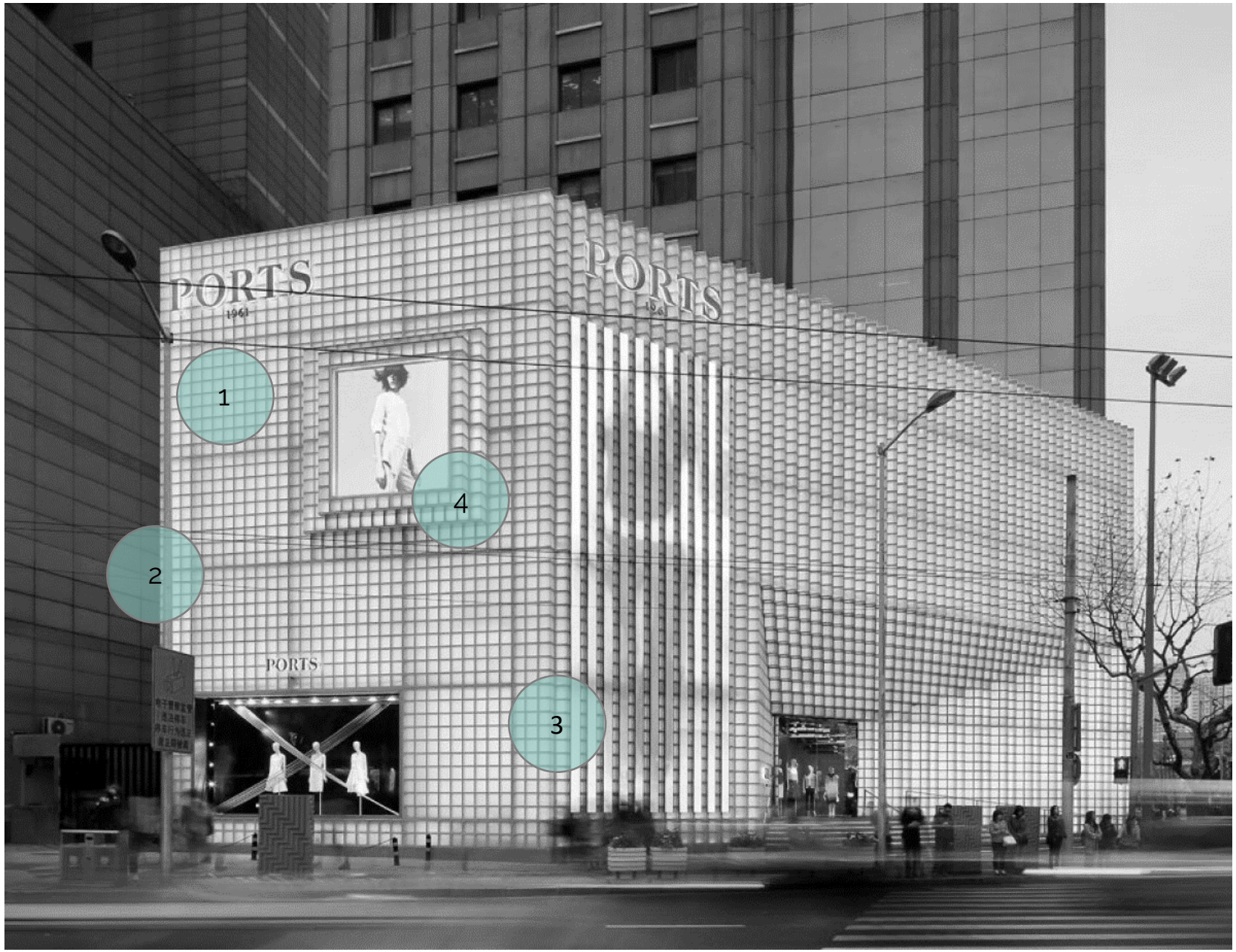


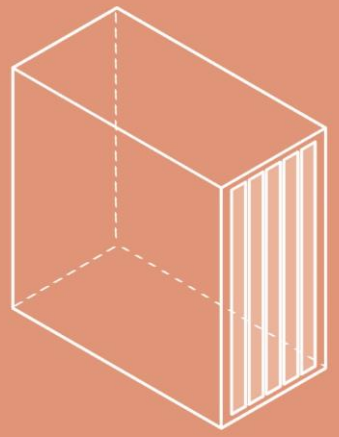
MANUFACTURING PROCESS OF FULL AND HALF BRICK – OP 2

Case Study

Design Aspects for Assembly:

1. Straight façade
2. L-Junction
3. Corbel Junction
4. Corbel Window





Lattice Block

DETAIL DESIGN

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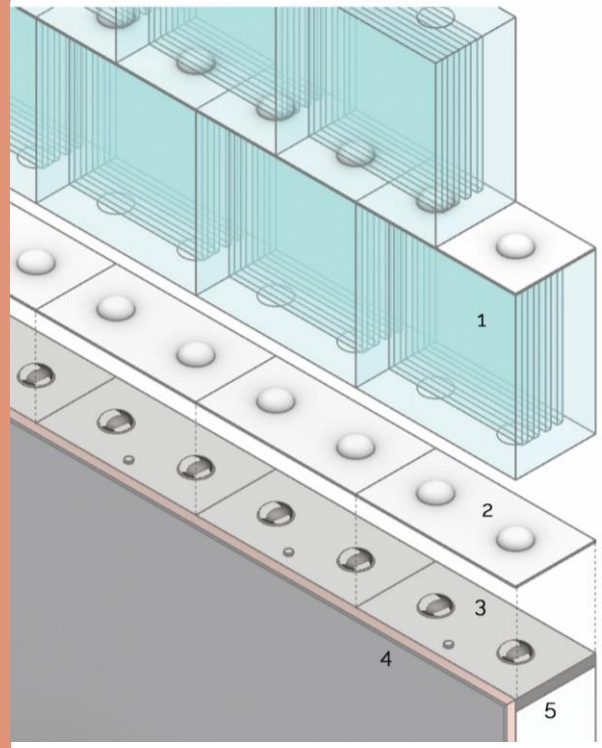
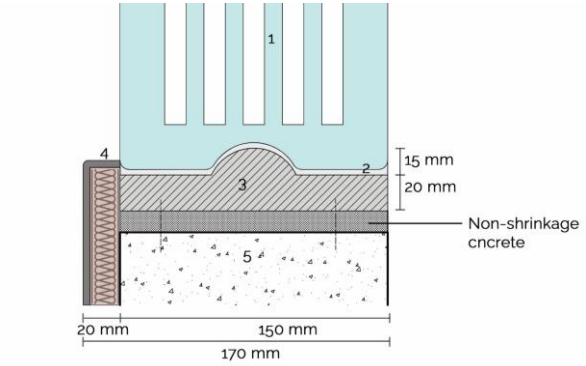
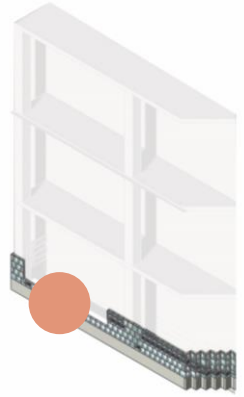
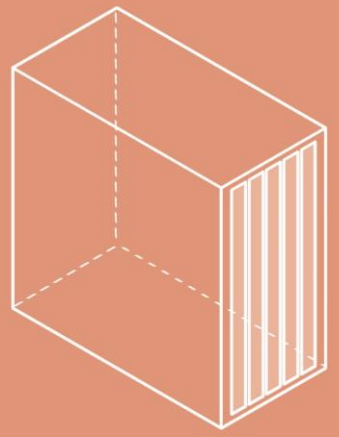
BOTTOM CONNECTION



1. Glass Block
2. Neoprene interlayer
3. Steel plate
4. Insulation with wall finish
5. Concrete base







Lattice Block

DETAIL DESIGN

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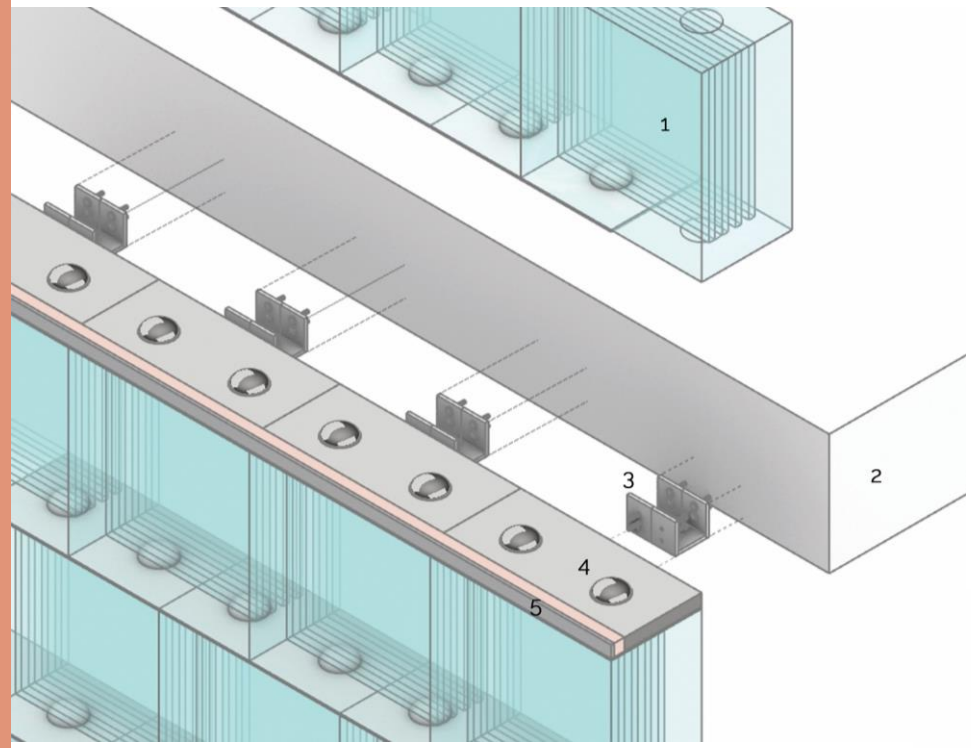
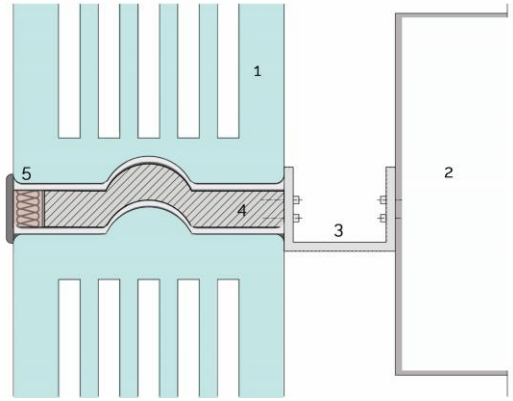
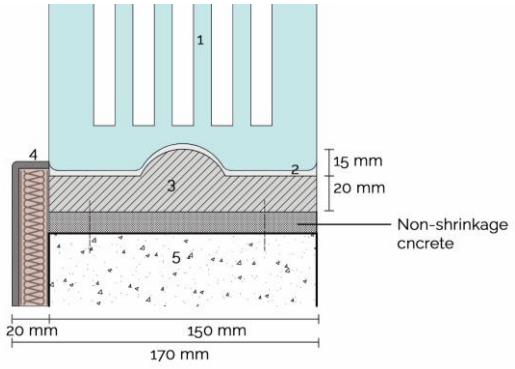
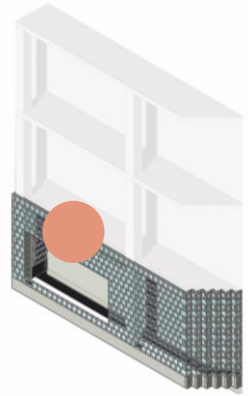
INTERMEDIATE FLOOR CONNECTION

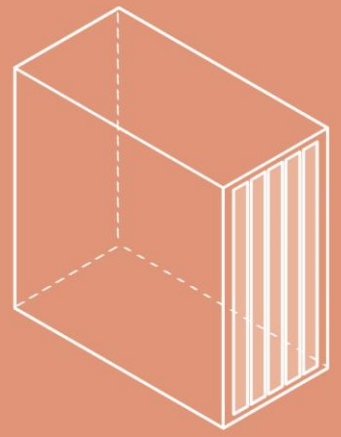


1. Glass Block
2. Floor slab
3. Steel angle-section
4. Steel plate
5. Insulation with wall finish









Lattice Block

DETAIL DESIGN

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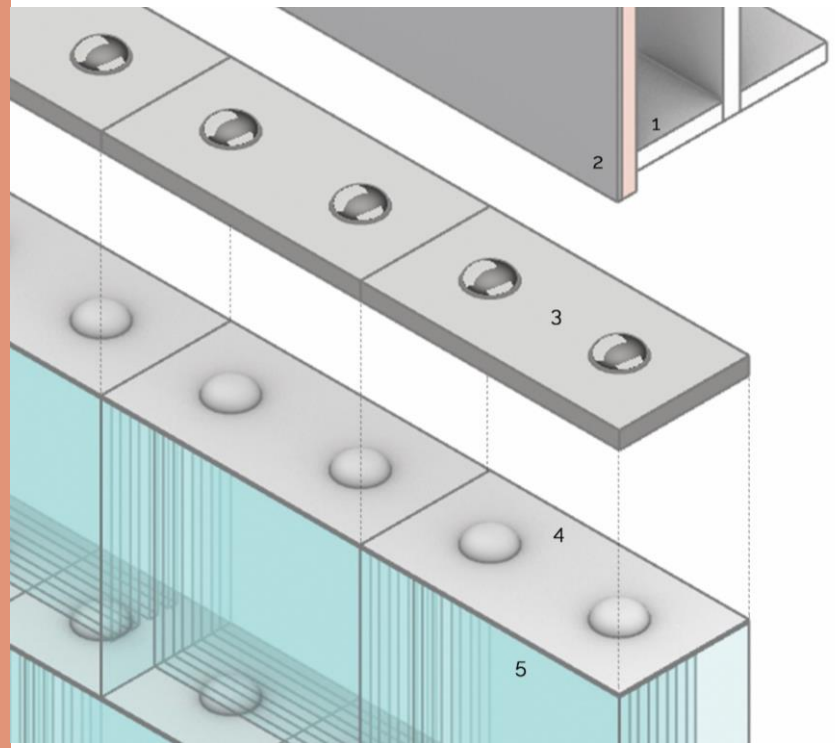
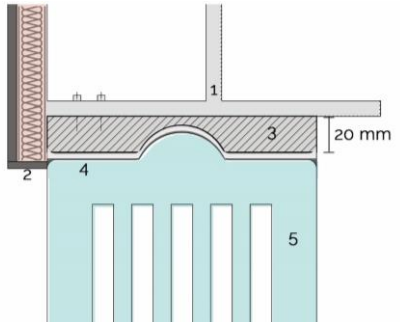
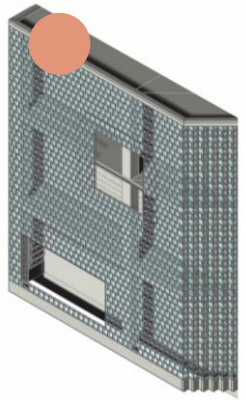
THERMAL PERFORMANCE

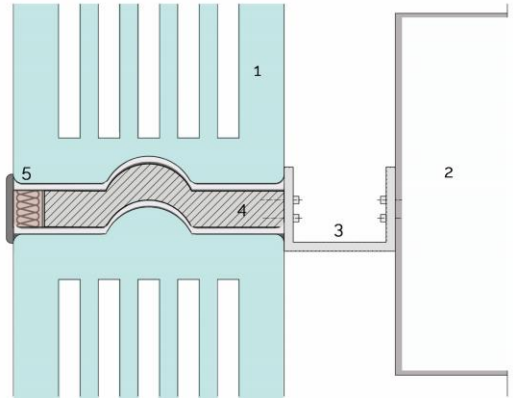
TOP CONNECTION

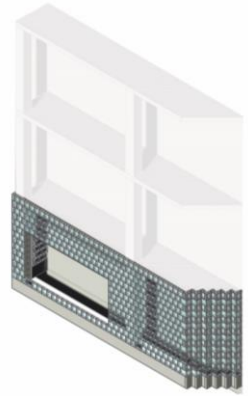


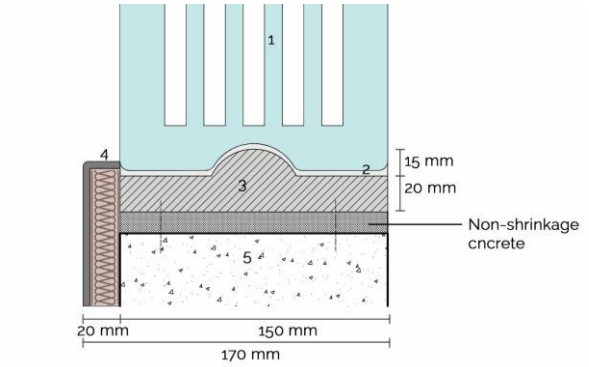
1. I-beam
2. Insulation with wall finish
3. Steel plate
4. Neoprene interlayer
5. Glass Block

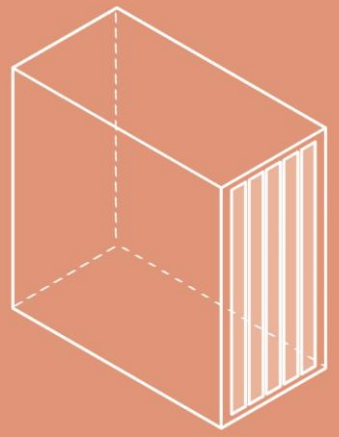












Lattice Block

DETAIL DESIGN

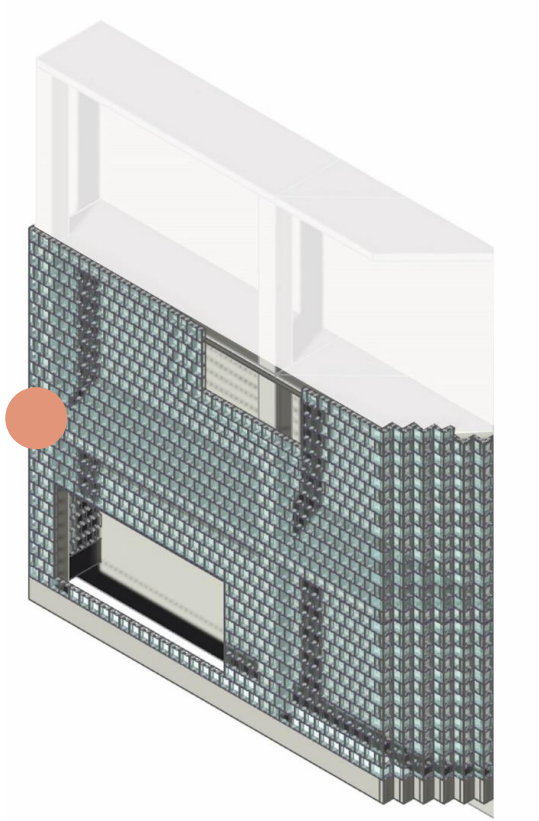
CONNECTION SYSTEM

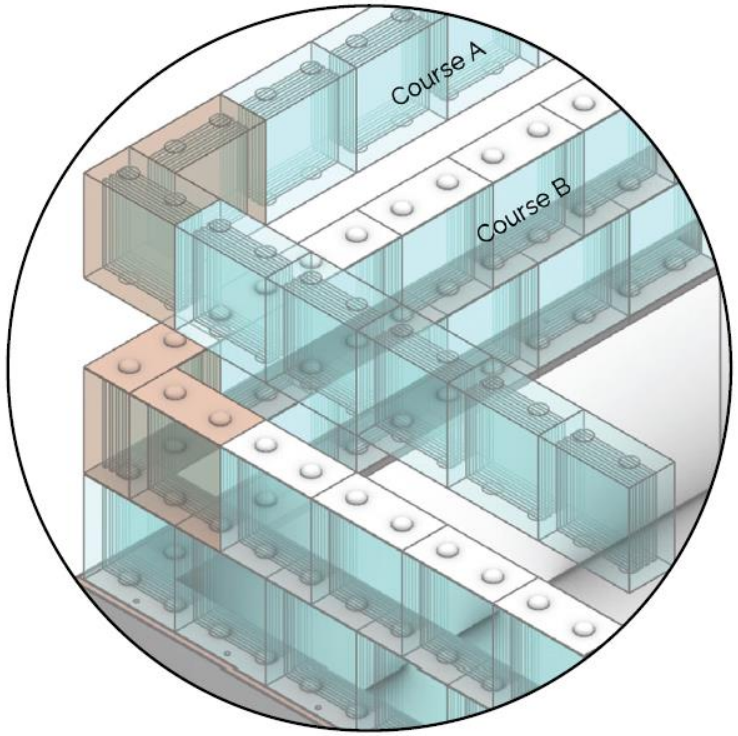
MANUFACTURING

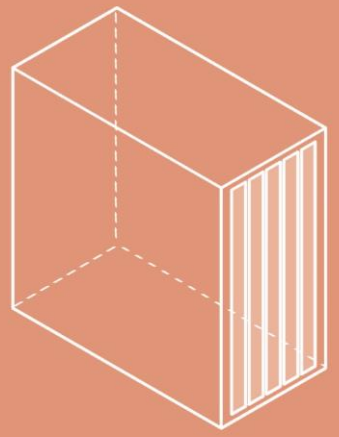
ASSEMBLY

THERMAL PERFORMANCE

L-JUNCTION







Lattice Block

DETAIL DESIGN

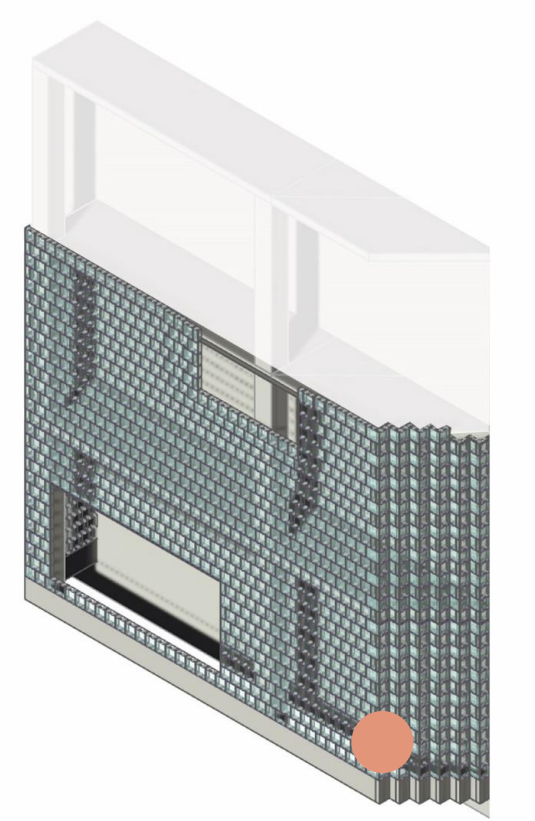
CONNECTION SYSTEM

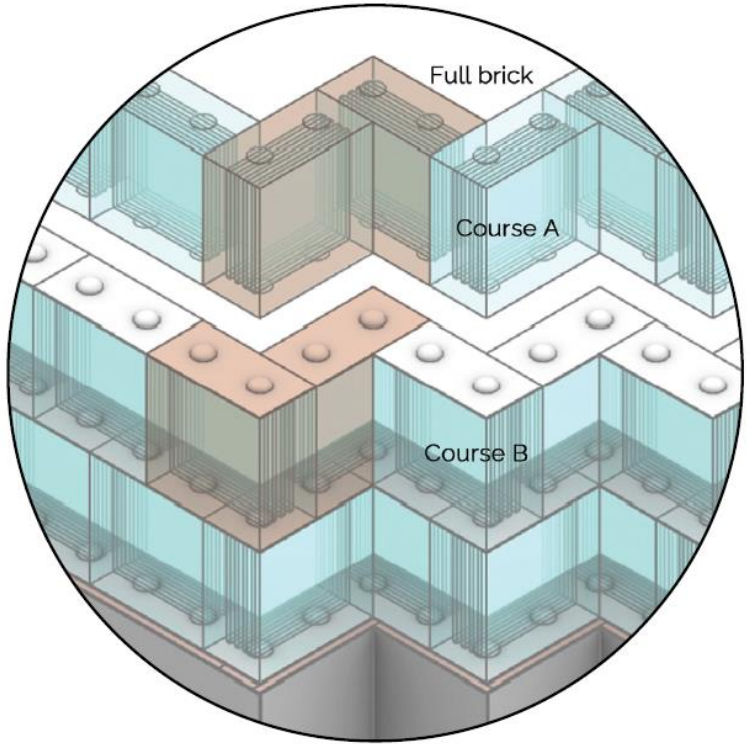
MANUFACTURING

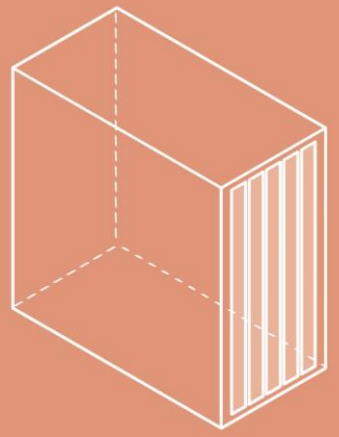
ASSEMBLY

THERMAL PERFORMANCE

CORBEL JUNCTION







Lattice Block

DETAIL DESIGN

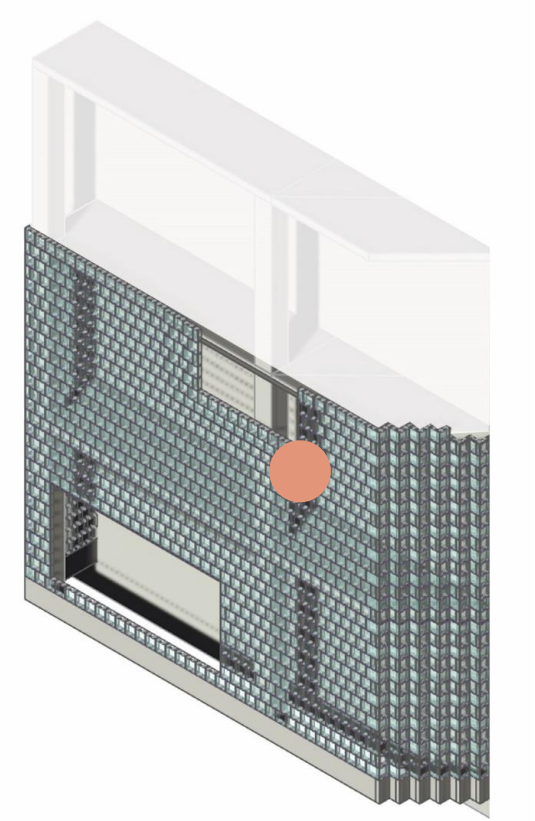
CONNECTION SYSTEM

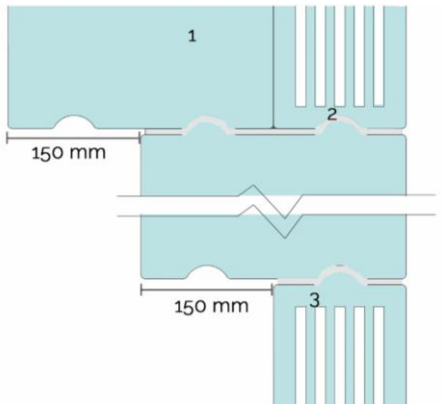
MANUFACTURING

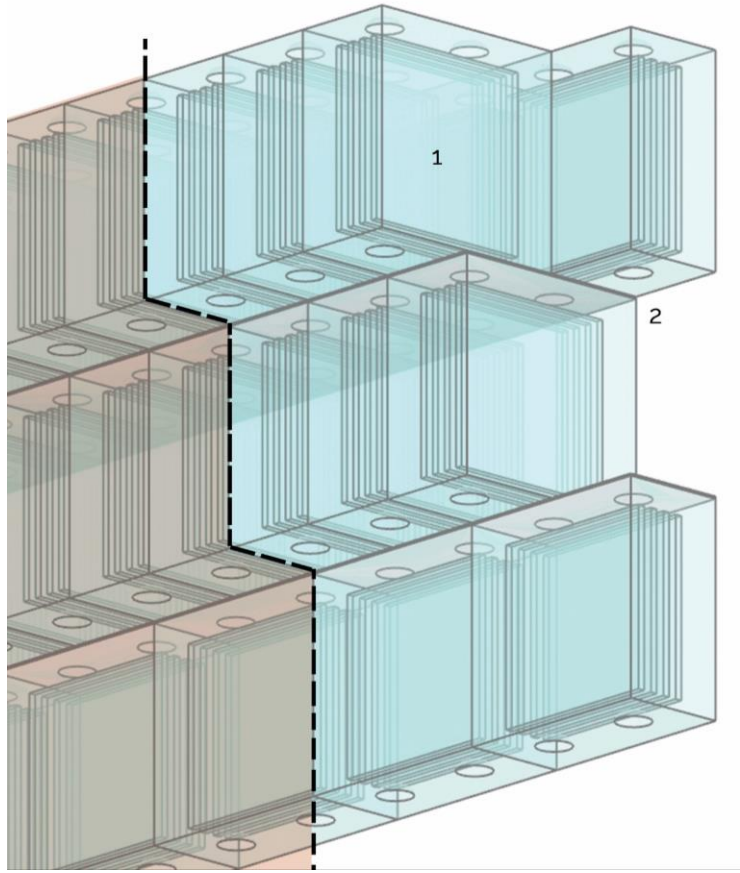
ASSEMBLY

THERMAL PERFORMANCE

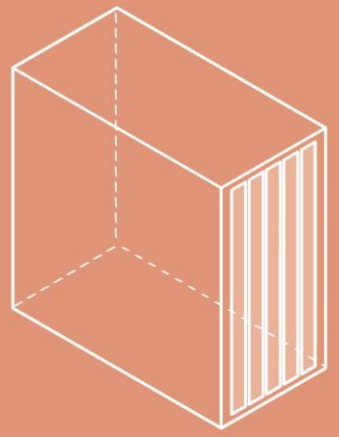
CORBEL WINDOW







1. Glass Block oriented 90 degrees to the original placement
2. Original placement of glass block



Lattice Block

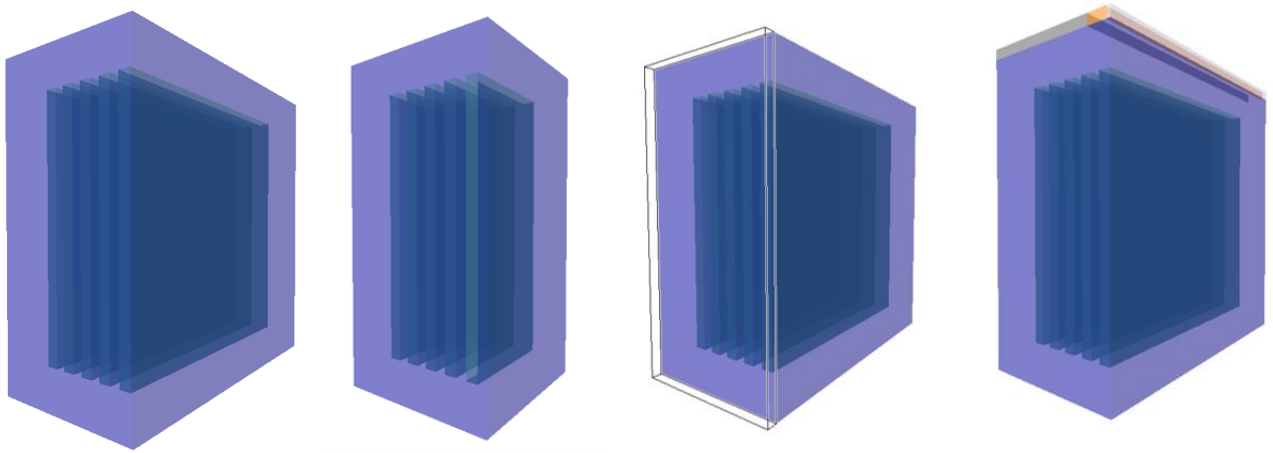
DETAIL DESIGN

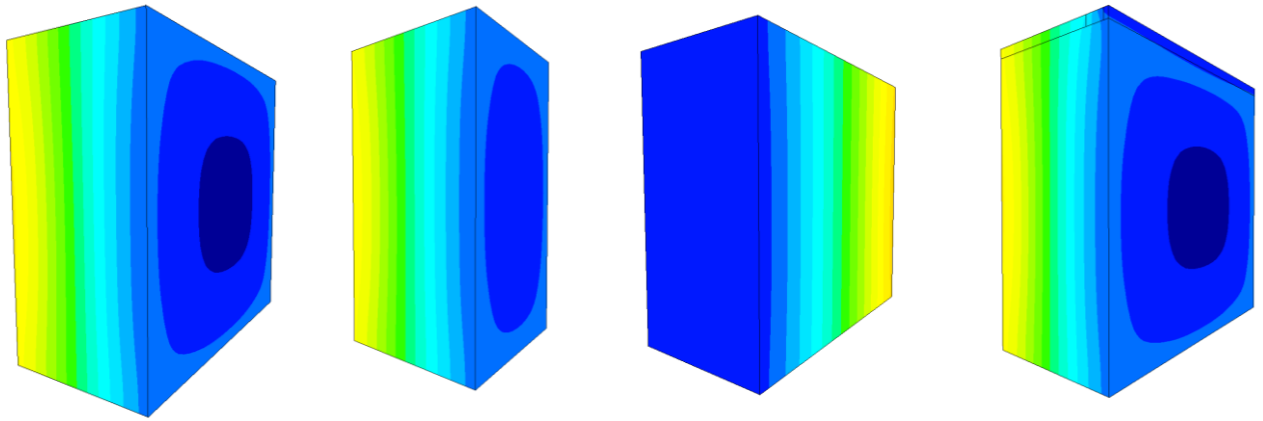
CONNECTION SYSTEM

MANUFACTURING

ASSEMBLY

THERMAL PERFORMANCE





Half Brick : U-value: 1.9 W/m2K

Half Brick : U-value: 2.3 W/m2K

Full Brick_corbel : U-value: 1.7 W/m2K

Full Brick_connection : U-value: 2.3 W/m2K

The total thermal transmittance of the facade with these block can be calculated as following:

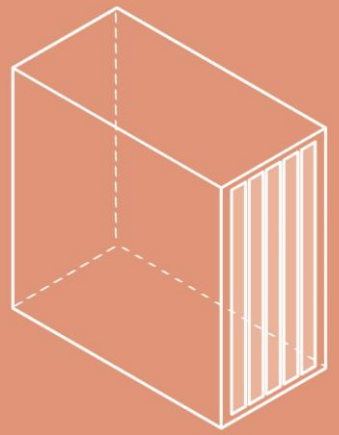
$$U_{fac} = \frac{U_{full}S_{full} + U_{half}S_{half} + U_{corbel}S_{corbel}}{S_{total}}$$

here,

U_{fac}	W/m²K	Thermal transmittance of facade
U_{full}, U_{half}, U_{corbel}	W/m²K	Thermal transmittance of full, half and corbel bricks
S_{full}, S_{half}, S_{corbel}	m²	Surface of full and half bricks
S_{total}	m²	Total surface area

The total thermal transmittance of the facade is:

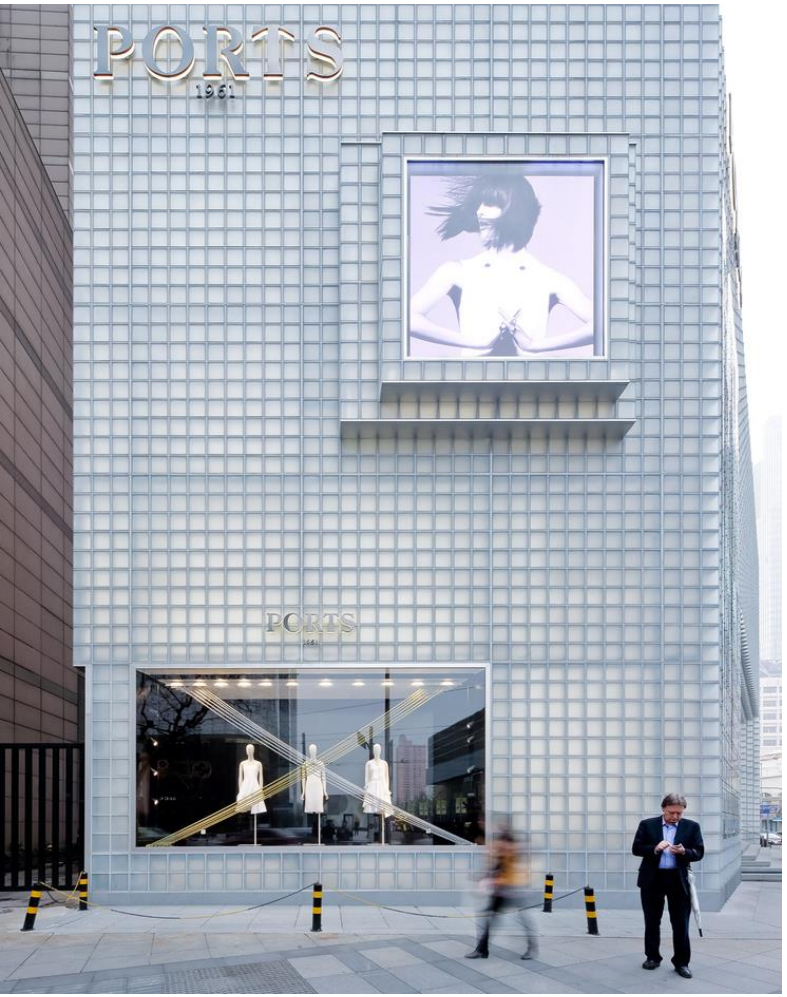
$$U_{fac} = \frac{1.93x93.78 + 2.3x0.9 + 1.7x9.16}{103.32} = \mathbf{1.92\ W/m^2K}$$



Lattice Block

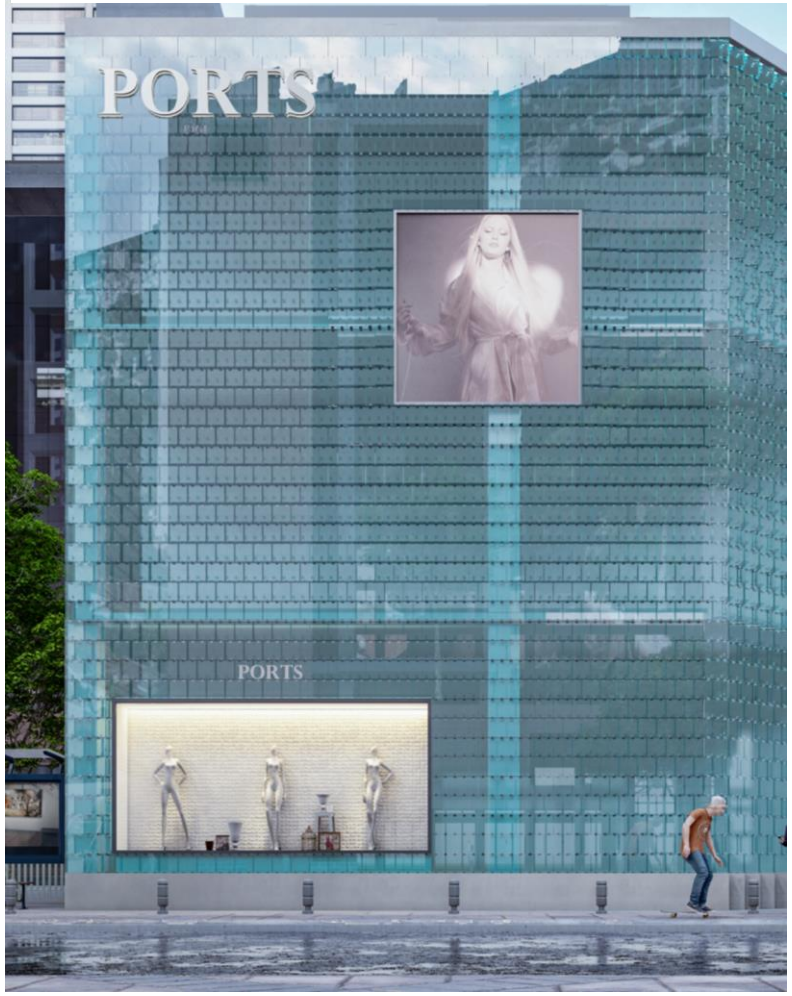
COMPARATIVE ANALYSIS – Thermal Performance

Existing building façade – hollow block



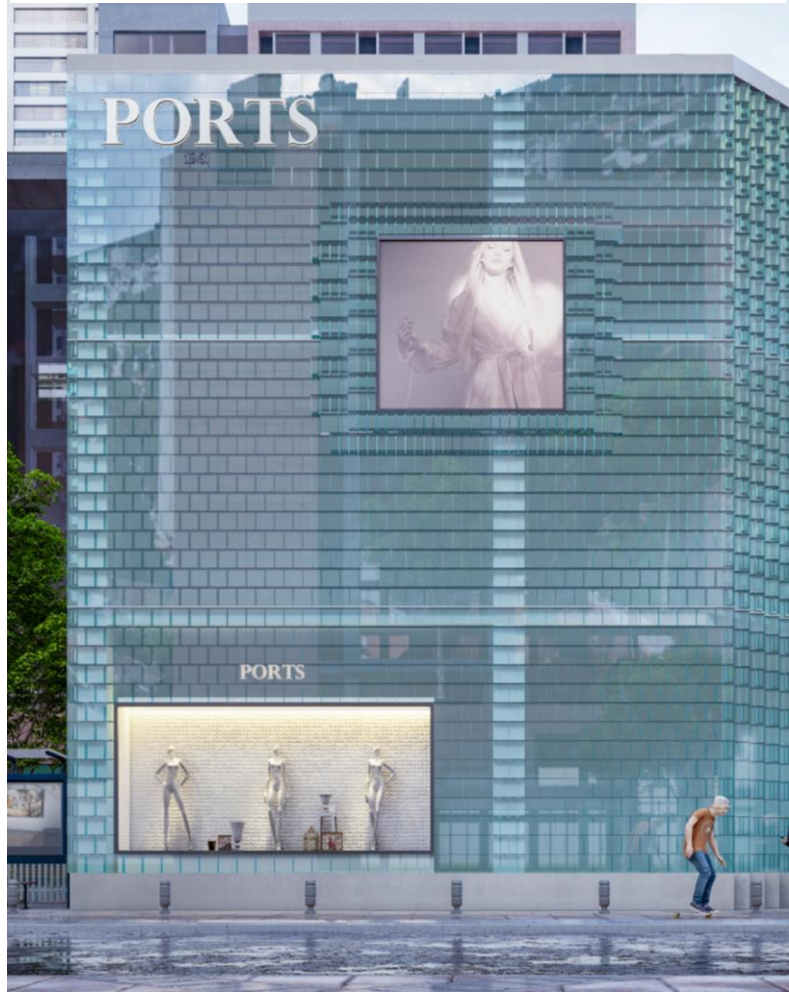
U-value: 2.6 W/m2K

Proposed building façade – Fusion block



U-value: 2.0 W/m2K

Proposed building façade – Lattice block



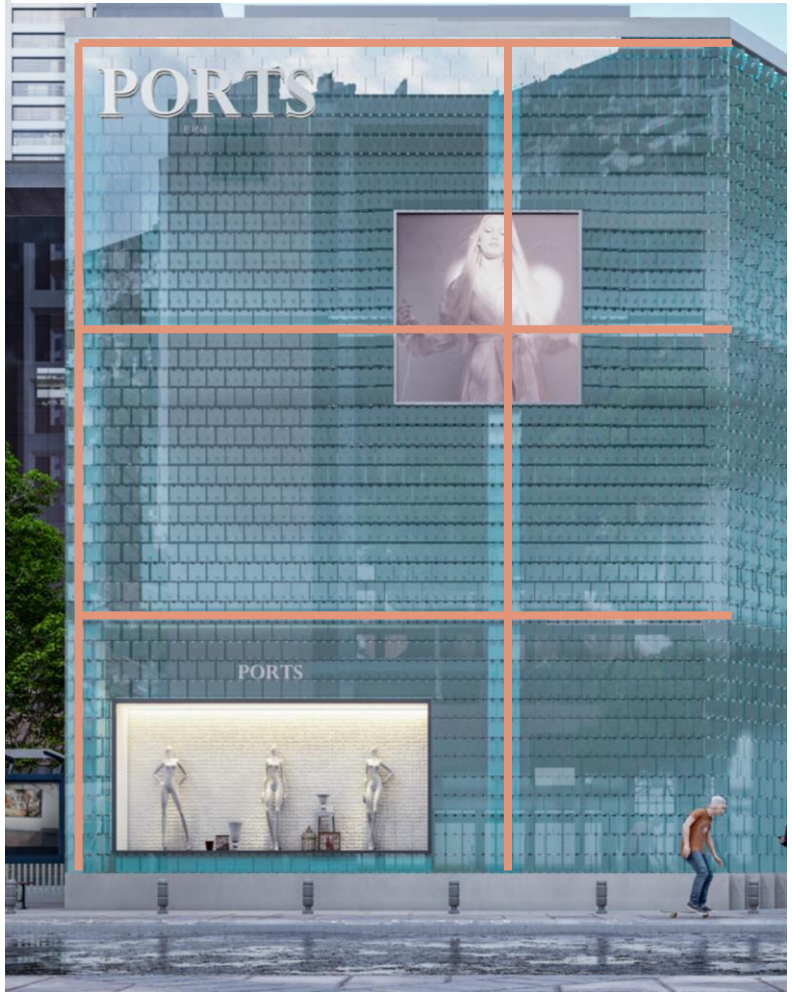
U-value: 1.9 W/m2K

COMPARATIVE ANALYSIS – Structural System

Existing building façade – hollow block

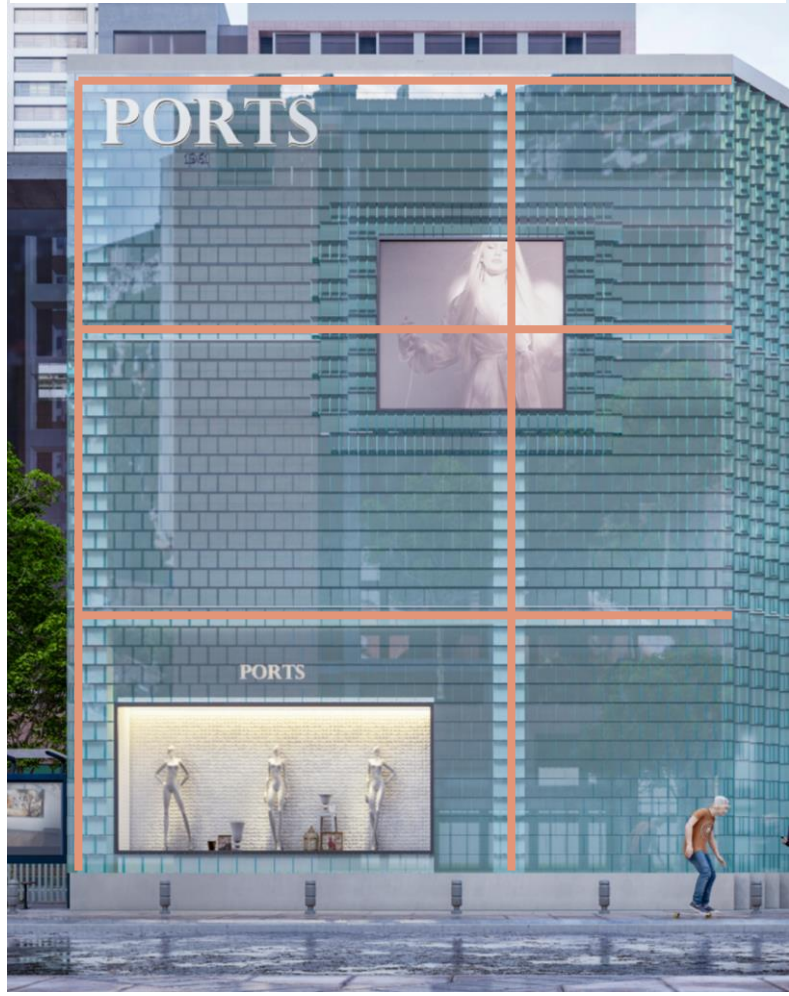
Substructure Required

Proposed building façade – Fusion block



No-substructure required

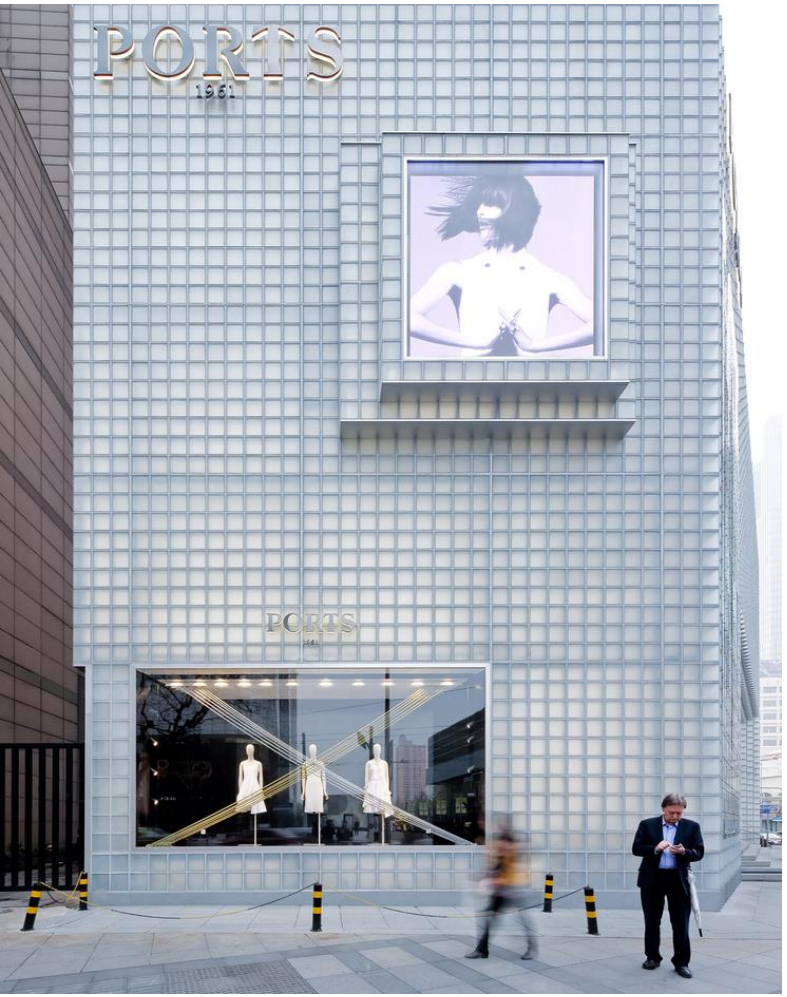
Proposed building façade – Lattice block



No substructure required

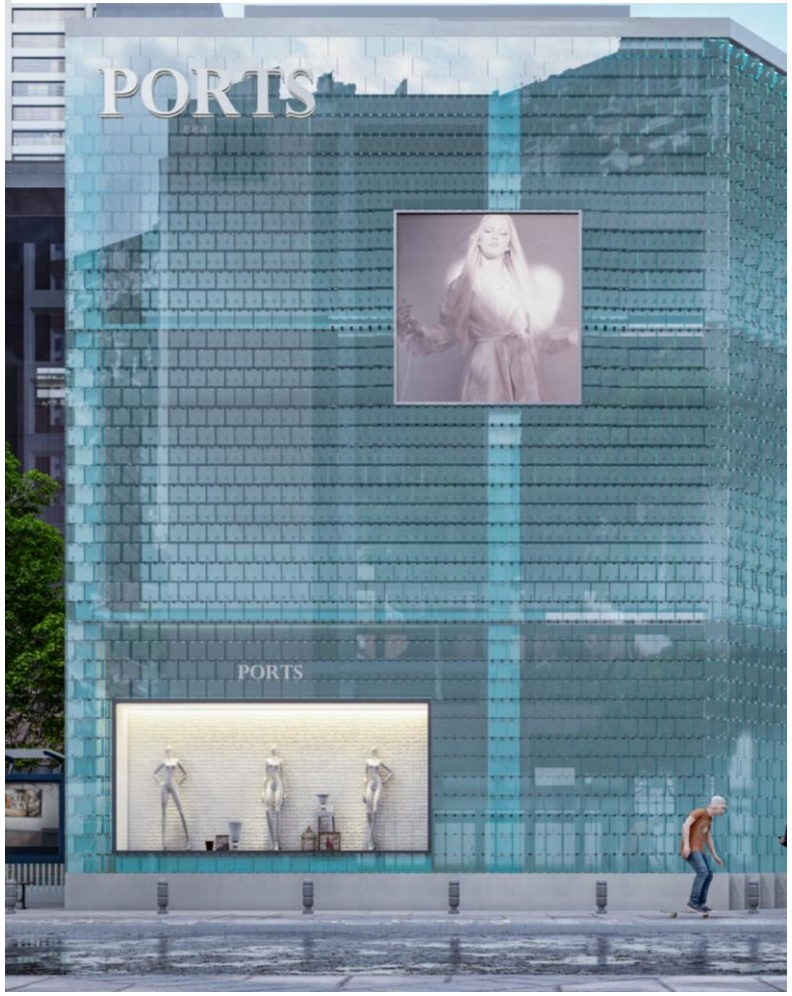
COMPARATIVE ANALYSIS – Fabrication

Existing building façade – hollow block



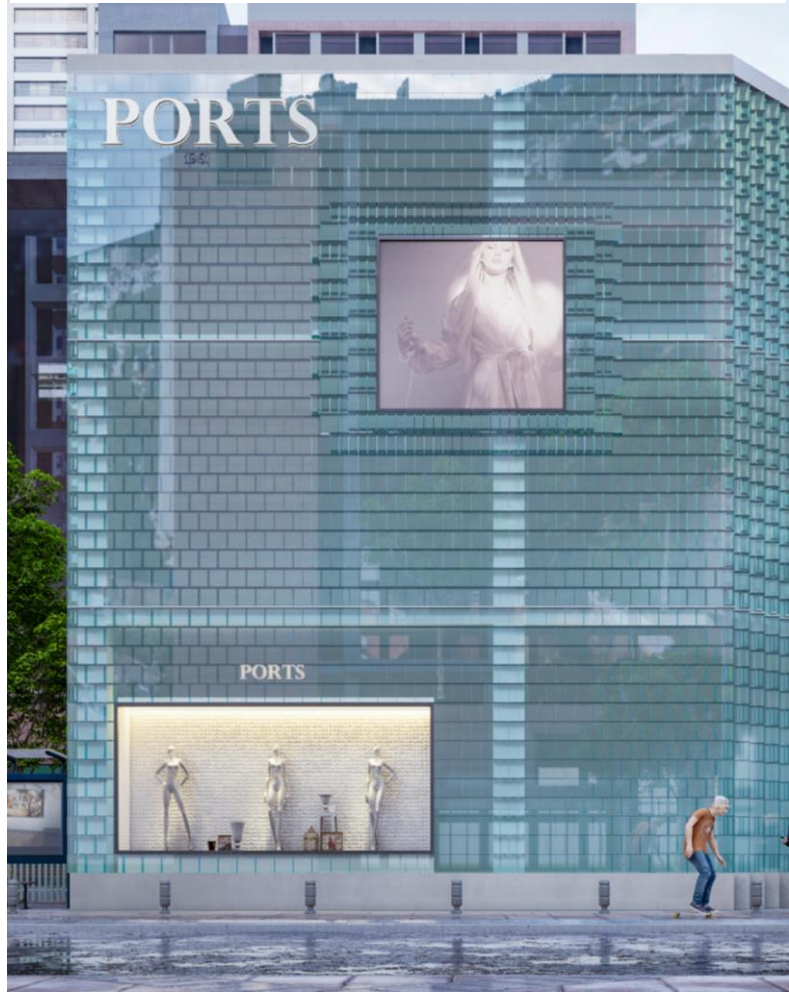
Block weight: 3- 5kgs

Proposed building façade – Fusion block



Block weight: 16kgs

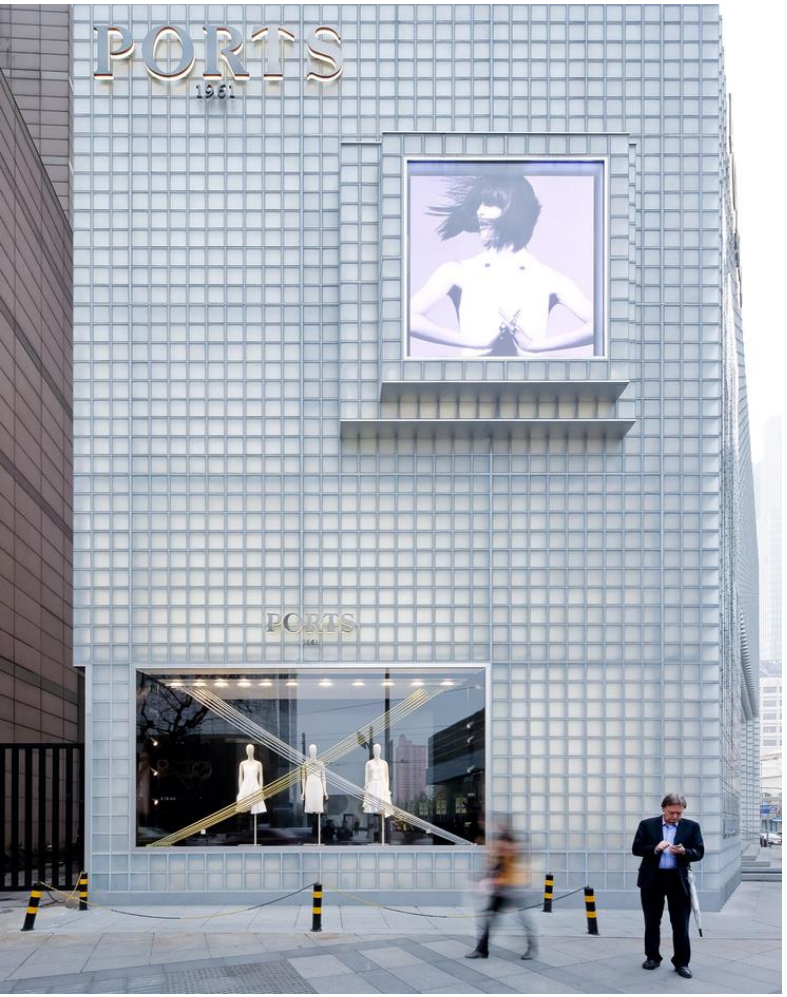
Proposed building façade – Lattice block



Block weight: 16kgs

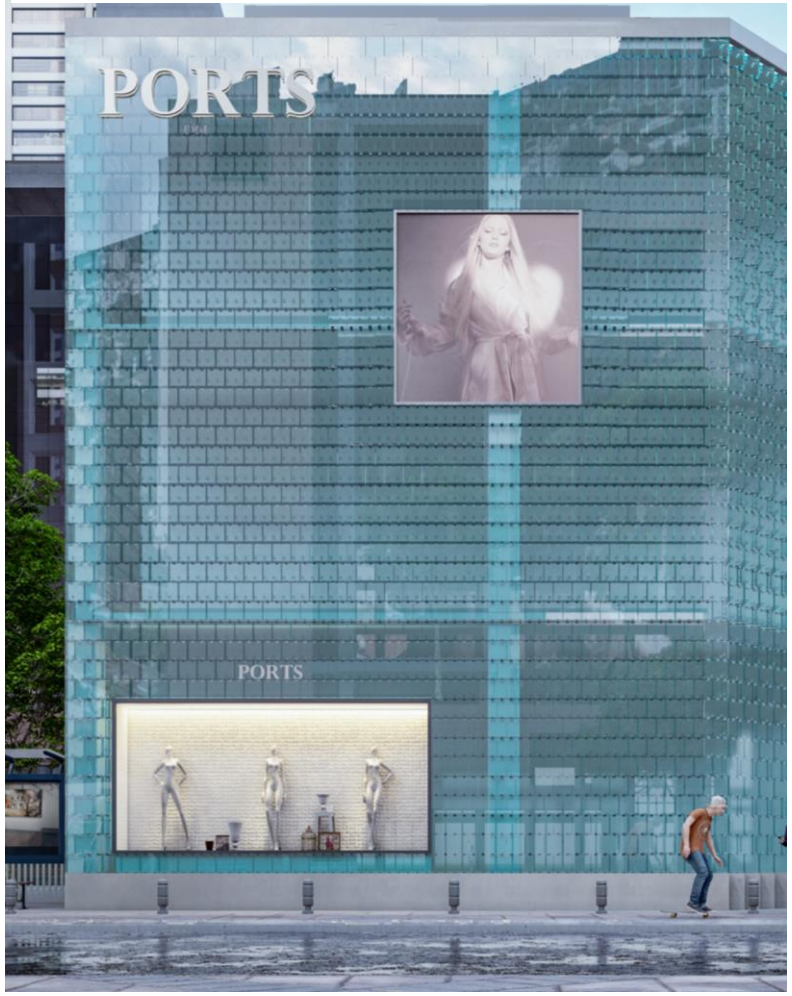
COMPARATIVE ANALYSIS – Assembly

Existing building façade – hollow block



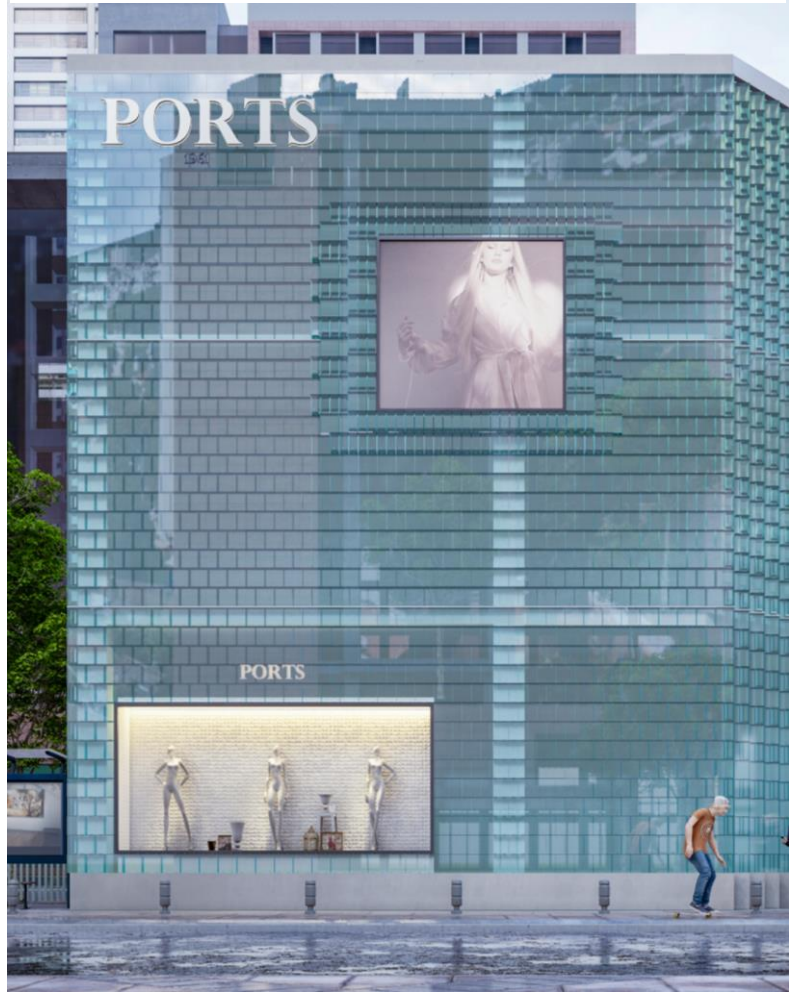
Metal substructure with mortar
Non-reversible

Proposed building façade – Fusion block



Load-bearing with embedded steel connection
Dry-stack and Reversible

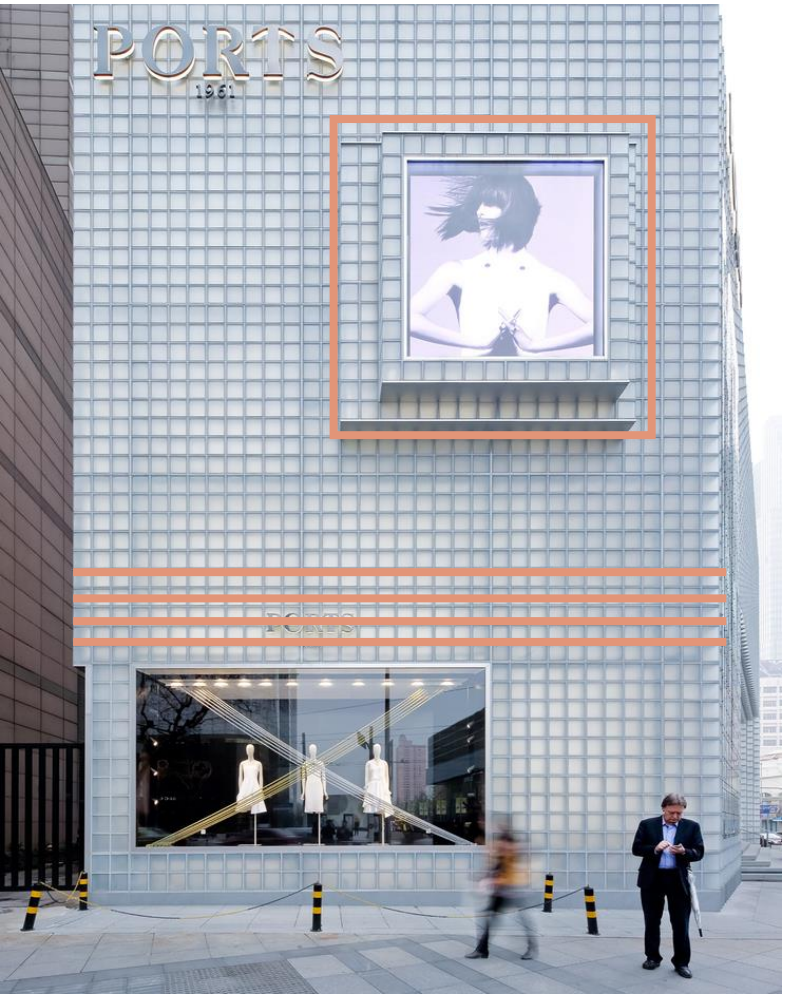
Proposed building façade – Lattice block



Load-bearing with interlocking connection
Dry stack and Reversible

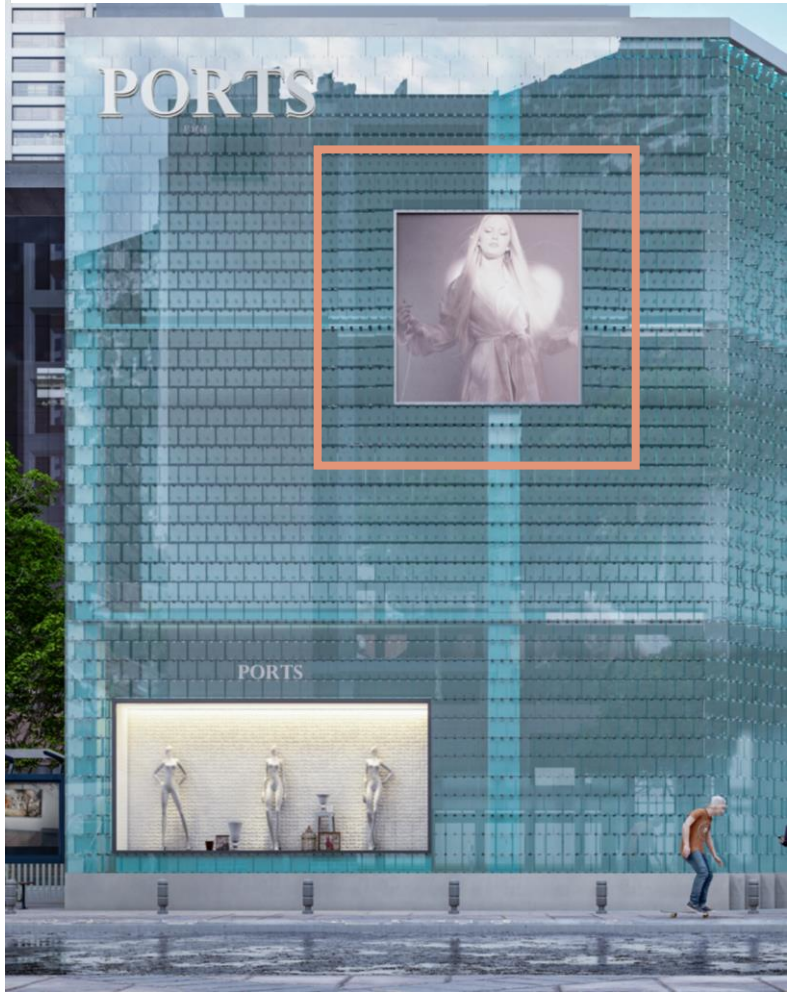
COMPARATIVE ANALYSIS – Aesthetical qualities

Existing building façade – hollow block



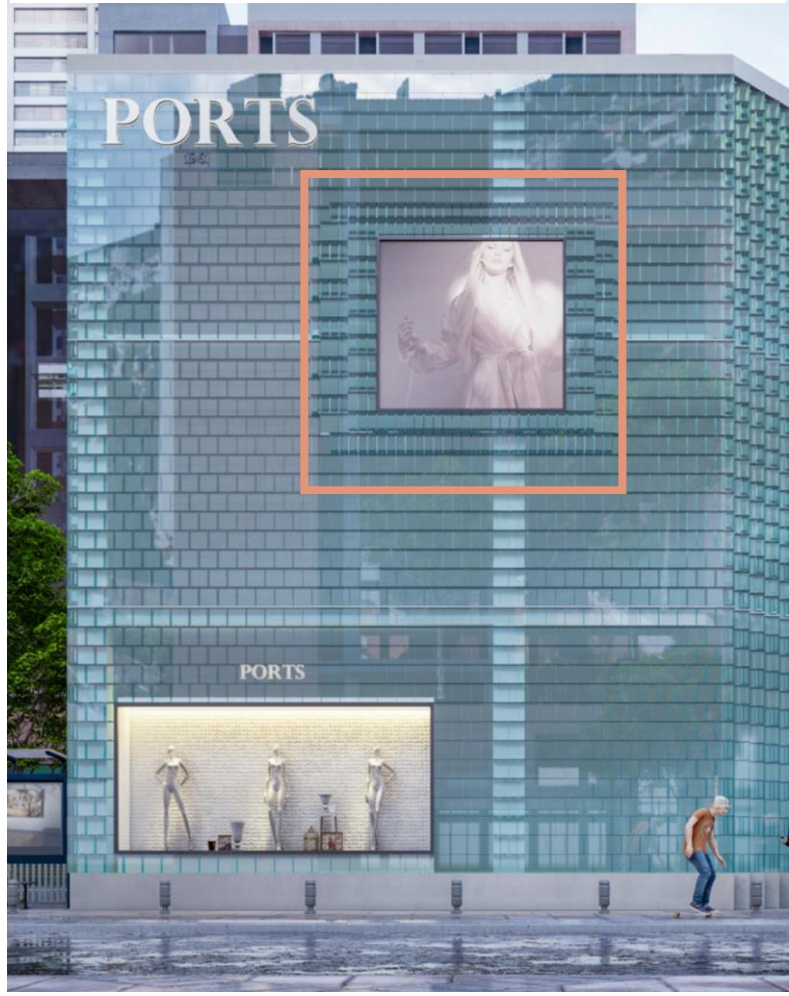
Non-transparent
Heavy with thick mortar lines

Proposed building façade – Fusion block



Transparent
Fluid

Proposed building façade – Lattice block



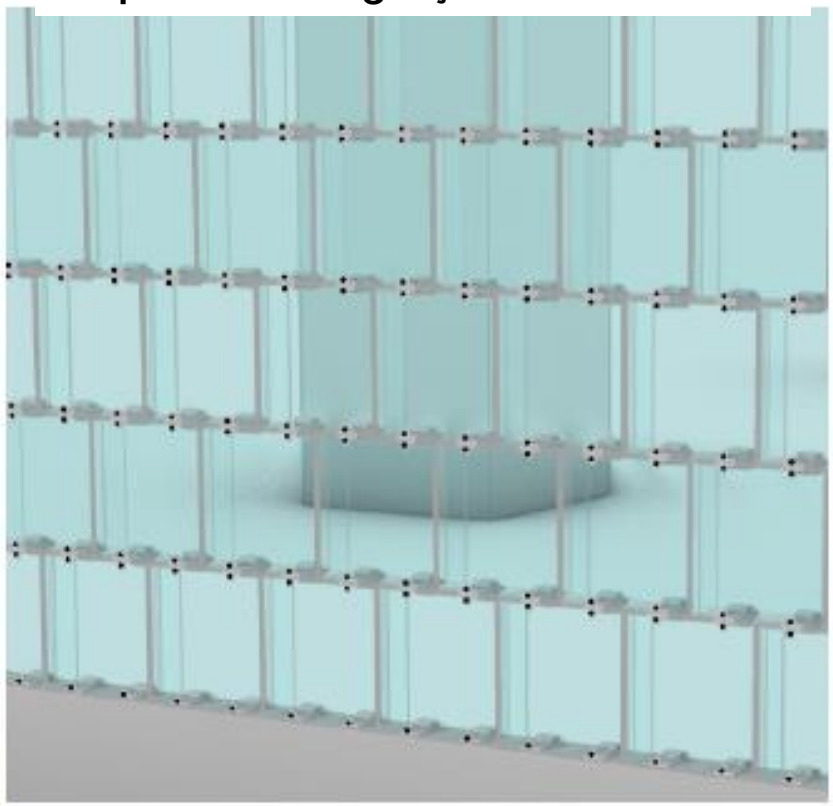
Transparent
Fluid

COMPARATIVE ANALYSIS – Optical Quality

Existing building façade – hollow block

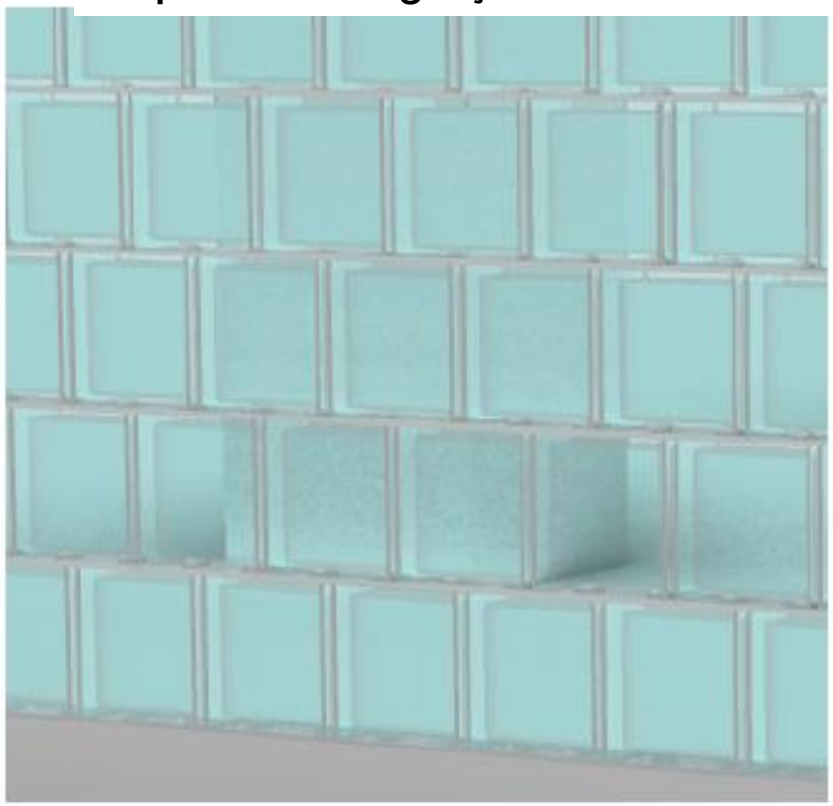
Non-transparent

Proposed building façade – Fusion block

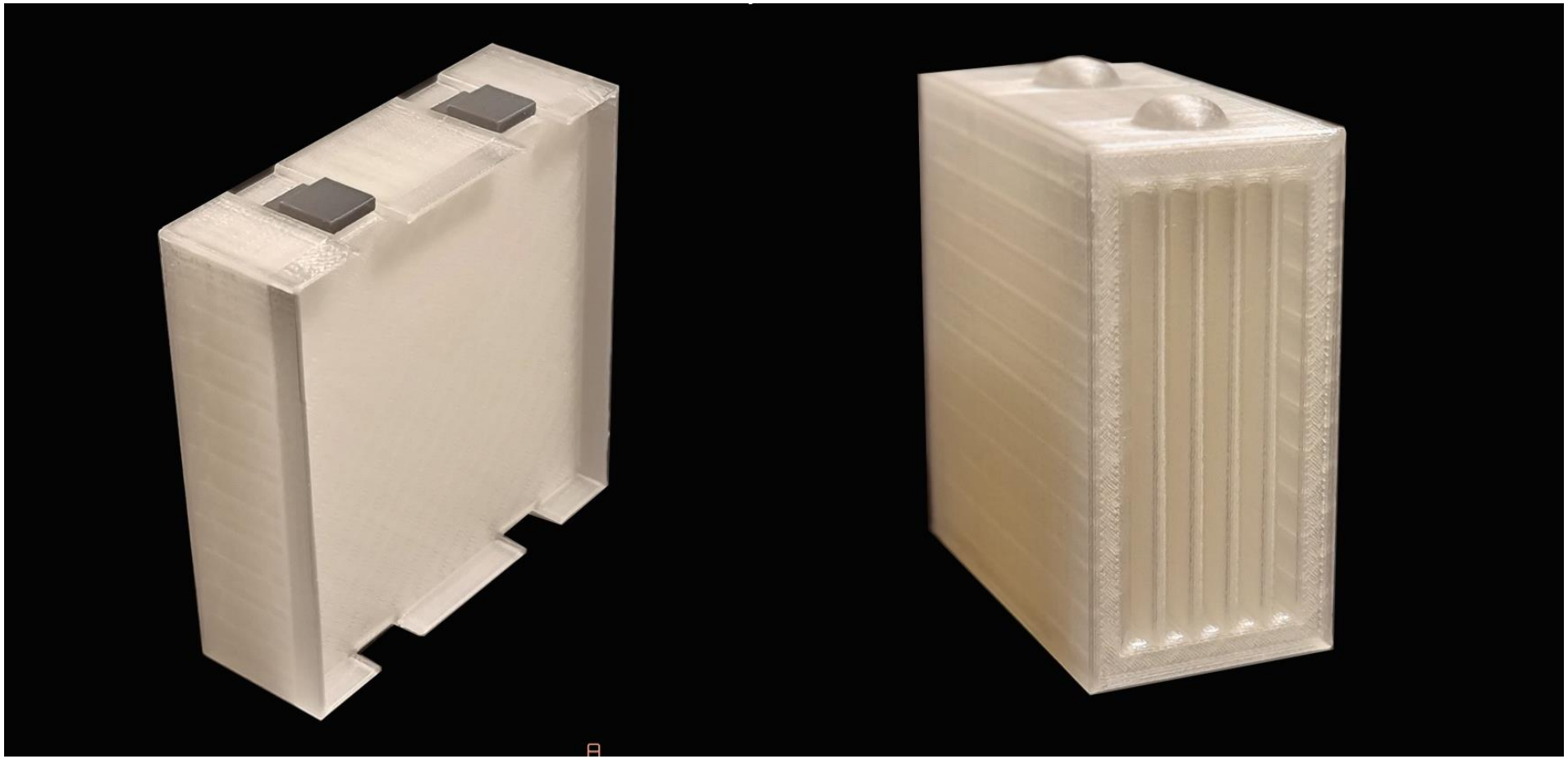


Transparent

Proposed building façade – Lattice block



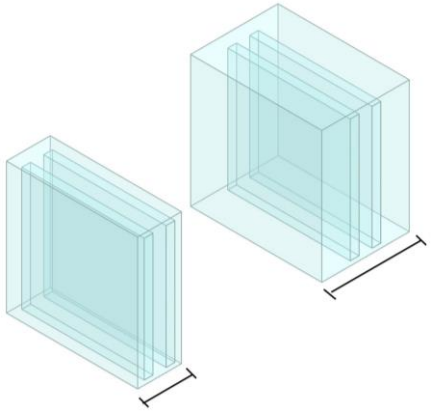
Transparent



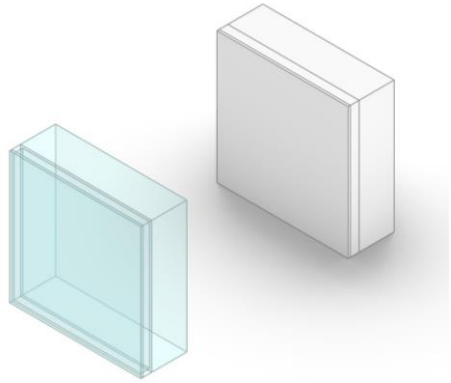
The present research concludes in two concepts that are then detailed to be applied in an existing scenario. The blocks exhibit good thermal properties (2 W/m2K) as well as a stable assembly system.

FACTORS AFFECTING THERMAL PERFORMANCE

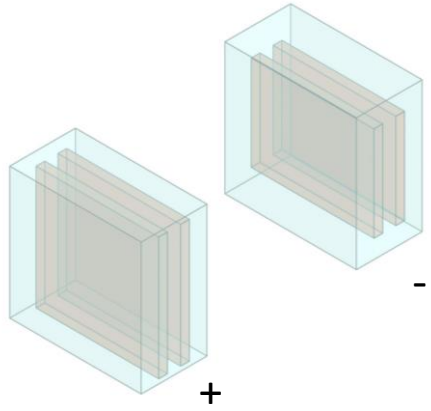
Size and Geometry



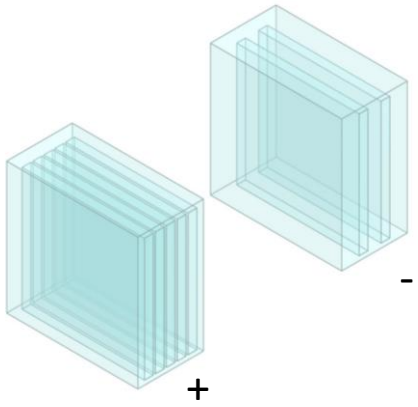
Material Properties



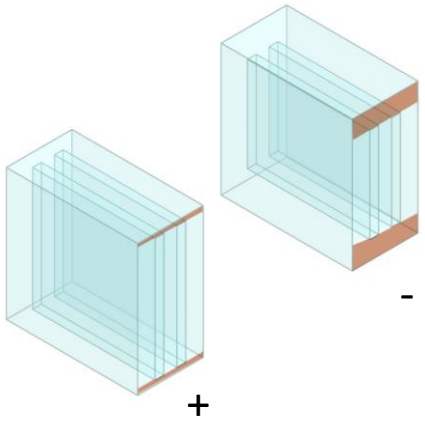
Size of cavities



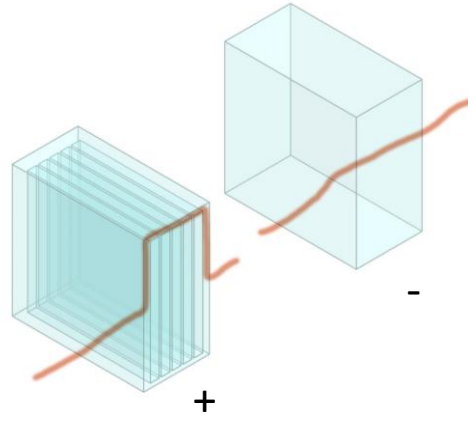
Number of Cavities



Thermal bridges

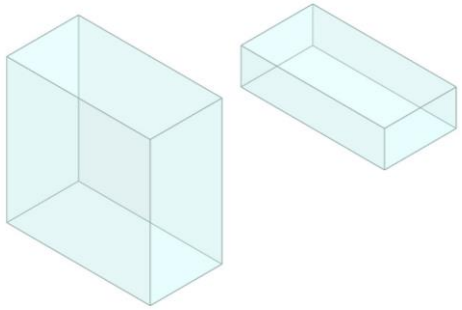


Path length of heat flows

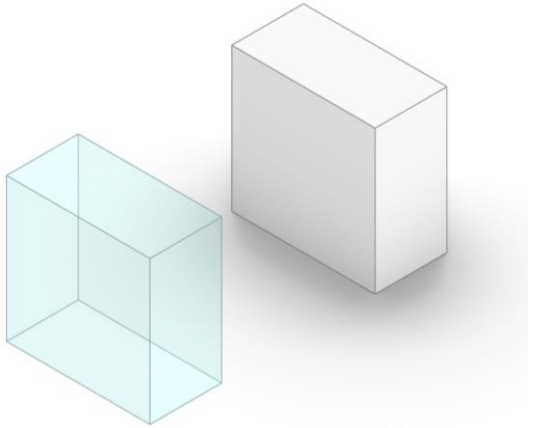


FACTORS AFFECTING FABRICATION

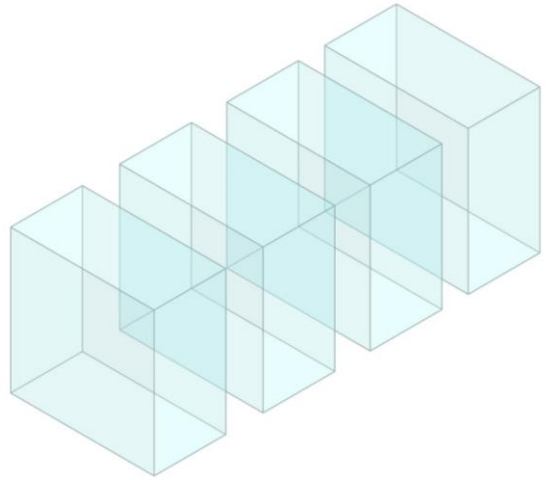
Size and Geometry



Material used



Amount of material

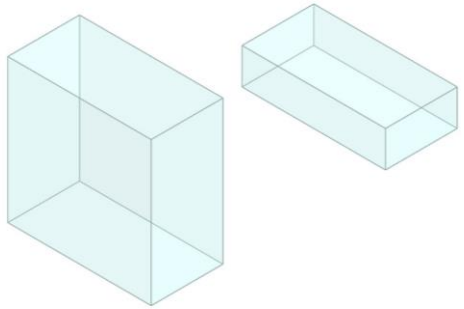


Cost

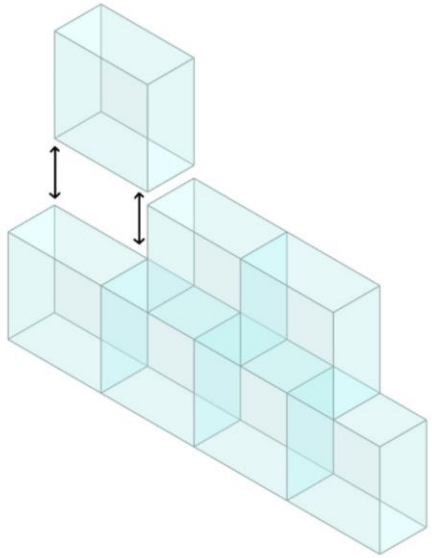
Time required

FACTORS AFFECTING BUILDABILITY

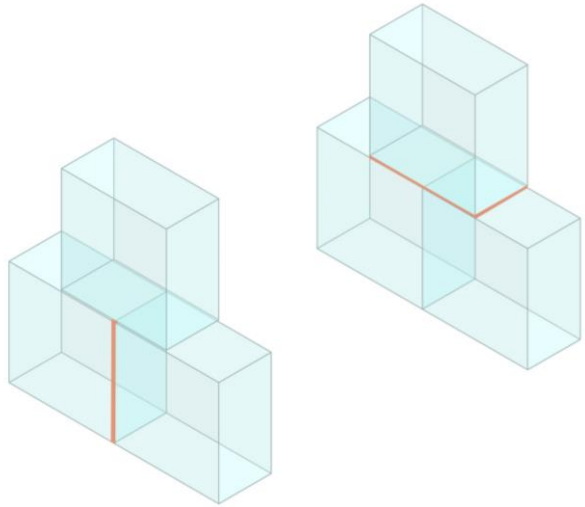
Size and Geometry



Connection system



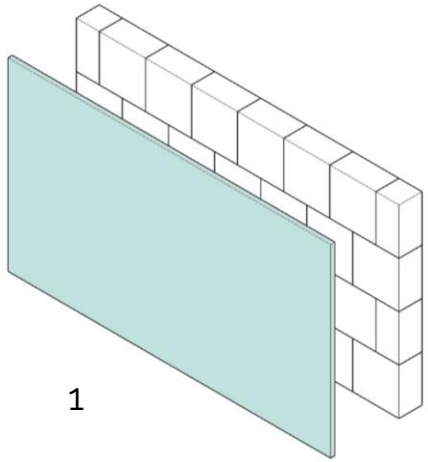
Tolerances



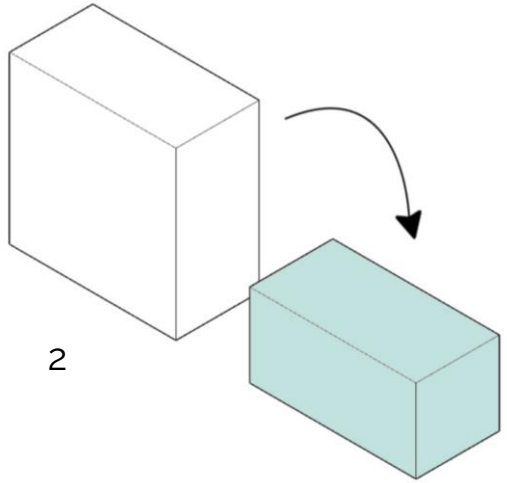
Assembly process

Durability

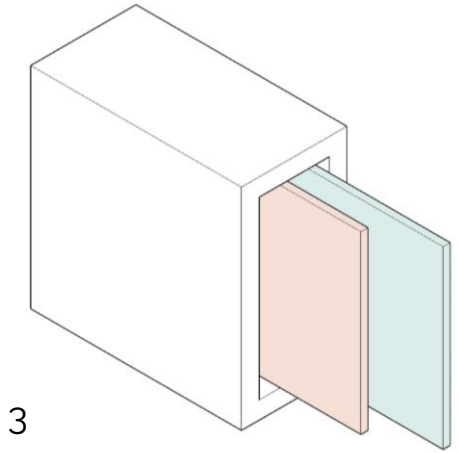
FURTHER RECOMMENDATIONS



A cavity wall between solid cast glass bricks and float glass



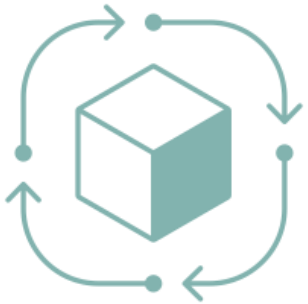
A more standardized size of block



Effect of different colors and textures of glass on dispersion of light and varying degrees of transparency.

FURTHER RECOMMENDATIONS

4



Life cycle assessment of the two blocks

5

Validation with experiments

6

Investigation of fire safety and acoustics

Thank You!

Student
Twinkle Nathani | Building Technology
5069041

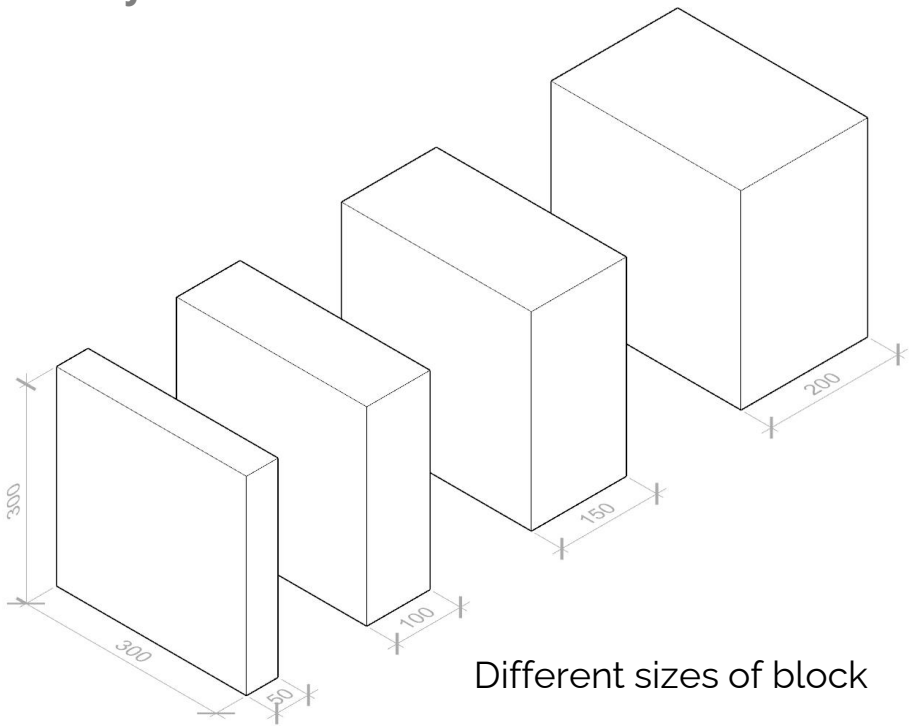
Comparison

Glass Block Type	Hollow Block	Solid Block		
	Seves (HTI WAVE) & Pittsburgh Corning (Thickset 90 VUE)	Seves (VISTABRICK) & Pittsburgh Corning (VISTABRICK)		
Properties				
U-Value	1.8 - 2.5 W/m2K	4.1 - 4.9 W/M2k		
Compressive Strength	3 - 6 MPa	82 - 400 MPa		
Light Transmission	70 - 76 %	60 - 90 %		
SHGC	0.32 - 0.68	0.52 - 0.78		
Sound	43 - 50 STC	43 - 50 STC		
Manufacturing				
		Crystal House	Atocha Memorial	Optical House
Process	Casting, Fusing and Annealing	Casting		
Glass Type	Soda-lime	Soda Lime	Borosilicate	Borosilicate
Mould Used	Pressed Steel Mould	Open Steel Mould	Pressed Steel Mould	Pressed Steel Mould
Annealing time	unknown	8 - 38 h (size dependant)	20 h	unknown
Installation				
System	Metal substructure with mortar	Adhesive bonded bricks	Adhesive bonded bricks	Metal substructure

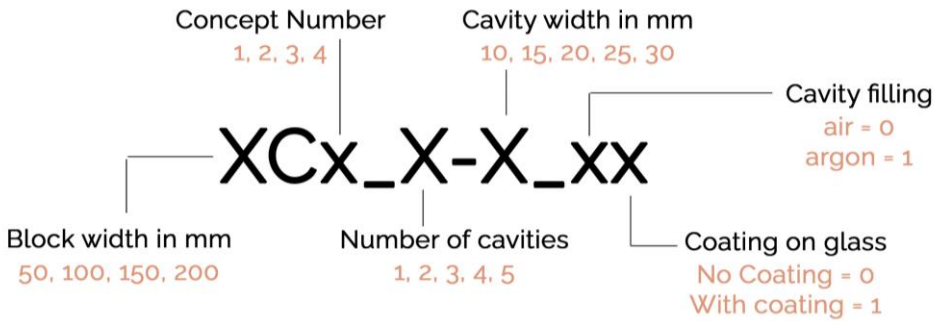
Difference in properties

Similar properties

Boundary Conditions



Different sizes of block



Naming Criteria

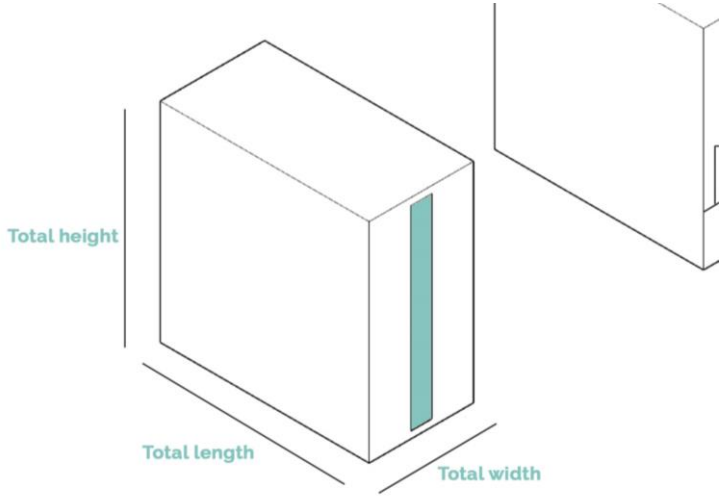
Cavity Width	Cavity Filling	Thermal Conductivity (W/mK)	
		No Coating	With Coating
10 mm	Air	0.066	0.026
	Argon	0.056	0.016
15 mm	Air	0.088	0.028
	Argon	0.0789	0.018
20 mm	Air	0.1184	0.038
	Argon	0.105	0.025
25 mm	Air	0.1485	0.049
	Argon	0.131	0.032
30 mm	Air	0.1785	0.06
	Argon	0.158	0.04

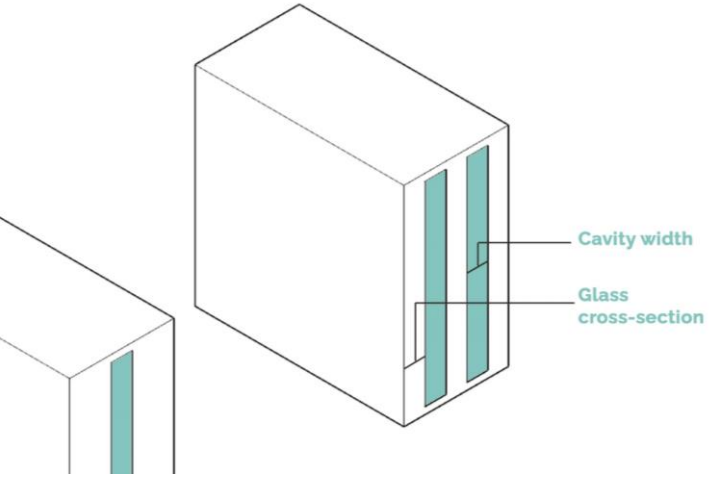
Table with thermal conductivity values

Standard Dutch values for a_i and a_e					
	α conduction	α convection	α radiation	α total	r
inside	0 W/m²K	2.3 W/m2K	5.5 W/m2K	7.8 W/m2K	0.13 W/m2K
outside	0 W/m2K	19.5 W/m2K	5.5 W/m2K	25 W/m2K	0.04 W/m2K
Temperature					
inside	20 °C				
outside	0 °C				
Glass properties					
Glass Type	conductivity	emissivity			
		with coating		without coating	
Borosilicate	1.0 W/mK	0.9		0.02	

Table with design inputs on TRISCO

Concept 1: Altering Cavities-
Single Cavity





STAGE 1

Cavity Width

	10mm	15mm	20mm	25mm	30mm
Block 50	3.33 W/m2K 50C1_1-10_00	3.22 W/m2K 50C1_1-15_00			
Block 100	2.86 W/m2K 100C1_1-10_00	2.79 W/m2K 100C1_1-15_00	2.78 W/m2K 100C1_1-20_00	2.77 W/m2K 100C1_1-25_00	2.77 W/m2K 100C1_1-30_00
Block 150	2.51 W/m2K 150C1_1-10_00	2.46 W/m2K 150C1_1-15_00	2.45 W/m2K 150C1_1-20_00	2.44 W/m2K 150C1_1-25_00	2.44 W/m2K 150C1_1-30_00
Block 200	2.23 W/m2K 200C1_1-10_00	2.18 W/m2K 200C1_1-15_00	2.18 W/m2K 200C1_1-20_00	2.17 W/m2K 200C1_1-25_00	2.17 W/m2K 200C1_1-30_00

STAGE 2

Cavity Width 15mm

3.14 W/m2K
50C1_1-15_10

Cavity Width

	25mm	30mm
Block 100	2.70 W/m2K 100C1_1-25_10	2.70 W/m2K 100C1_1-30_10
Block 150	2.38 W/m2K 150C1_1-25_10	2.38 W/m2K 150C1_1-30_10
Block 200	2.13 W/m2K 200C1_1-25_10	2.13 W/m2K 200C1_1-30_10

STAGE 3

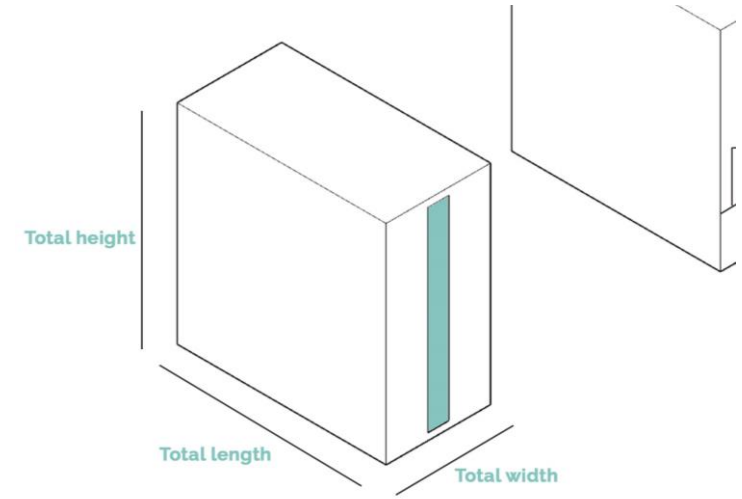
Cavity Width 15mm

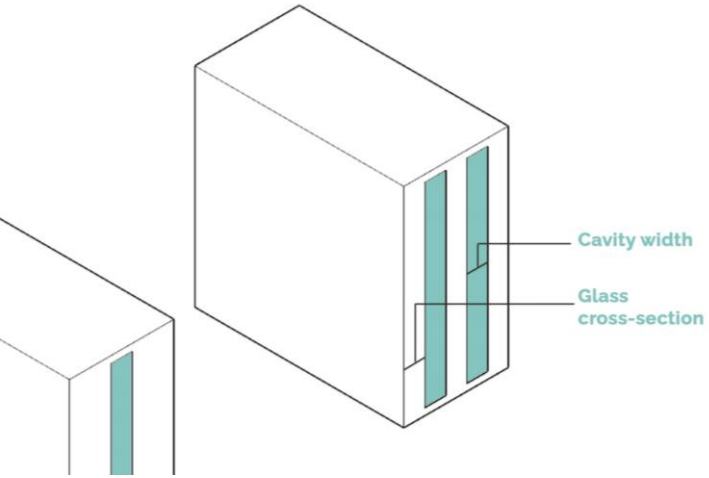
	Air cavity	Argon cavity
	2.50 W/m2K 50C1_1-15_01	2.31 W/m2K 50C1_1-15_11

Cavity Width 25mm

Block 100	2.17 W/m2K 100C1_1-25_01	2.0 W/m2K 100C1_1-30_11
Block 150	1.96 W/m2K 150C1_1-25_01	1.83 W/m2K 150C1_1-30_11
Block 200	1.79 W/m2K 200C1_1-25_01	1.68 W/m2K 200C1_1-30_11

Concept 1: Altering Cavities - Double Cavity





STAGE 1

Cavity Width

	10mm	15mm	20mm	25mm	30mm
Block 50	2.704 W/m2K 50C1_2-10_00				
Block 100	2.38 W/m2K 100C1_2-10_00	2.27 W/m2K 100C1_2-15_00	2.26 W/m2K 100C1_2-20_00		
Block 150	2.11 W/m2K 150C1_2-10_00	2.03 W/m2K 150C1_2-15_00	2.02 W/m2K 150C1_2-20_00		
Block 200	1.91 W/m2K 200C1_2-10_00	1.84 W/m2K 200C1_2-15_00	1.83 W/m2K 200C1_2-20_00	1.82 W/m2K 200C1_2-25_00	1.82 W/m2K 200C1_2-30_00

STAGE 2

Cavity Width

	10mm	15mm
		2.58 W/m2K 50C1_2-10_10
	2.22 W/m2K 100C1_2-10_10	2.20 W/m2K 100C1_2-15_10
	2.01 W/m2K 150C1_2-10_10	1.98 W/m2K 150C1_1-15_10

Cavity Width

	20mm	25mm
	1.77 W/m2K 200C1_2-20_10	1.76 W/m2K 200C1_2-25_10

STAGE 3

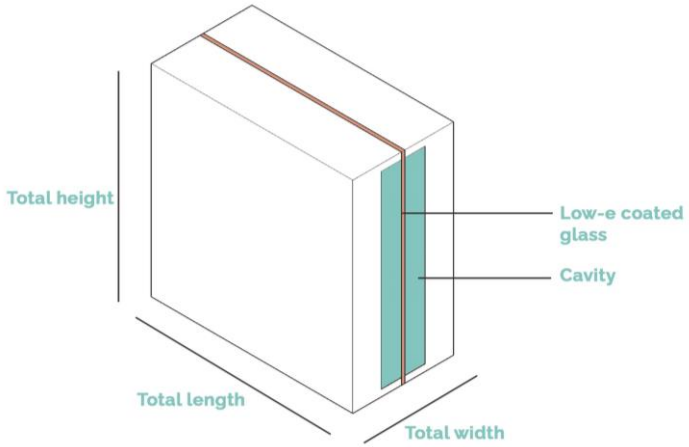
Cavity Width 10mm

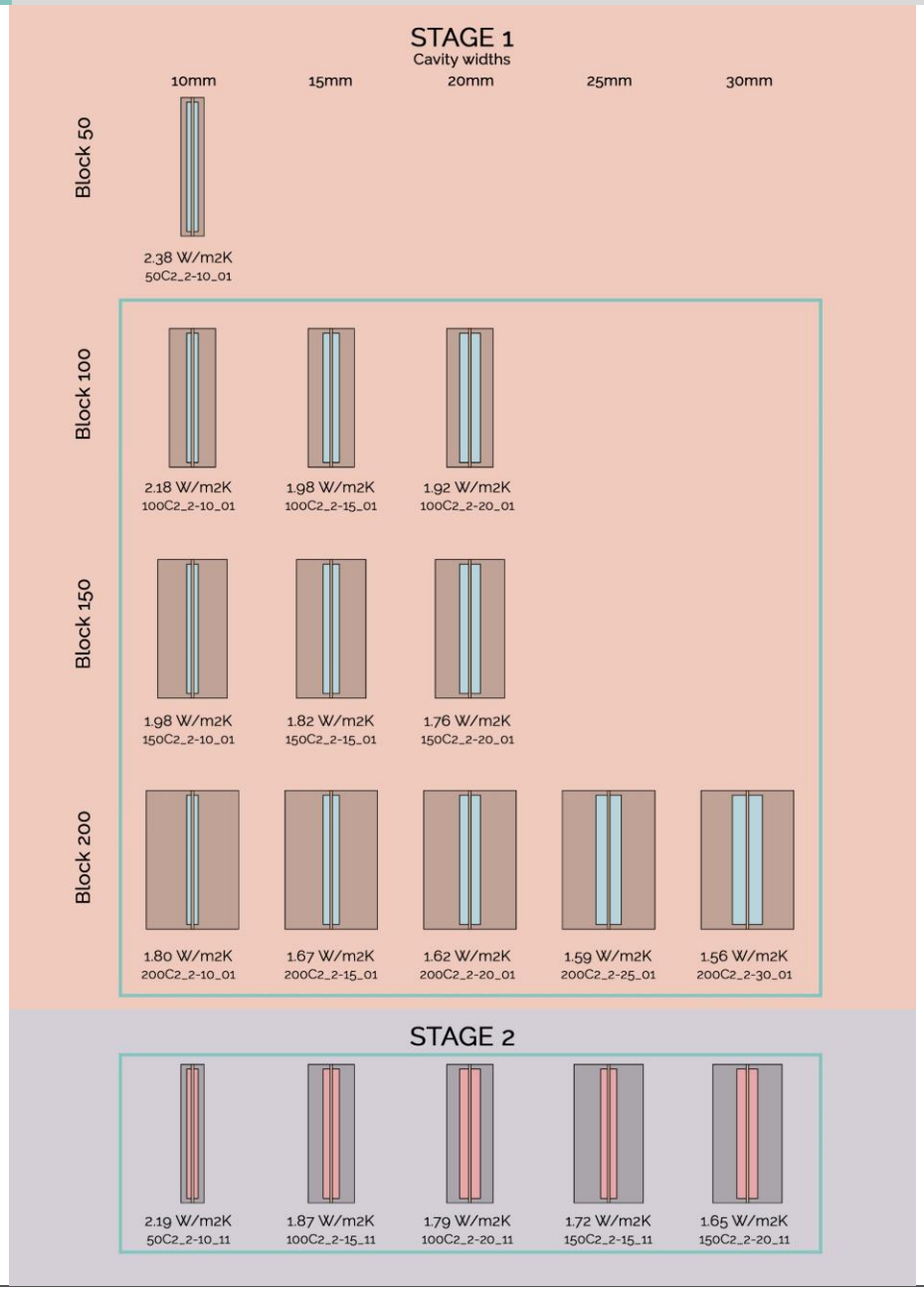
	Air cavity	Argon cavity
	2.13 W/m2K 50C1_2-10_01	1.93 W/m2K 50C1_2-10_11
	1.92 W/m2K 100C1_2-10_01	1.76 W/m2K 100C1_2-10_11
	1.73 W/m2K 150C1_2-10_01	1.60 W/m2K 150C1_2-10_11

Cavity Width 20mm

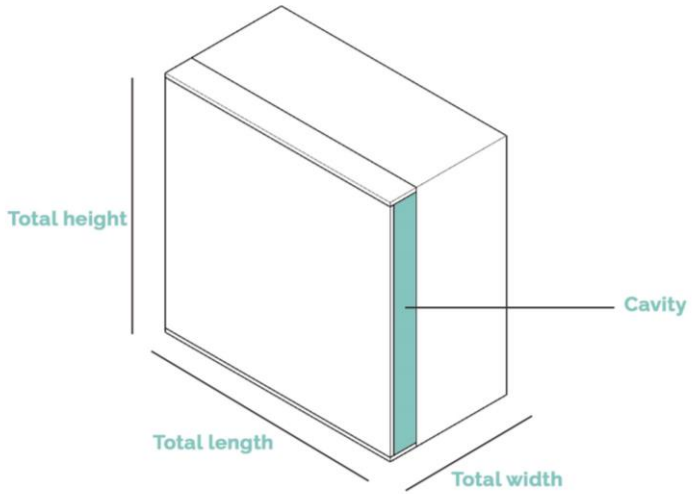
	1.39 W/m2K 200C1_2-20_01	1.29 W/m2K 200C1_2-20_11

Concept 2: Coated Glass in middle





Concept 3: Merging Hollow and Solid – Block 50mm



STAGE 1

Cavity Width

Hollow Glass Thickness

	10mm	15mm	20mm
2.5mm	2.89 W/m2K 2.5-50C3_1-10_00	2.74 W/m2K 2.5-50C3_1-15_00	2.72 W/m2K 2.5-50C3_1-20_00
5mm	2.98 W/m2K 5-50C3_1-10_00	2.84 W/m2K 5-50C3_1-15_00	2.80 W/m2K 5-50C3_1-20_00
10mm	3.10 W/m2K 10-50C3_1-10_00	2.96 W/m2K 10-50C3_1-15_00	2.92 W/m2K 10-50C3_1-20_00
15mm	3.16 W/m2K 15-50C3_1-10_00	3.03 W/m2K 15-50C3_1-15_00	2.98 W/m2K 15-50C3_1-20_00

STAGE 2

Cavity Width 15mm

2.64 W/m2K
2.5-50C3_1-15_10

Cavity Width 20mm

2.61 W/m2K
2.5-50C3_1-20_10

Cavity Width 20mm

2.71 W/m2K
5-50C3_1-20_10

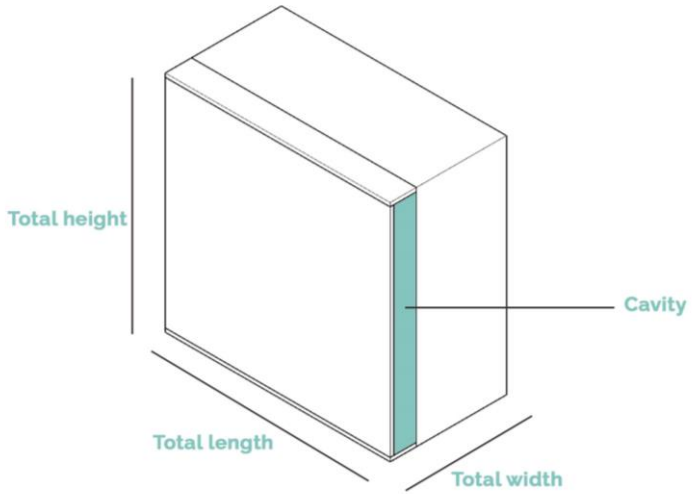
STAGE 3

Cavity Width 20mm

1.73 W/m2K
2.5-50C3_1-20_01
Air cavity

1.46 W/m2K
2.5-50C3_1-20_11
Argon cavity

Concept 3: Merging Hollow and Solid – Block 100mm



STAGE 1

Cavity Width

Hollow Glass Thickness	10mm	15mm	20mm	25mm	30mm
10mm	2.83 W/m2K 10-100C3_1-10_00	2.76 W/m2K 10-100C3_1-15_00	2.76 W/m2K 10-100C3_1-20_00	2.75 W/m2K 10-100C3_1-25_00	2.76 W/m2K 10-100C3_1-30_00
15mm	2.92 W/m2K 15-100C3_1-10_00	2.86 W/m2K 15-100C3_1-15_00	2.85 W/m2K 15-100C3_1-20_00	2.85 W/m2K 15-100C3_1-25_00	2.85 W/m2K 15-100C3_1-30_00
20mm	3.01 W/m2K 20-100C3_1-10_00	2.95 W/m2K 20-100C3_1-15_00	2.94 W/m2K 20-100C3_1-20_00	2.90 W/m2K 20-100C3_1-25_00	2.85 W/m2K 20-100C3_1-30_00
25mm	3.08 W/m2K 25-100C3_1-10_00	3.02 W/m2K 25-100C3_1-15_00	2.97 W/m2K 25-100C3_1-20_00	2.92 W/m2K 25-100C3_1-25_00	

STAGE 2

Cavity Width 10mm	2.75 W/m2K 10-100C3_1-10_10
Cavity Width 25mm	2.68 W/m2K 10-100C3_1-25_10
Cavity Width 30mm	2.64 W/m2K 10-100C3_1-30_10

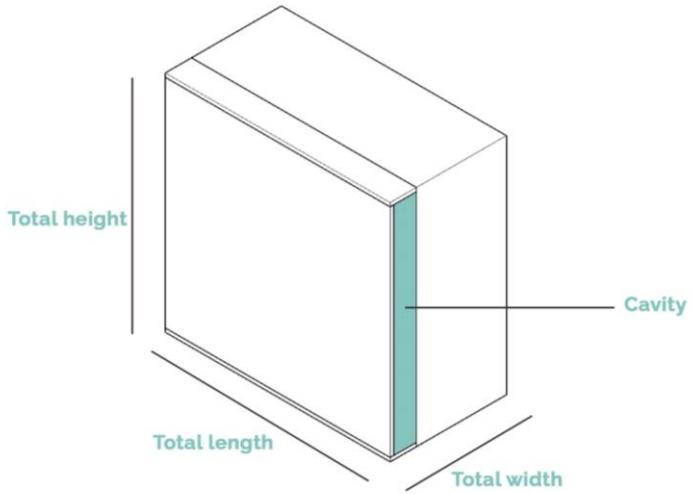
STAGE 3

Cavity Width 25mm

2.12 W/m2K
10-100C3_1-25_01
Air cavity

1.93 W/m2K
10-100C3_1-25_11
Argon cavity

Concept 3: Merging Hollow and Solid – Block 150mm



STAGE 1

Cavity Width

Hollow Glass Thickness	10mm	15mm	20mm	25mm	30mm
30mm			2.67 W/m2K 30-150C3_1-20_00	2.67 W/m2K 30-150C3_1-25_00	2.67 W/m2K 30-150C3_1-30_00
35mm		2.73 W/m2K 35-150C3_1-15_00	2.72 W/m2K 35-150C3_1-20_00	2.72 W/m2K 35-150C3_1-25_00	2.71 W/m2K 35-150C3_1-30_00
40mm	2.80 W/m2K 40-150C3_1-10_00	2.77 W/m2K 40-150C3_1-15_00	2.76 W/m2K 40-150C3_1-20_00	2.76 W/m2K 40-150C3_1-25_00	2.75 W/m2K 40-150C3_1-30_00
45mm	2.84 W/m2K 45-150C3_1-10_00	2.81 W/m2K 45-150C3_1-15_00	2.80 W/m2K 45-150C3_1-20_00	2.80 W/m2K 45-150C3_1-25_00	2.80 W/m2K 45-150C3_1-30_00

STAGE 2

Cavity Width 20mm

2.64 W/m2K
30-150C3_1-20_10

Cavity Width 25mm

2.64 W/m2K
30-150C3_1-25_10

Cavity Width 30mm

2.63 W/m2K
30-150C3_1-30_10

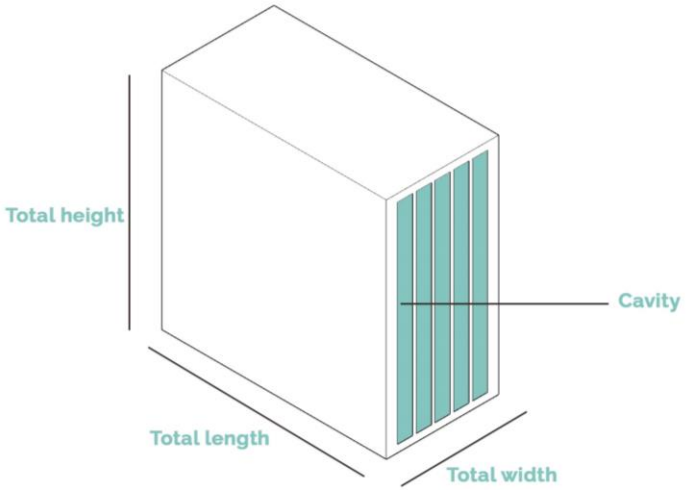
STAGE 3

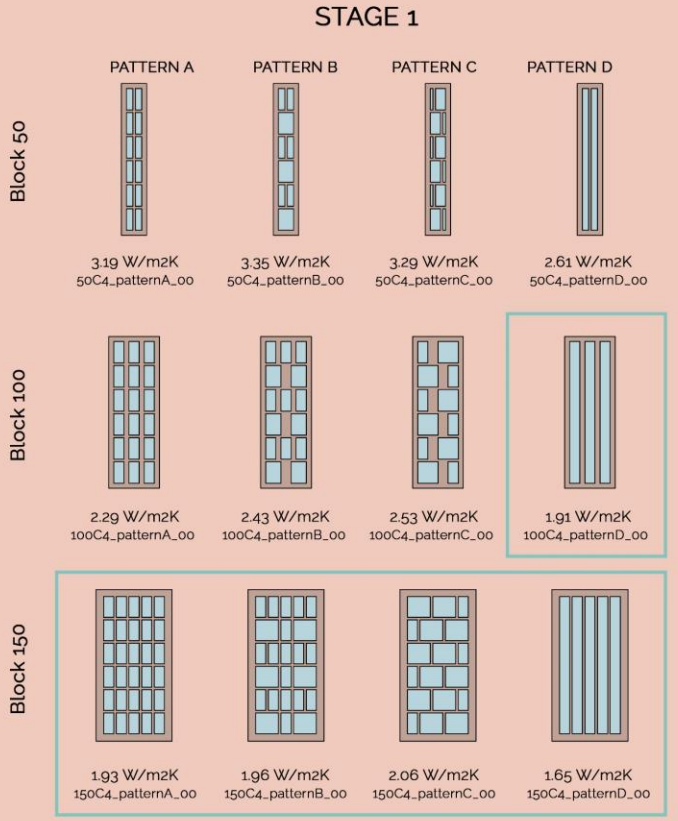
Cavity Width 30mm

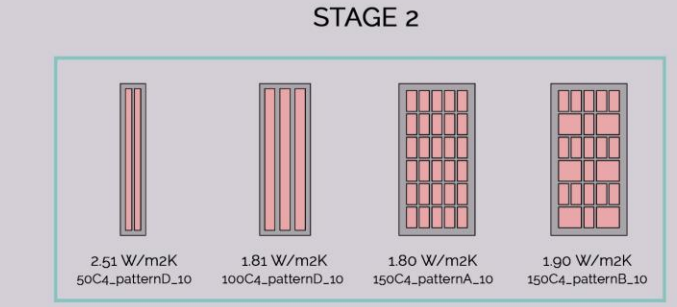
2.38 W/m2K
30-150C3_1-30_01
Air cavity

2.31 W/m2K
30-150C3_1-30_11
Argon cavity

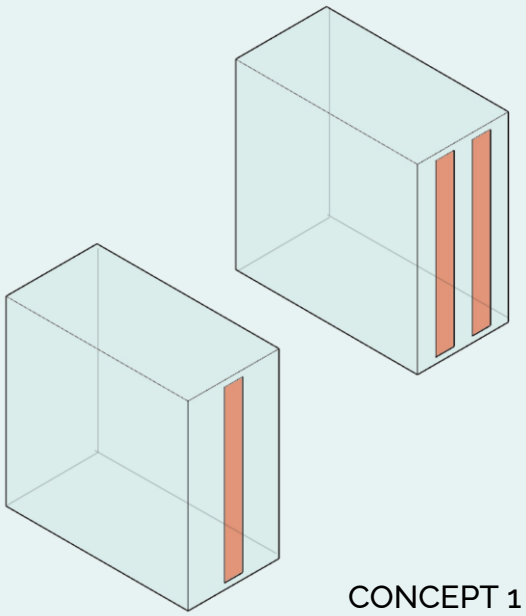
Concept 4: Honeycomb Block



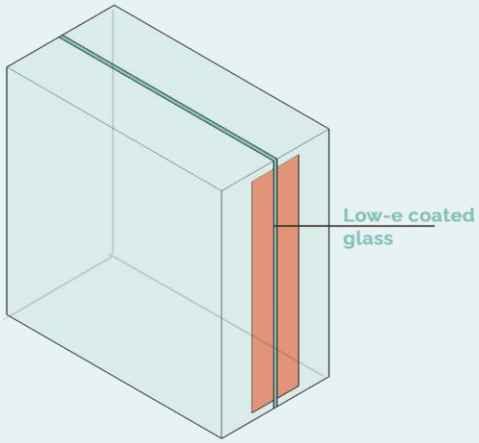




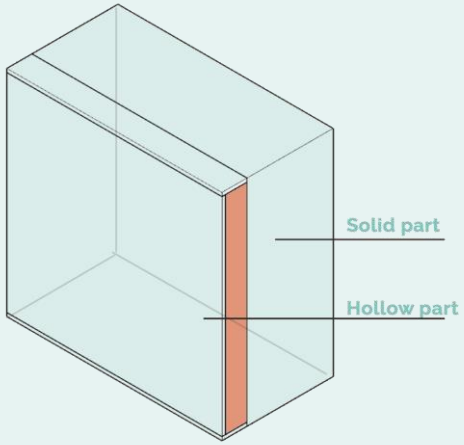
Concepts



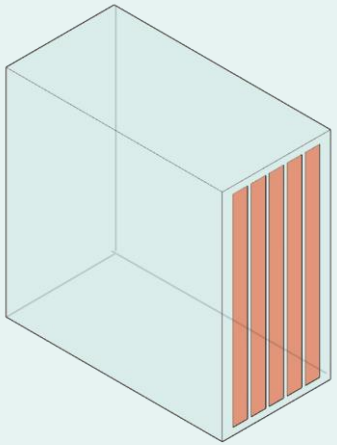
CONCEPT 1



CONCEPT 2

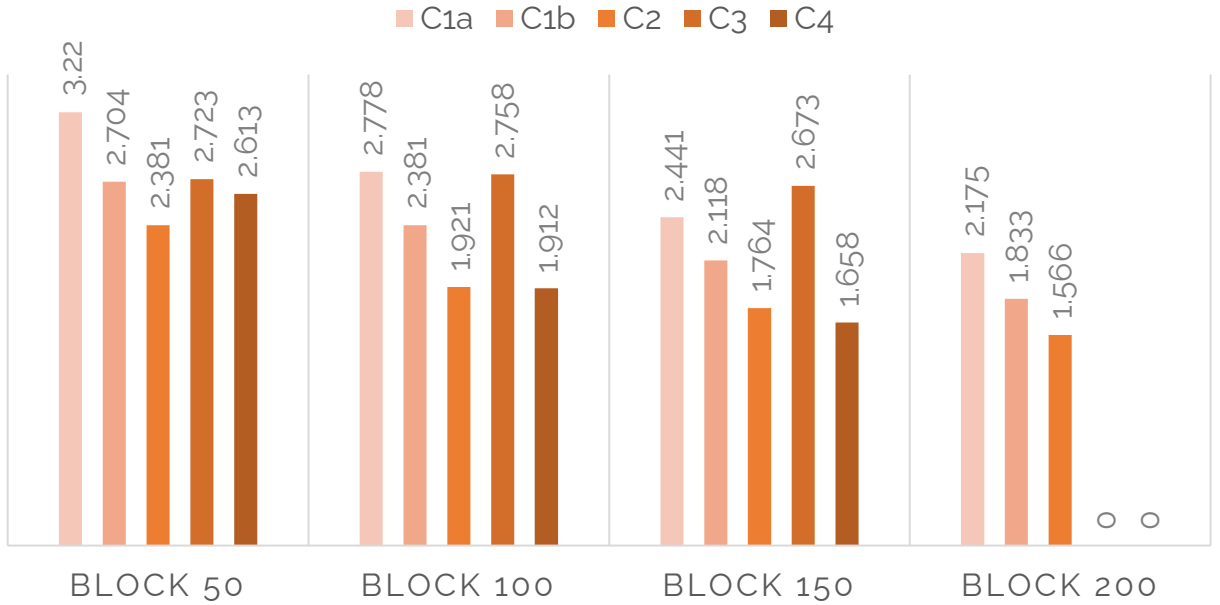


CONCEPT 3



CONCEPT 4

COMPARISON OF DIFFERENT CONCEPTS



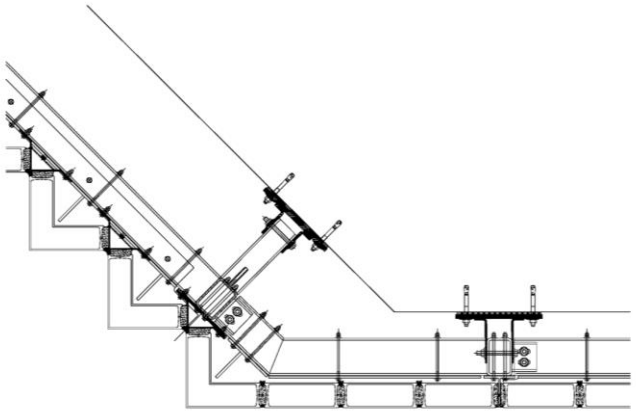
Note: All dimensions are in mm. All U-Values are in W/m2K.

Case Study – Ports 1961, Shanghai – UUFIE

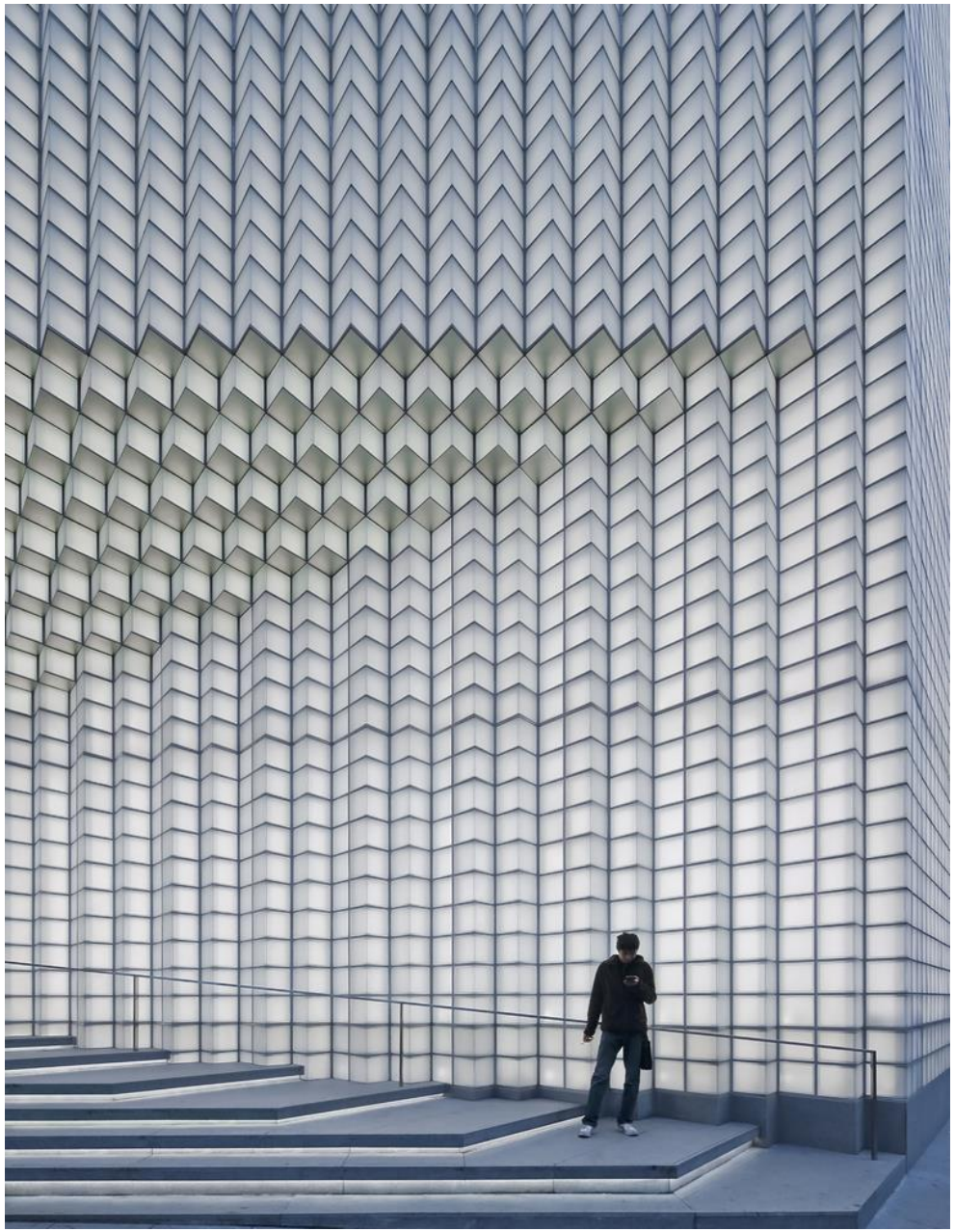
Two types of Satin finished Glass block:

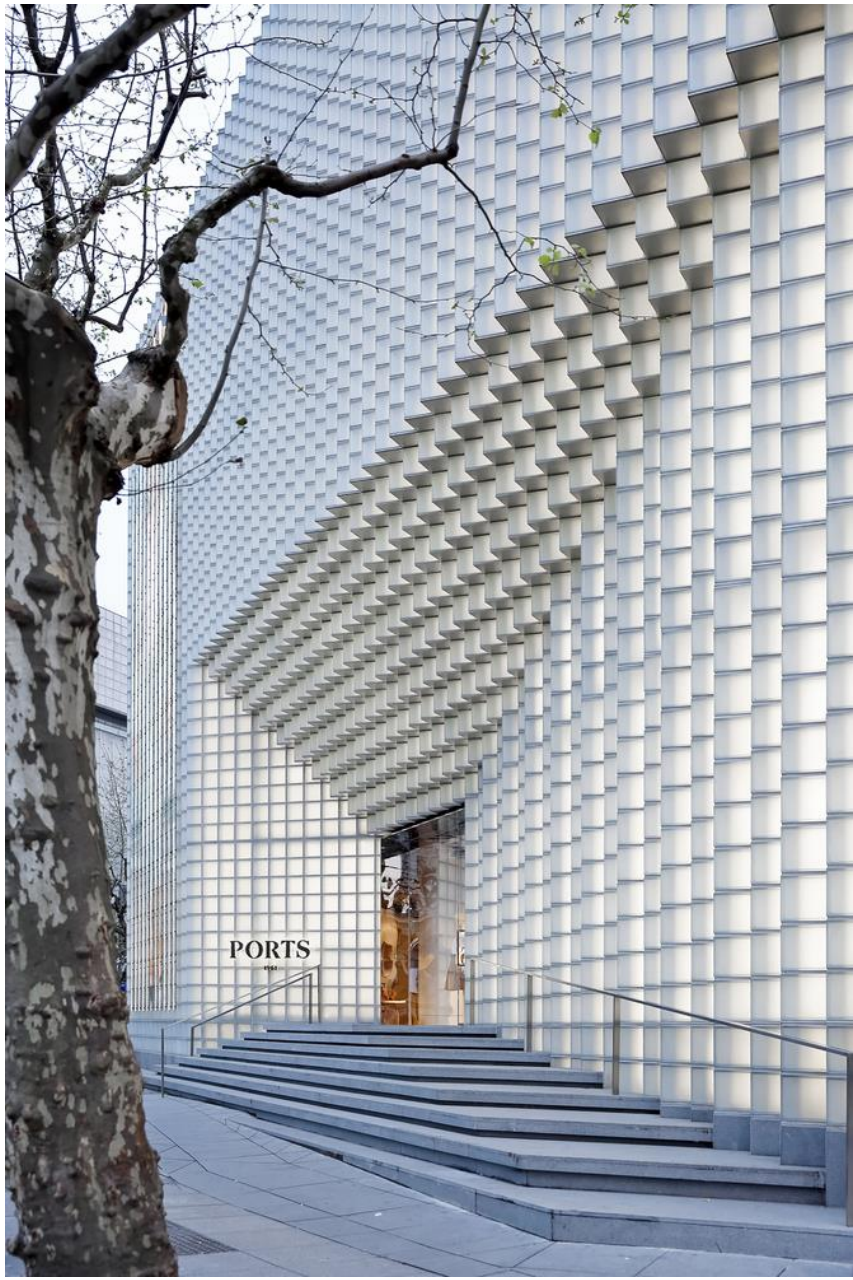
- Standard square block of 300mm x 300mm
- Custom mitered block of 300mm x 300mm

This custom block is used in the corners to create a corbelled façade.

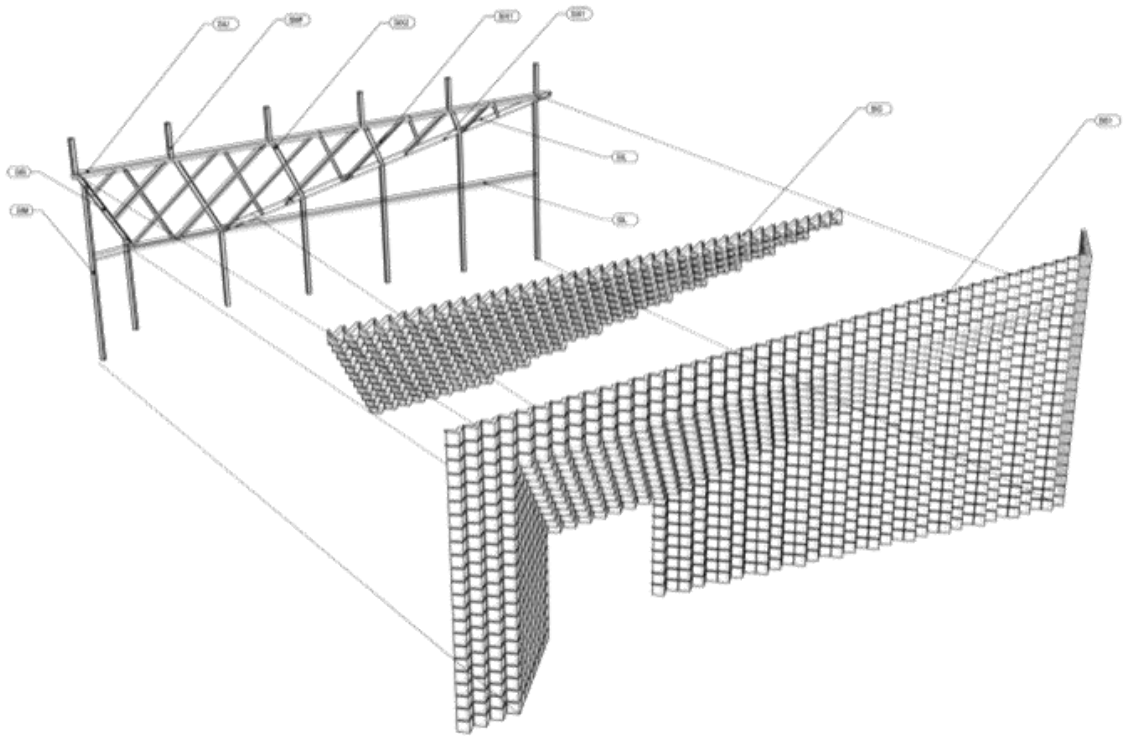


Façade detail in Plan (Castro, 2015)

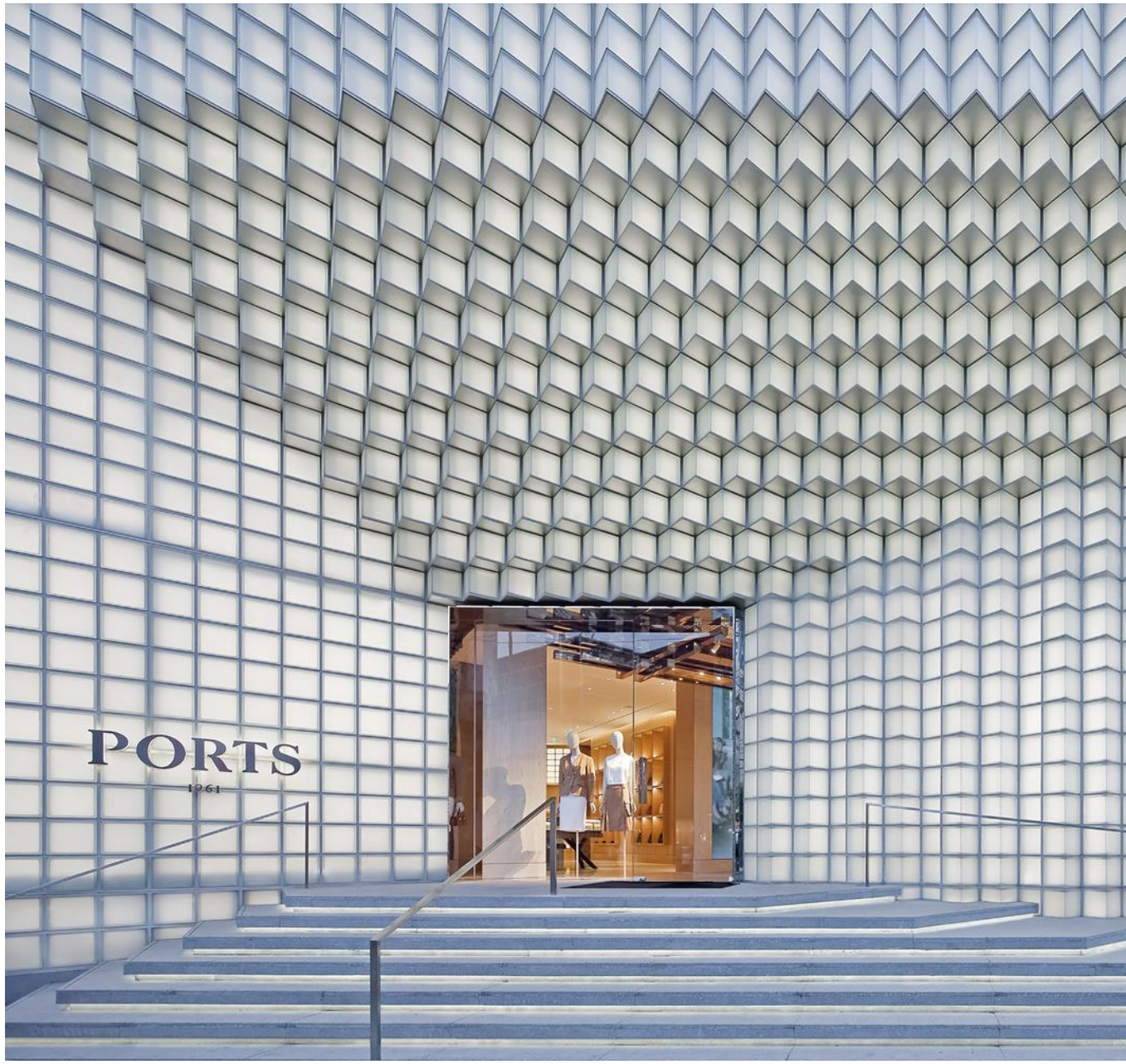




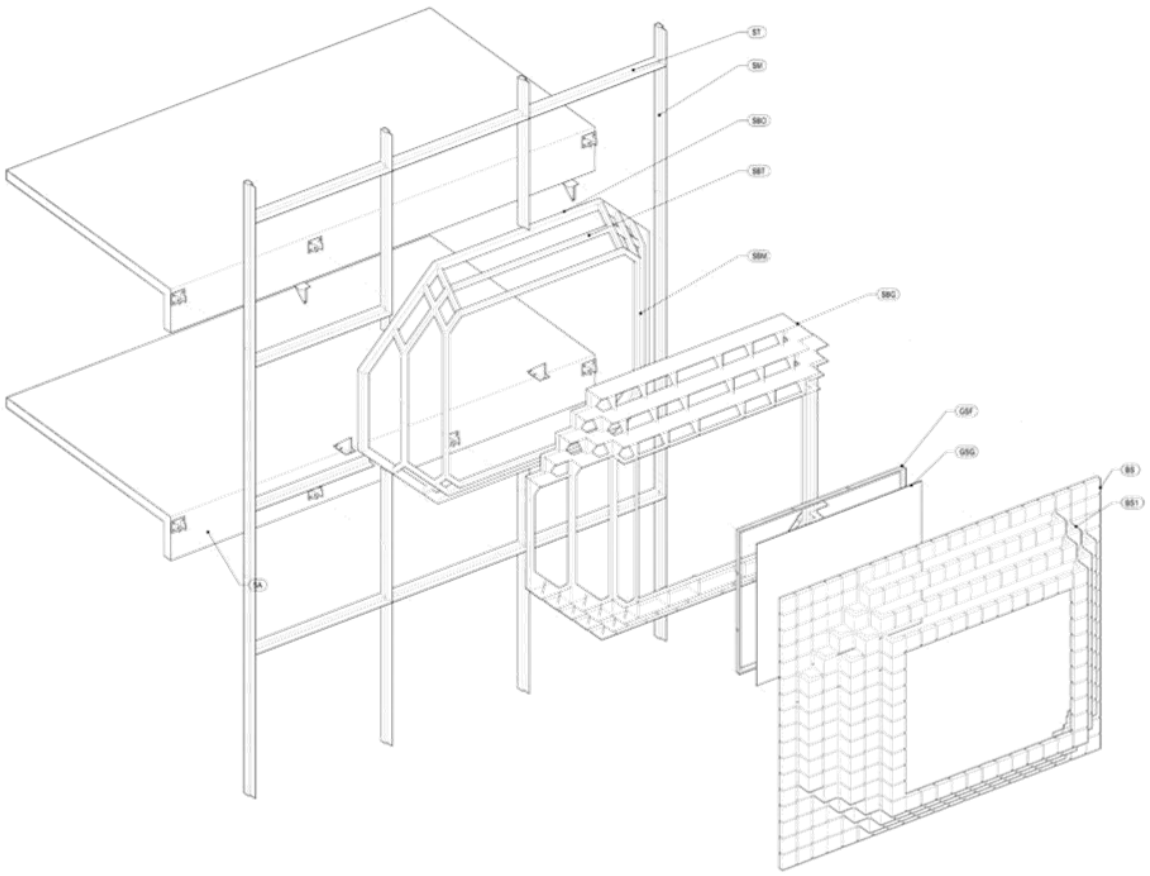
Case Study

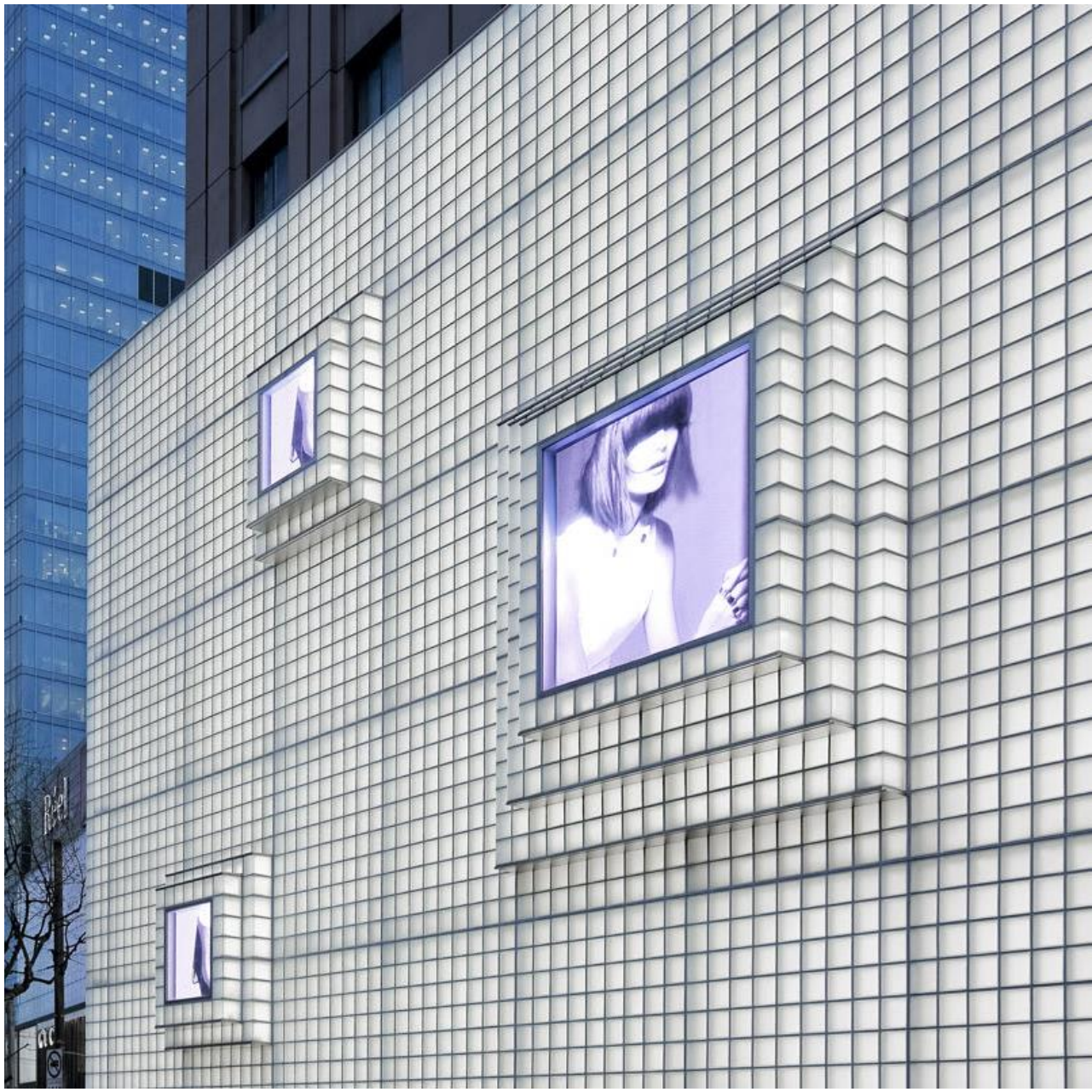


The blocks are placed over shot blasted stainless steel plates of the same dimension, extending to a steel frame. These metal strips divide the glass blocks into groups of 64.



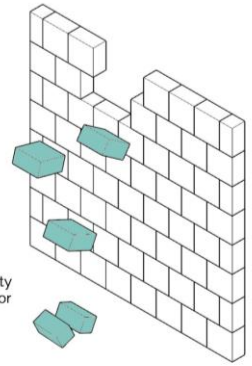
Case Study





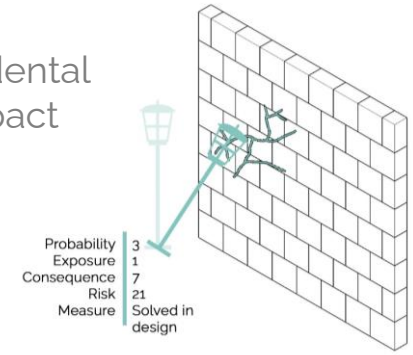
Risk Analysis

Structural Damage



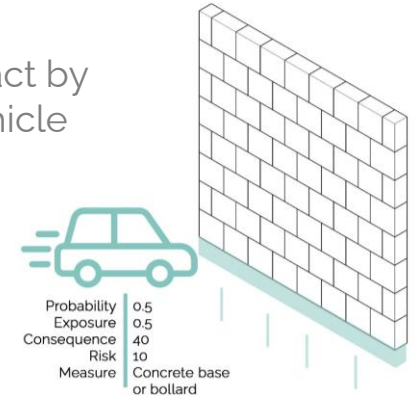
Probability	0.5
Exposure	0.5
Consequence	40
Risk	10
Measure	Safety Factor -4

Accidental Impact



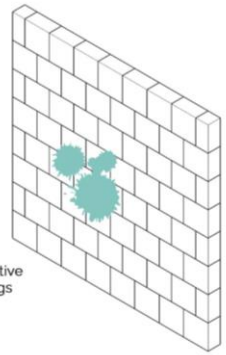
Probability	3
Exposure	1
Consequence	7
Risk	21
Measure	Solved in design

Impact by Vehicle



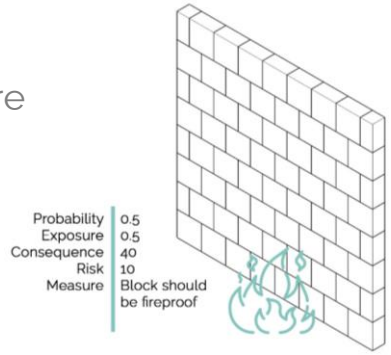
Probability	0.5
Exposure	0.5
Consequence	40
Risk	10
Measure	Concrete base or bollard

Vandalism



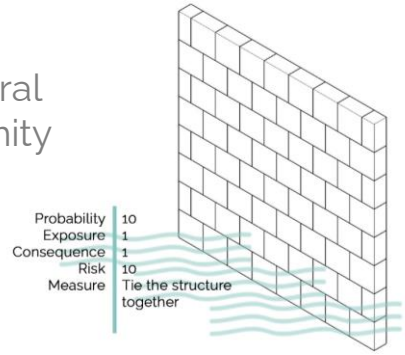
Probability	0.5
Exposure	0.5
Consequence	7
Risk	1.75
Measure	Protective coatings

Fire



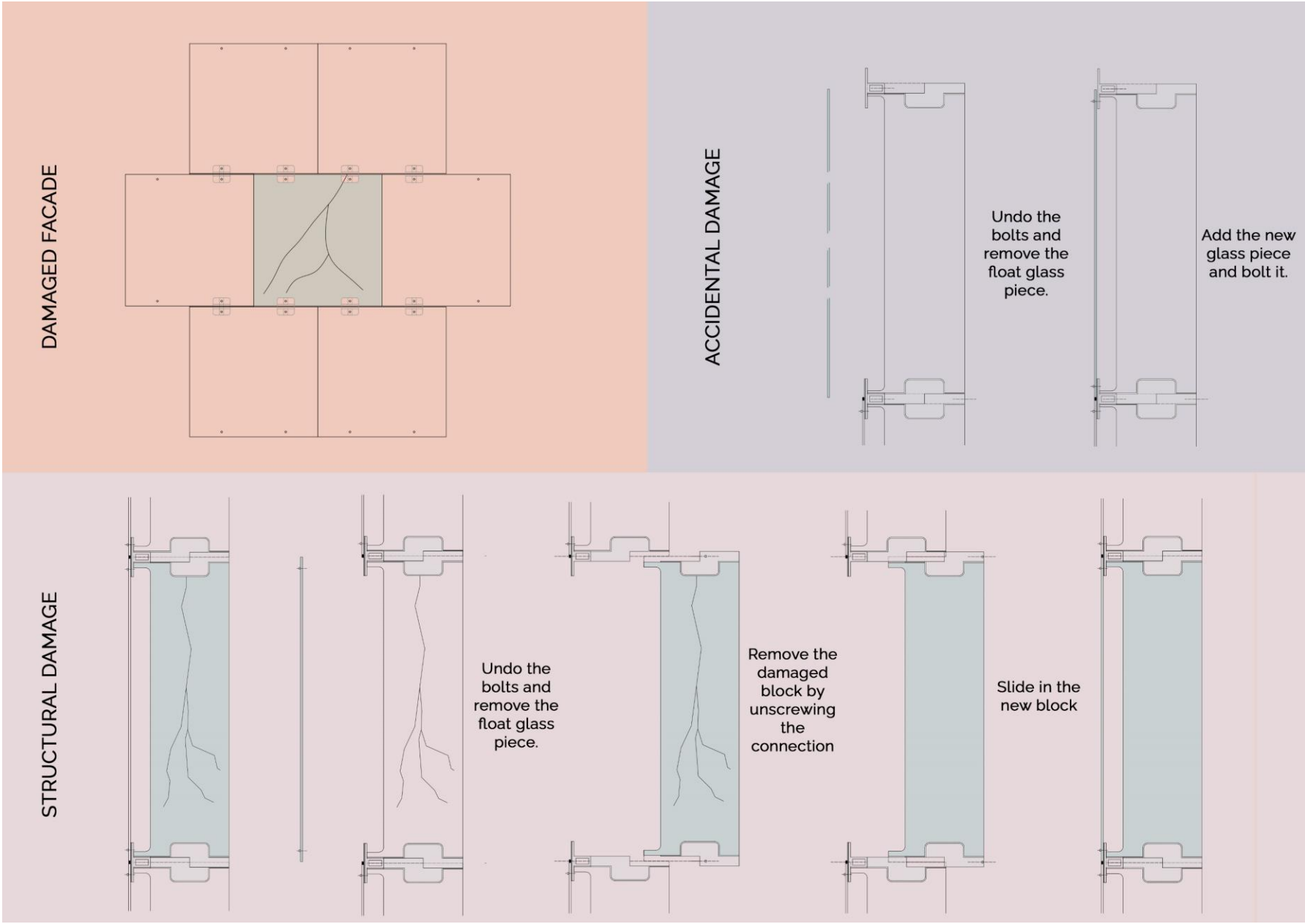
Probability	0.5
Exposure	0.5
Consequence	40
Risk	10
Measure	Block should be fireproof

Natural calamity



Probability	10
Exposure	1
Consequence	1
Risk	10
Measure	Tie the structure together

Maintenance



Maintenance