Building Technology Graduation Studio
P5 Presentation, June 2022

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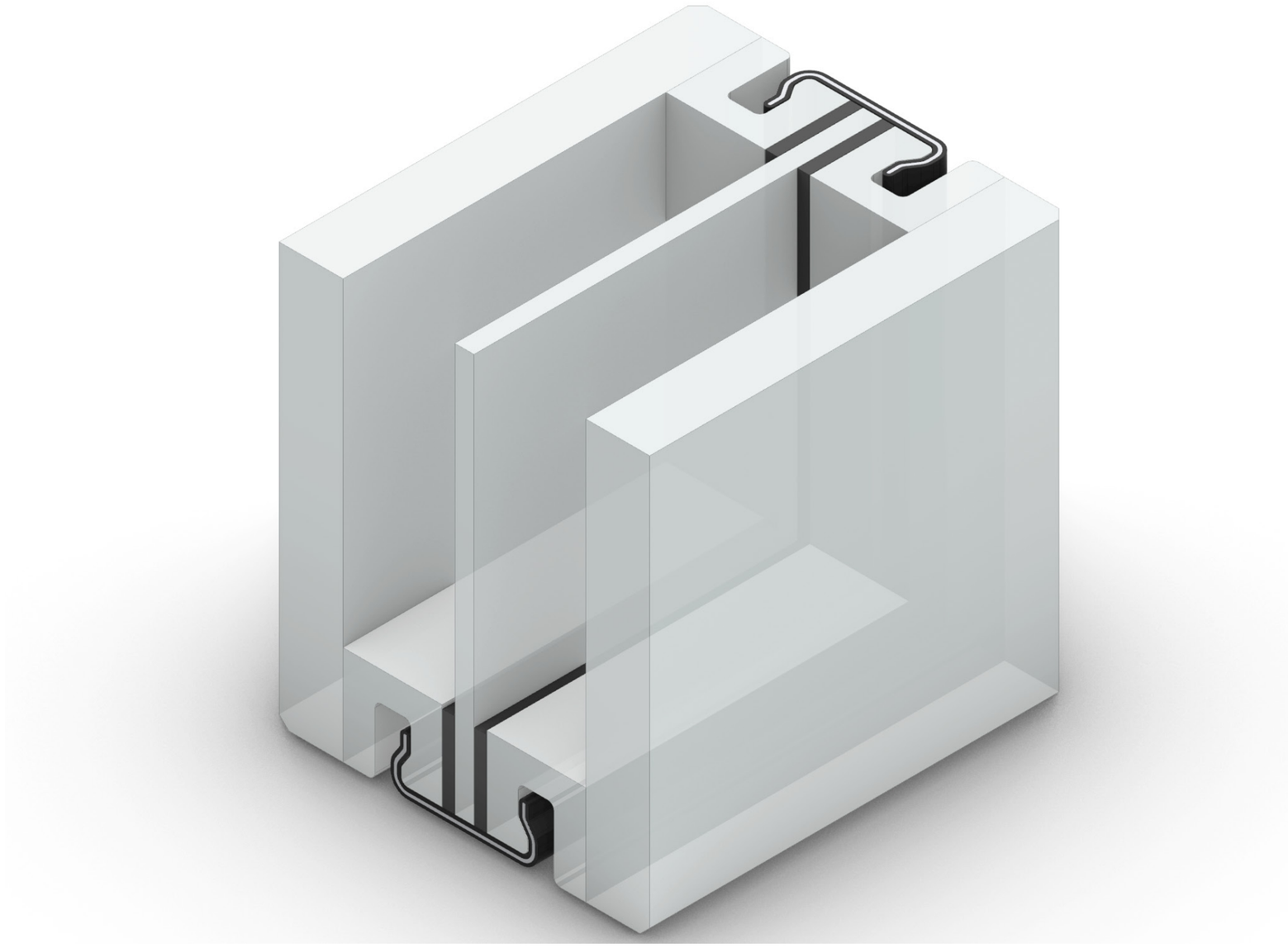
TU Delft



Re-LOOP TRANSPARENCY

Exploring the potential of maximising circularity and transparency in an Insulated Glass Unit (IGU)

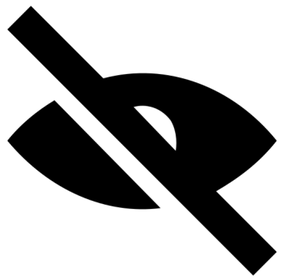
Glass facade. From https://seele.com/facades/structural-glass

Insulated glass unit. From https://www.glastory.net/insulating-glass-types/

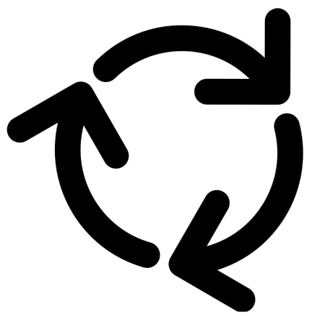
Two aspects to be improved

in IGUs

Visible Black Edge Seals



Circularity



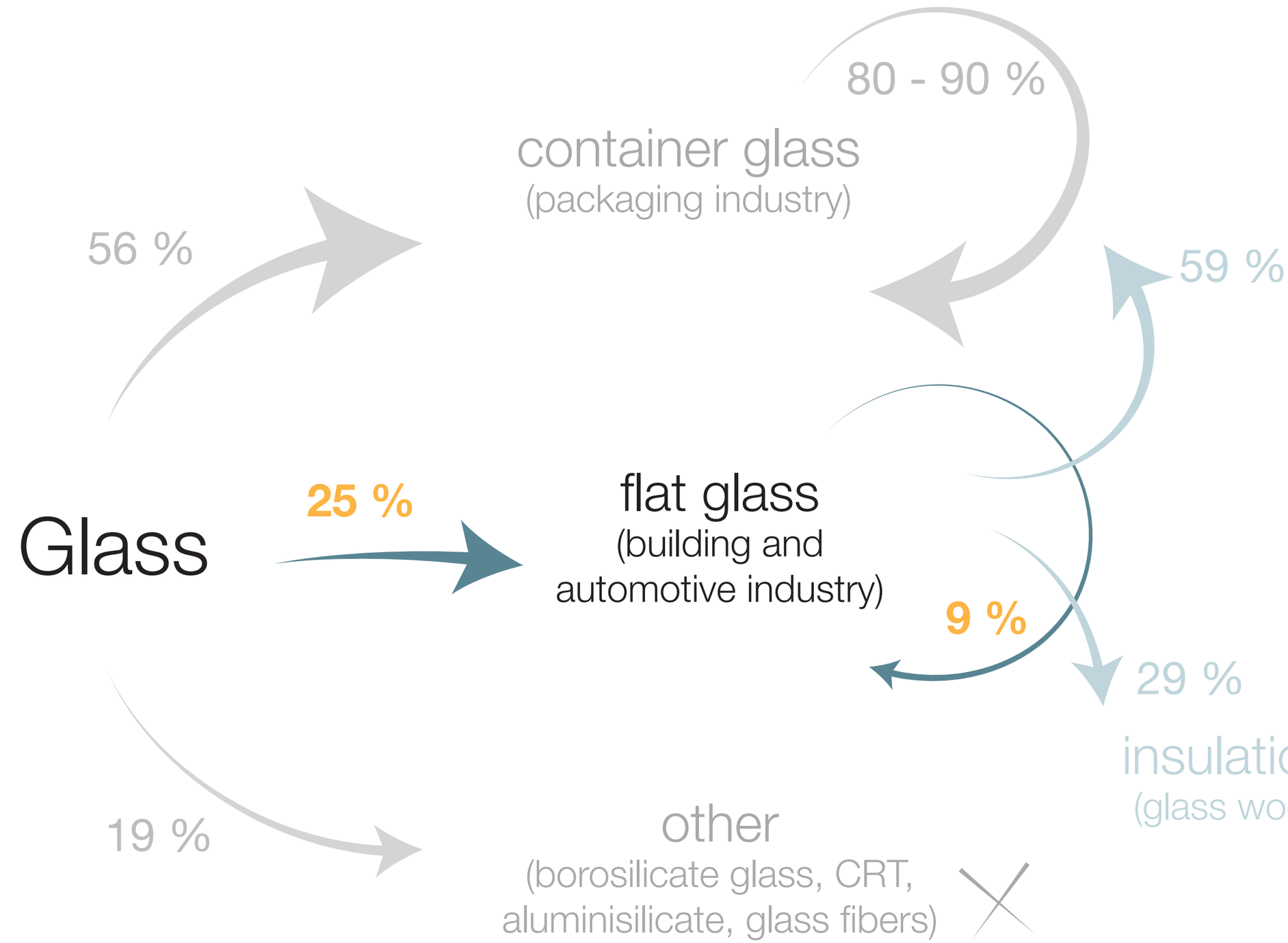


Diagram of the current glass recycling scheme in the Netherlands compared to the Re3 Glass proposal. Original From (Oikonomopoulou, 2019),

Contaminating Factors

Glass cullet. From https://www.sibelco.com/materials/recycled-glass

Insulated Glass Units. From https://glassupply.com/insulated-glass-units/

100 years +

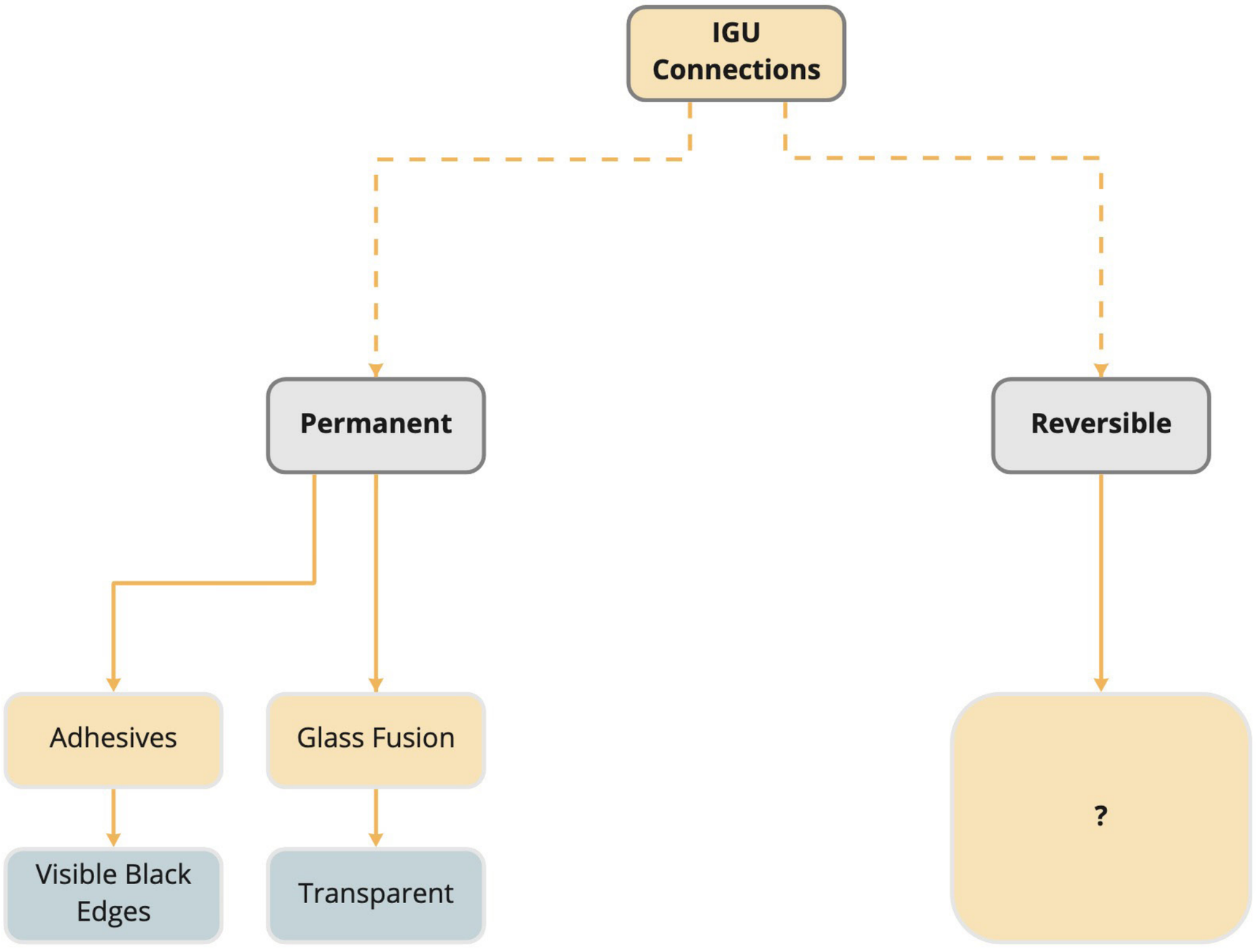
Reduced Life-Span

25 years

Single-Life Component

Window glass recycling-momentum recycling. From https://colorado.momentumrecycling.com/colorado-window-recycling/

Research Gap

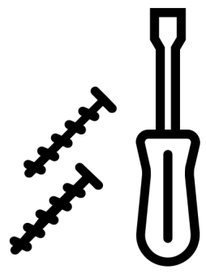


Main research question

To what extent can **transparency** and **circularity** be combined in an insulated glass unit (IGU) that can be applied in fully glazed facades?

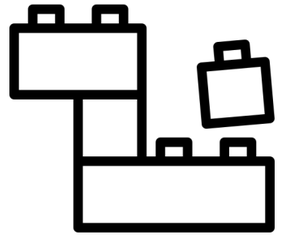
*** Definition of circularity:**

DESIGN FOR **DISASSEMBLY**



enabling **refurbishment** of the unit

and **recycling** of glass panes at end of life of the unit



*** Definition of guidelines for transparency:**

Minimised and optically discrete connection elements

Research Sub-Questions

1. What are the main **design criteria** in the development of a circular IGU of maximised transparency?

   (a) in terms of the whole unit

   and

   (b) in terms of its edge seal connection?

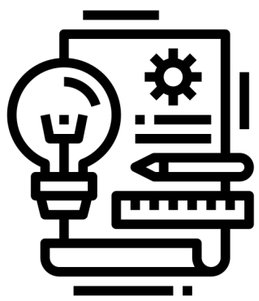
2. What are the current **potential** and **limitations** of implementing a circular design of maximised transparency in:

   (a) an insulated glass unit

   and

   (b) during its application in a fully glazed facade

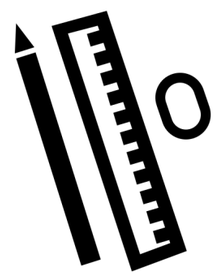
Focus of the Thesis



Research through Design

focusing on

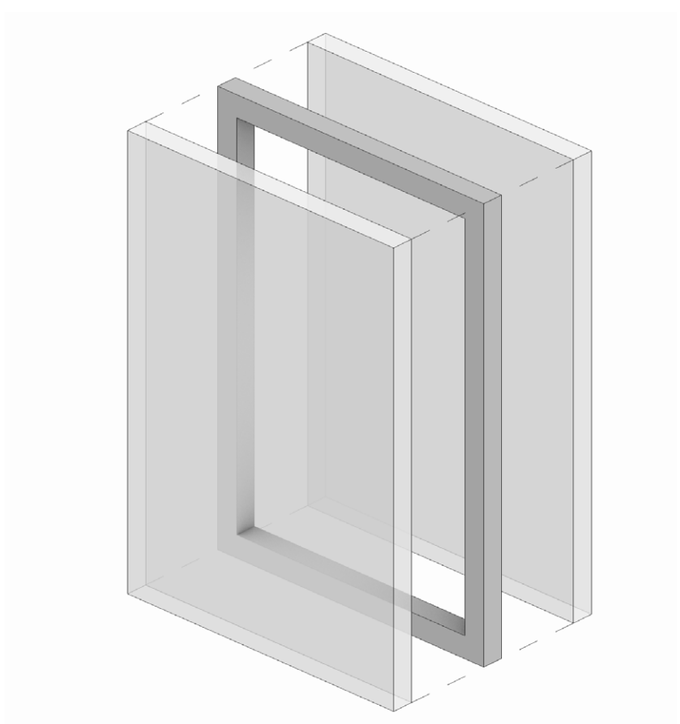
Constructability and **Detailing**

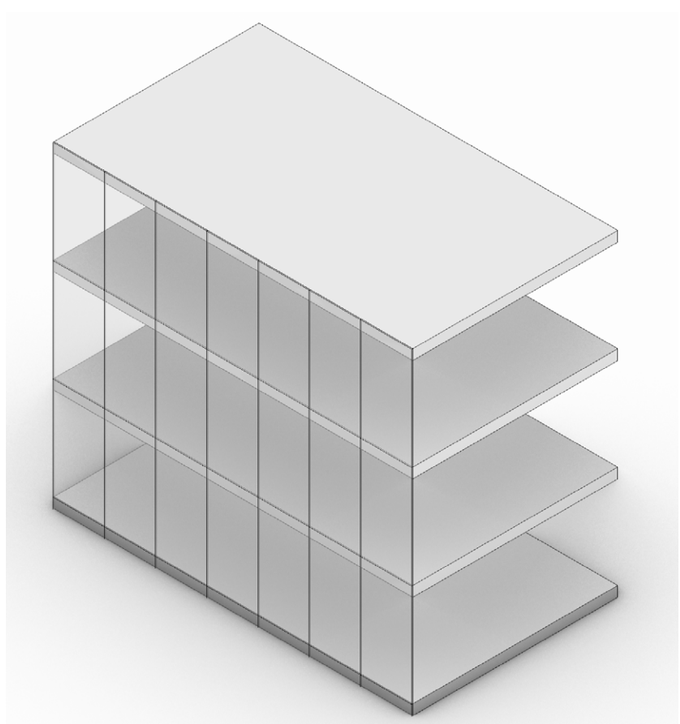


Design Assignment

1 Reversible Connections of Maximum Transparency in an **Insulated Glass Unit** (IGU)

2 Application in a **Fully Glazed Facade**





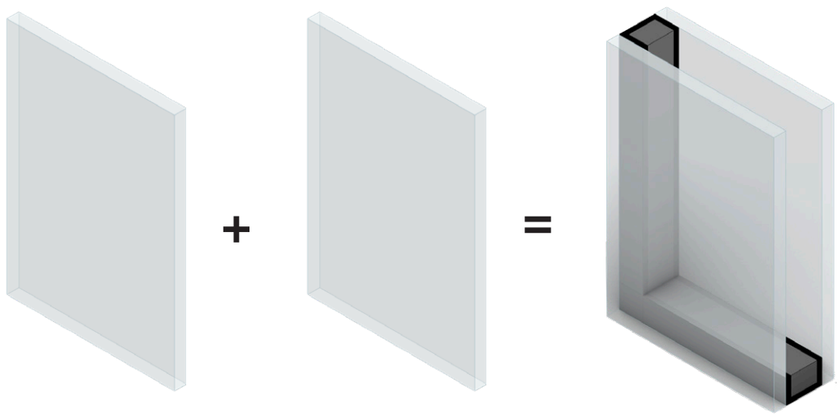
Literature Review

Answer to Research Sub-Question:

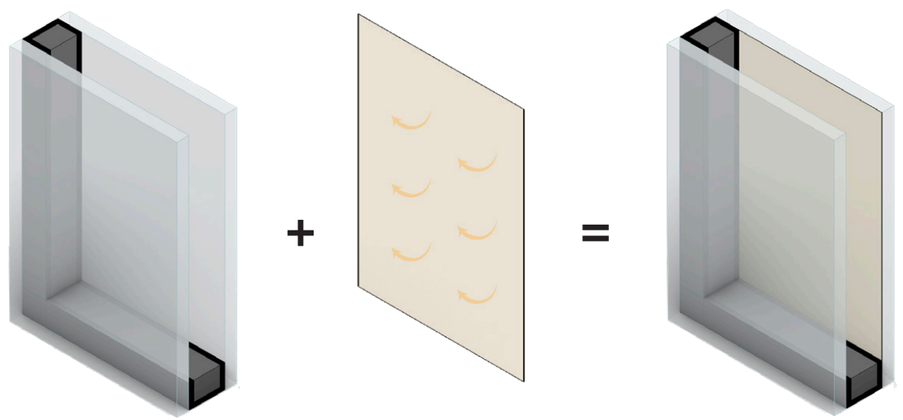
1. What are the main **design criteria** in the development of a circular IGU of maximised transparency

(a) in terms of the whole unit?
and
(b) in terms of its edge seal connection?

How can we create an IGU?



5.6 W/m²K



2.8 W/m²K

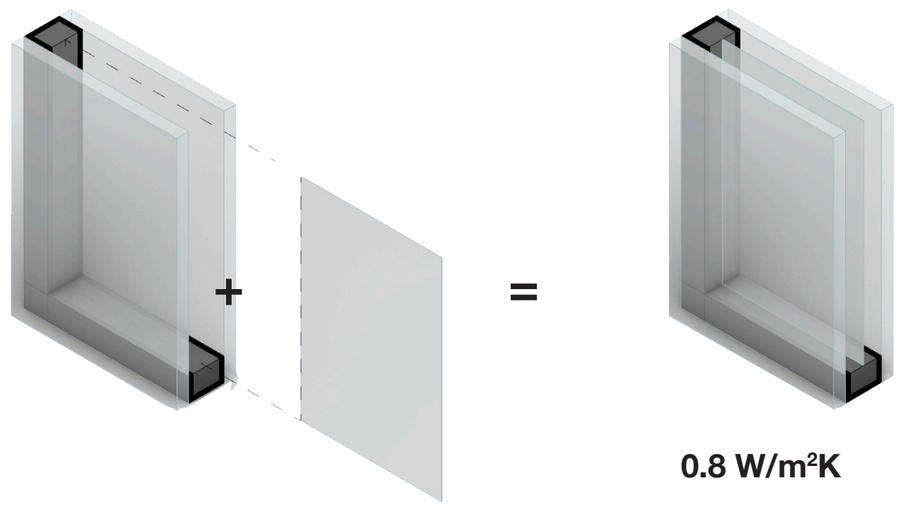
1.8 W/m²K

Create a cavity

1.2 W/m²K

Fill the cavity with an inert gas

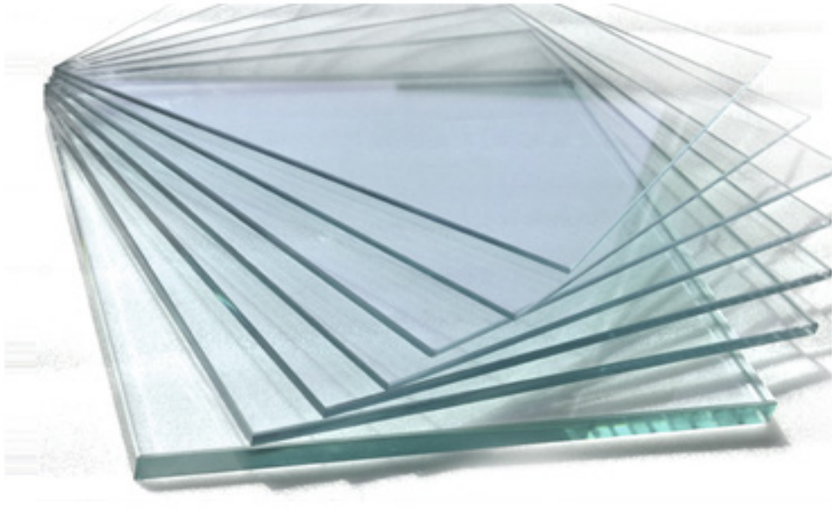
Apply low-emissivity coatings



0.8 W/m²K

Convective barriers

What type of glass can we use to create an IGU?



Float Glass

Automated process

Highest optical transparency

Limited shape options

Cast Glass

Not automated process

Varying levels of optical distortion

Great freedom of shape options

Which contaminating factors need to be avoided in an IGU assembly?

Associated with glass surfaces

Lamination

Heavy Contamination

Current de-laminating process does not allow for closed-loop recycling

Fritting

Heavy Contamination

Cannot be burnt off

Coatings

Light Contamination

Can be burnt off but reduces optical quality

Structural Silicone Adhesives

Heavy Contamination

Even careful removal of silicone leaves contamination traces

Which contaminating factors need to be avoided in an IGU assembly?

Associated with
IGU edge seals

Lamination

Heavy Contamination

Current de-laminating process does not allow for closed-loop recycling

Fritting

Heavy Contamination

Cannot be burnt off

Coatings

Light Contamination

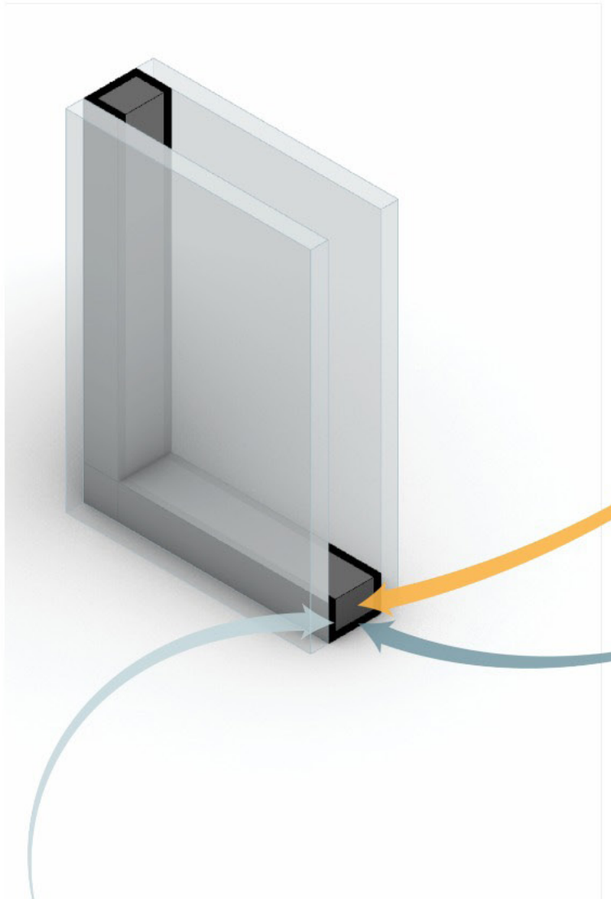
Can be burnt off but reduces optical quality

Structural Silicone Adhesives

Heavy Contamination

Even careful removal of silicone leaves contamination traces

What are the Properties of the Existing IGU Edge Seals?



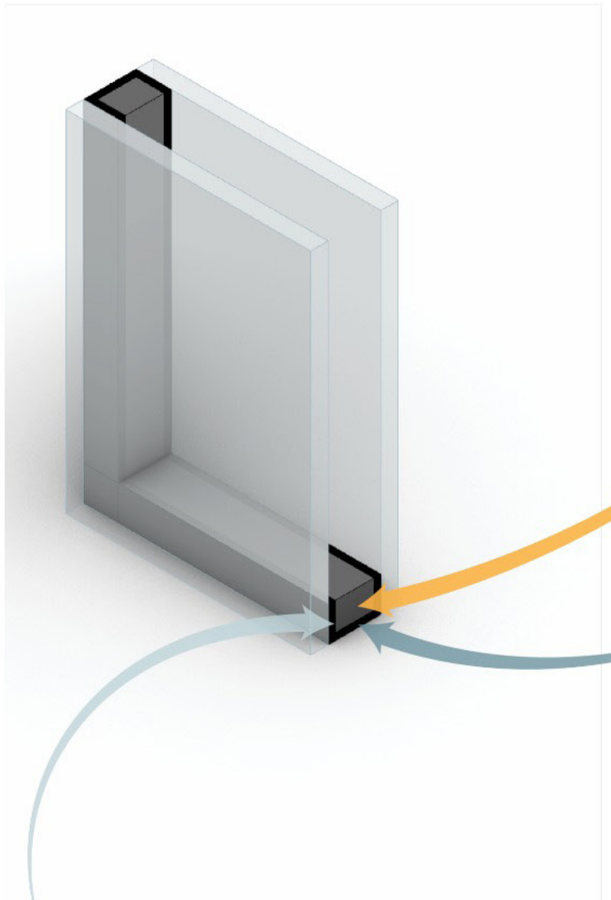
- **spacer bar**
  - resistance in compression → not critical
  - stiffness → > 4.8 GPa
  - thermal conductivity → 0,25 - 2 W/mK
  - integrated dessicant → molecular sieves; blend of 3-Å molecular sieve and silica gel
- **secondary seal**
  - resistance in tension → > 1.5MPa
  - flexibility for movements
  - materials → hot-melt butyl; epoxy-based sealants; Polyurethane (PU); silicone (Si); polysulfide (PS)
- **primary seal**
  - high moisture vapour transmission resistance → gas leakage rate (Li) < 1% per year; water vapor transmission rate (< 0.1 gr/m3 d); high gas permeation rate (< 0.002 gr/m2 h)
  - materials → polyisobutylene (PIB)

*Extra Elements that need to be integrated:

1. Metal foil as vapour and gas barrier

2. Desiccant

How can these Properties of be Translated in the Design of the New IGU Edge Seal?



spacer bar

secondary seal

new spacer bar

transfer loads between glass panes

low thermal conductivity

flexibility for movements

primary seal

transparent polyisobutylene (PIB)

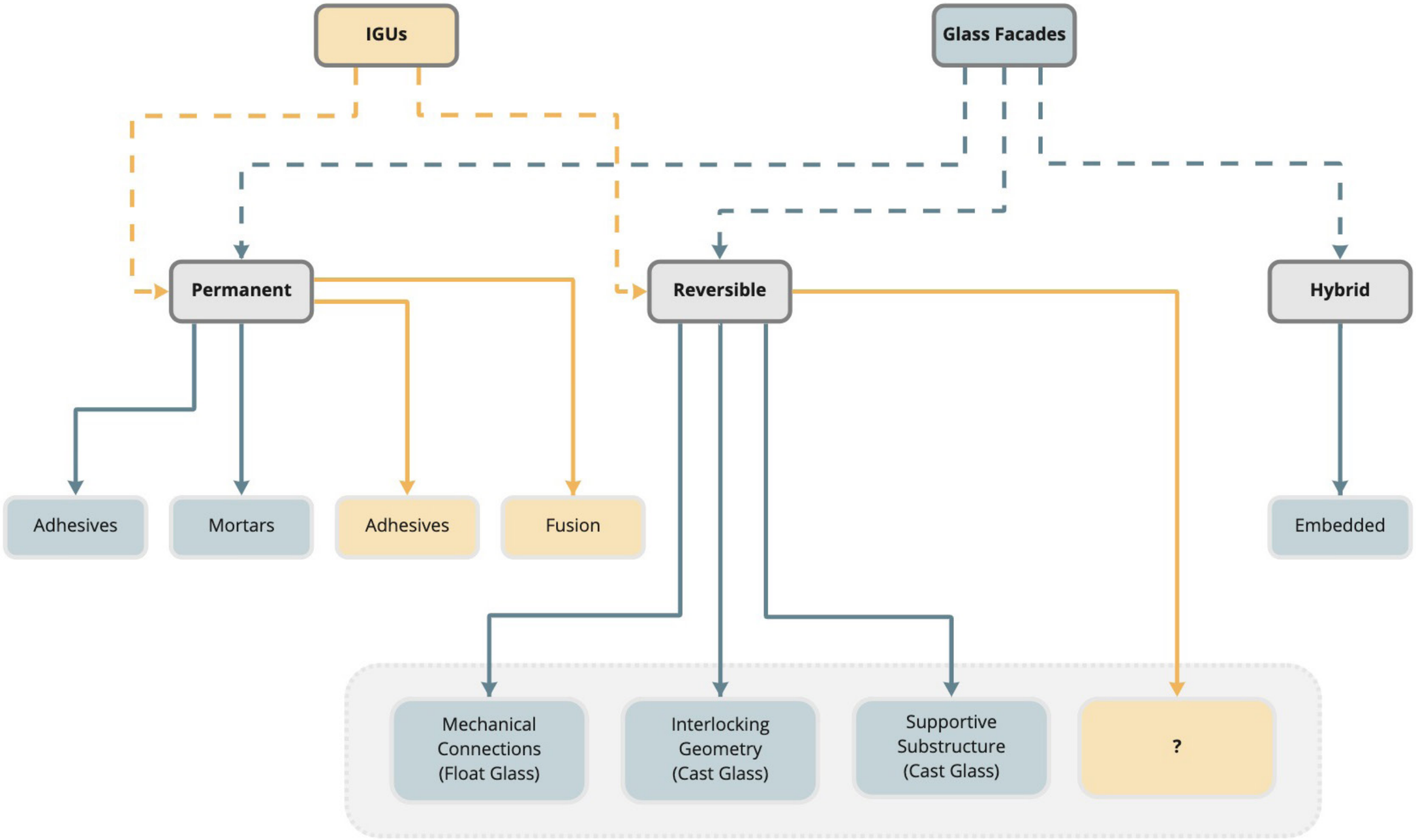
needs water protection

extra elements

integrated dessicant

metal foil

Mapping the Existing Connections



Design Criteria

Unit

thermal insulation

u-value <1.25 W/m2K

contamination-free

avoid adhesives, lamination

Connection

transparency

optically discrete connection

structural rigidity

ensure load-sharing between glass panels

demountable

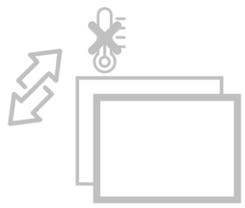
reversible connection without contaminating glass

airtight cavity

air tight
water and moisture tight

moisture absorption

integrated desiccant



thermal conductivity

low thermal conductivity
(0,25 - 2 W/mK)
avoid thermal bridges

feasibility of construction

accommodate tolerances,
thermal expansions and movements

simplicity of construction

simply applied principle

Unit

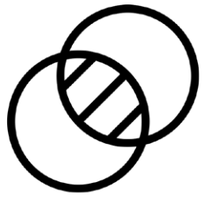
thermal insulation

u-value <1.25 W/m2K

contamination-free

avoid adhesives, lamination

Connection

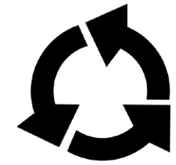


transparency

optically discrete connection

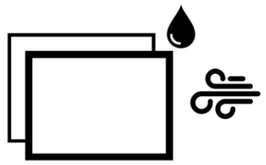
structural rigidity

ensure load-sharing between glass panels



demountable

reversible connection without contaminating glass

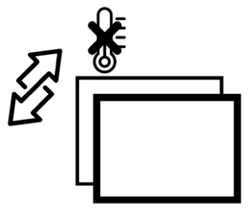


airtight cavity

air tight
water and moisture tight

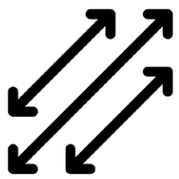
moisture absorption

integrated desiccant



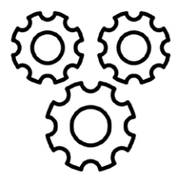
thermal conductivity

low thermal conductivity
(0,25 - 2 W/mK),
avoid thermal bridges



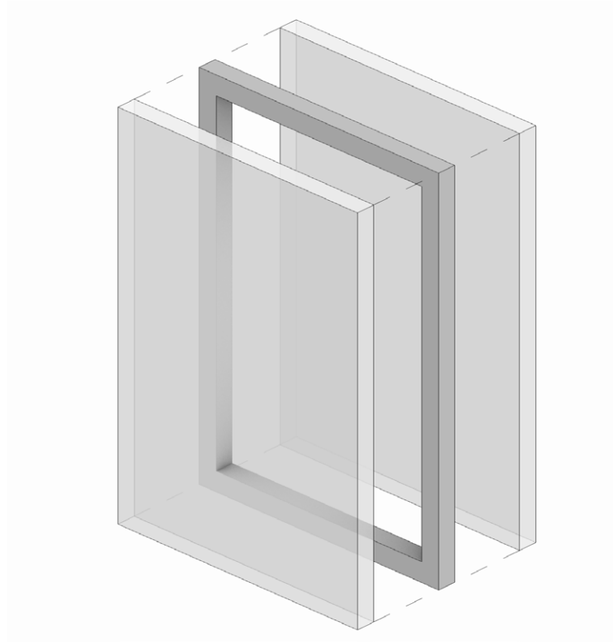
feasibility of construction

accommodate tolerances,
thermal expansions and movements



simplicity of construction

simply applied principle



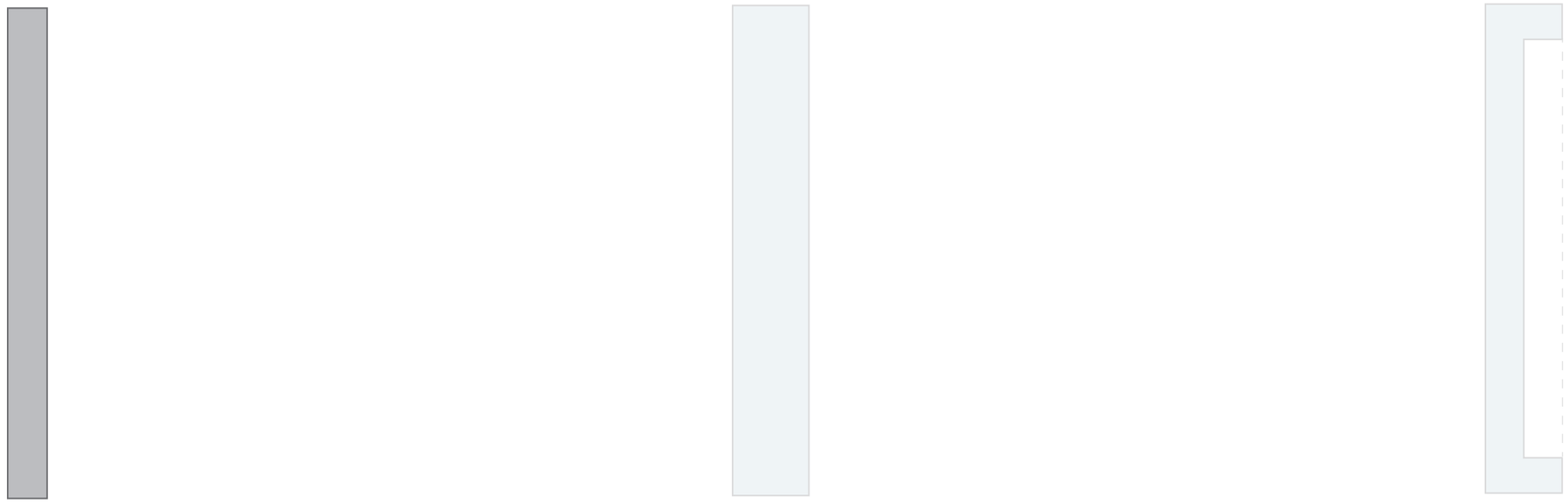
Investigation of Design Concepts

Answer to Research Sub-Question:

2. What are the current **potential** and **limitations** of implementing a circular design of maximised transparency in:

(a) in an IGU?

Possible Glass Cross Sections



Float Glass

+ Perfectly Smooth Surfaces

+ Safety Treatment

- Restricted Shape

Solid
Cast Glass

+ Great Shape Freedom

+ Great Recyclability

- Lack of Perfectly Smooth Surfaces

- Lack of Safety Treatment

Hollow
Cast Glass

Float Glass

+ Perfectly Smooth Surfaces

+ Safety Treatment

- Restricted Shape

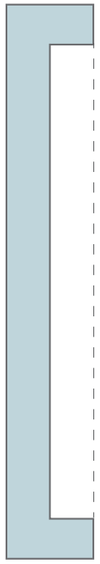
Solid
Cast Glass

+ Great Shape Freedom

+ Great Recyclability

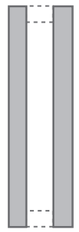
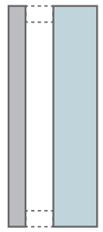
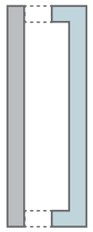
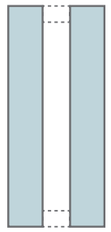
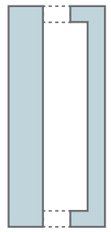
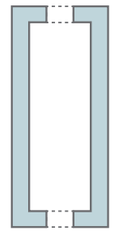
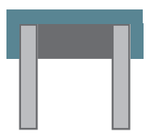
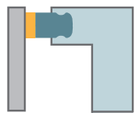
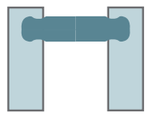
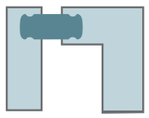
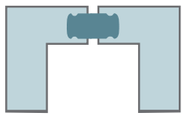
- Lack of Perfectly Smooth Surfaces

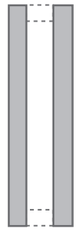
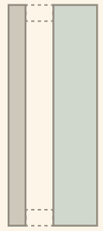
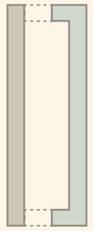
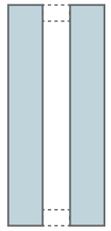
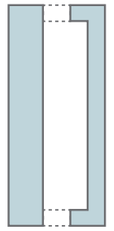
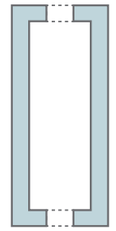
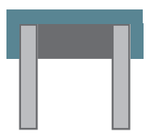
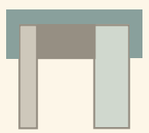
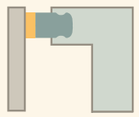
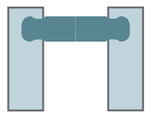
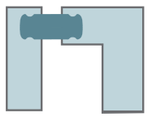
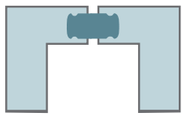
- Lack of Safety Treatment



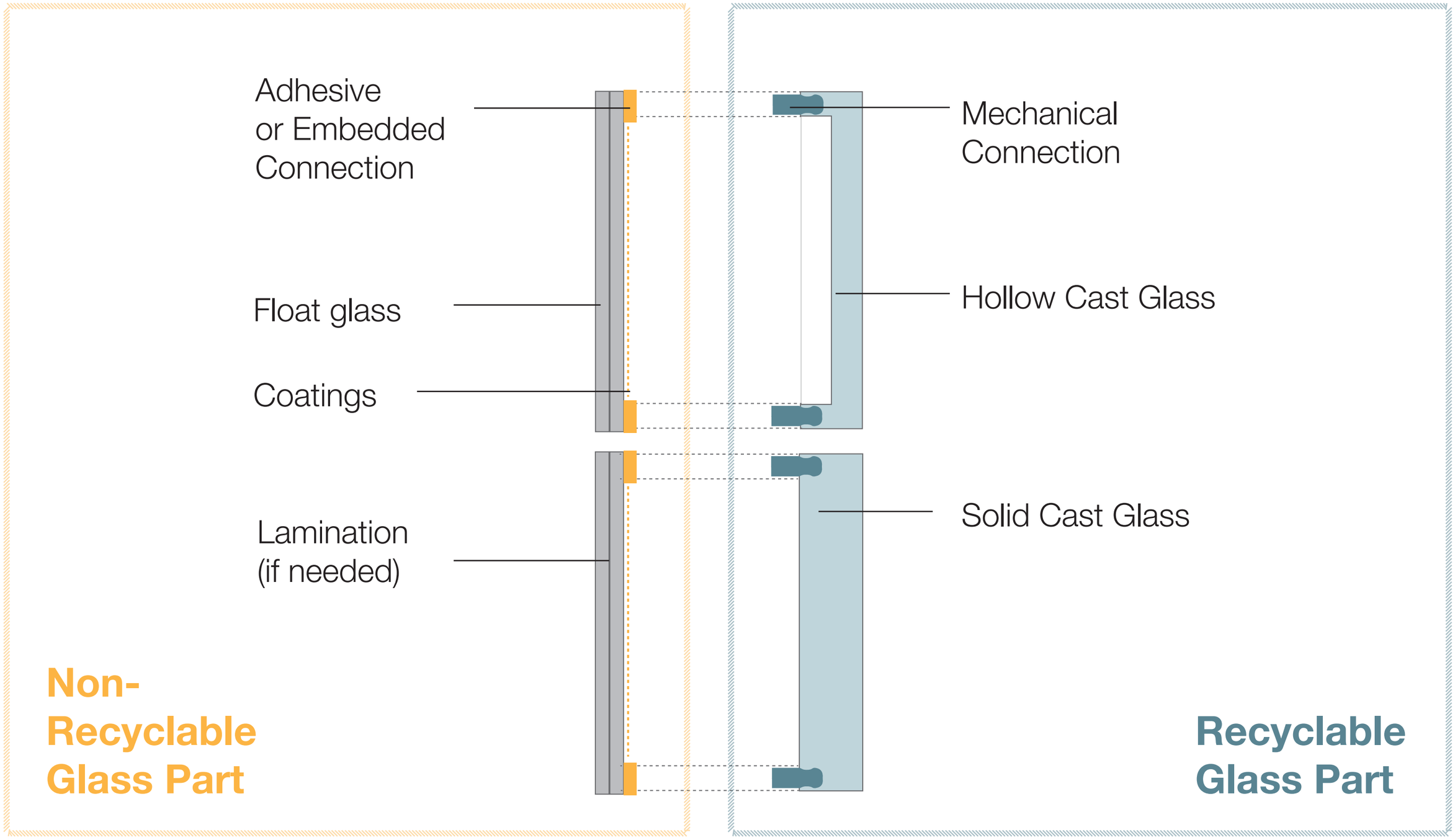
Hollow
Cast Glass

Possible Glass Cross-Section Combinations

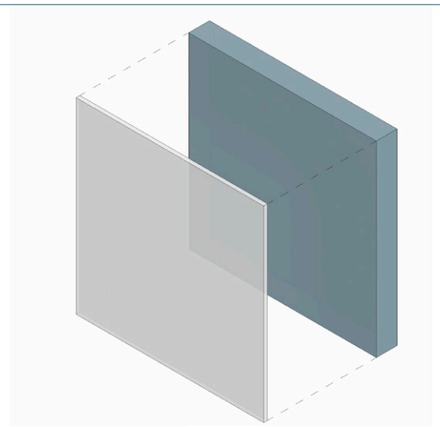
Combination of Glass Types						
Glass Types	Float Glass + Float Glass	Float Glass + Solid Cast Glass	Float Glass + Hollow Cast Glass	Solid Cast Glass + Solid Cast Glass	Solid Cast Glass + Hollow Cast Glass	Hollow Cast Glass + Hollow Cast Glass
Possible Connection Types for each Glass Combination	 Adhesion OR  Mechanical	 Adhesion to float glass + Mechanical to cast glass OR  Mechanical	 Adhesion to float glass + Mechanical to cast glass	 Mechanical	 Mechanical	 Mechanical
reversibility	+ ++++	++ ++++	++	++++	++++	++++
optical transparency	+++ +	+++ +	++++	++	++ +++	+++ ++++
safety	++++	++++	++++	+	+	+

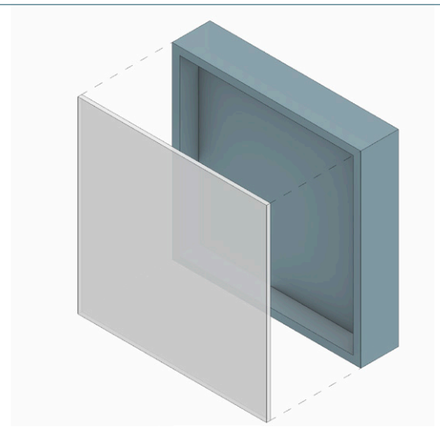
Combination of Glass Types						
Glass Types	Float Glass + Float Glass	Float Glass + Solid Cast Glass	Float Glass + Hollow Cast Glass	Solid Cast Glass + Solid Cast Glass	Solid Cast Glass + Hollow Cast Glass	Hollow Cast Glass + Hollow Cast Glass
Possible Connection Types for each Glass Combination	 Adhesion OR  Mechanical	 Adhesion to float glass Mechanical to cast glass OR  Mechanical	 Adhesion to float glass + Mechanical to cast glass	 Mechanical	 Mechanical	 Mechanical
reversibility	+ ++++	++ ++++	++	++++	++++	++++
optical transparency	+++ +	+++ +	++++	++	++ +++	+++ ++++
safety	++++	++++	++++	+	+	+

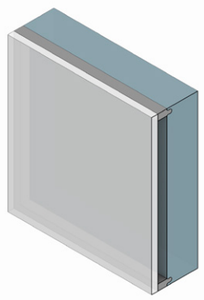
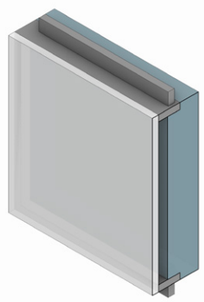
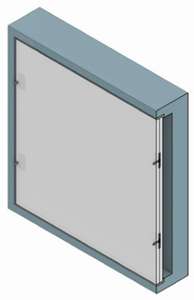
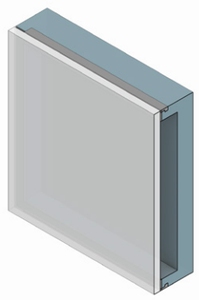
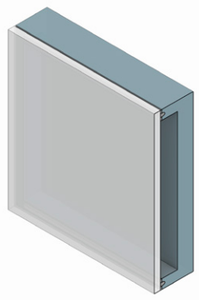
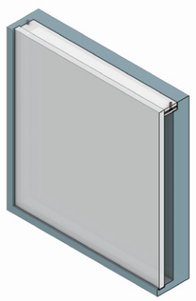
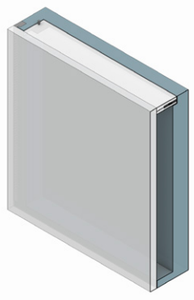
Development of Preliminary Concepts

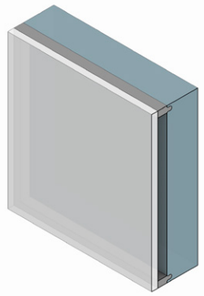
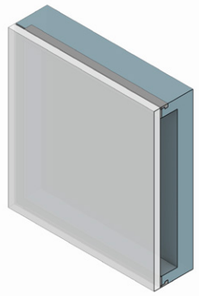


Altarnative Design Concepts

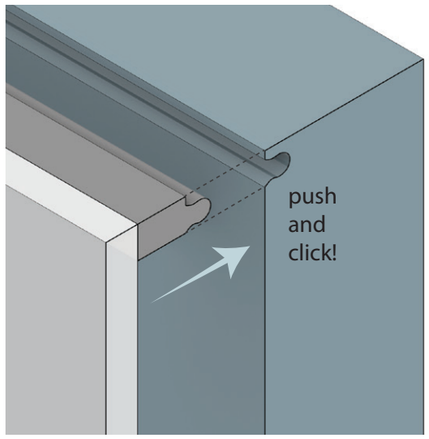




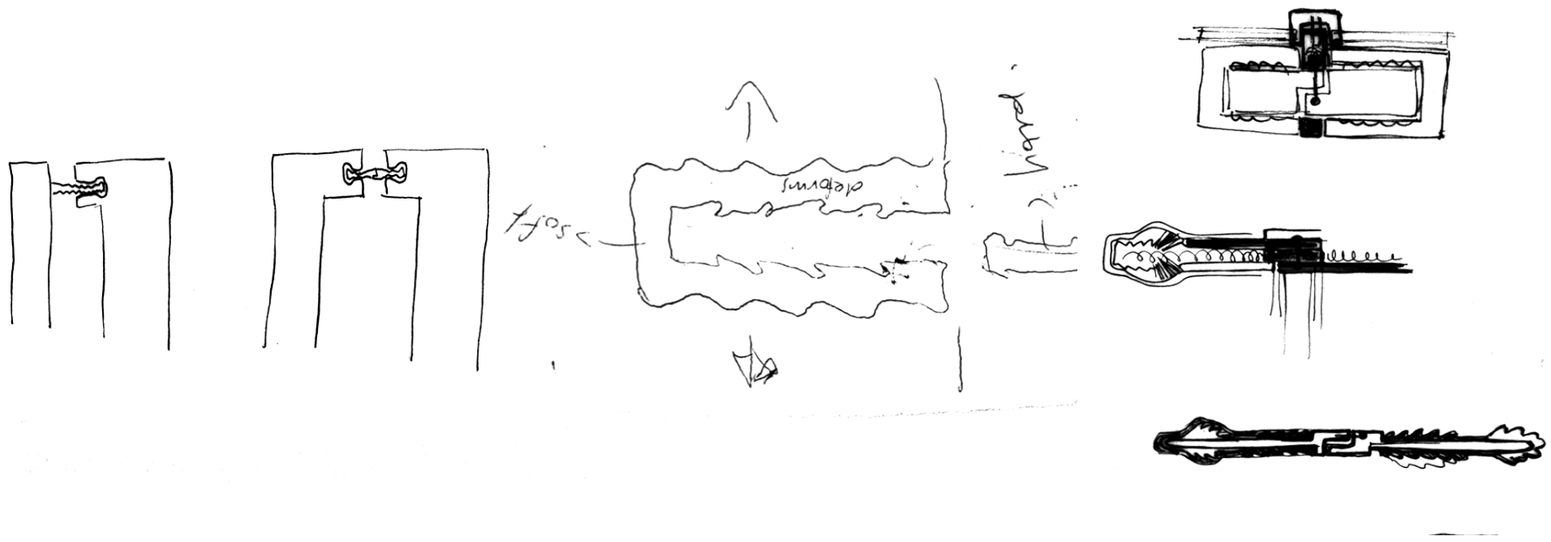
Design Option / Evaluation Criteria	 1. Interlocking Gasket	 2. “Tetris” Lock	 3. Pushed Embedded Lock	 4. “Tupper” Lock	 5. Sliding Embedded Lock A	 6. Sliding Embedded Lock B	 7. Sliding Embedded Lock C
Optical Quality	+++	++	+++	+++	+++	+	++
Feasibility of Assembly	+++	++	+++	++++	+	+	+
Thermal Bridges	+++	+++	+	++++	+++	++	++
Simplicity of Design	++++	++	+++	++++	+++	+	+++
Potential for Full Reversibility	++++	+	+	++	++	+	+
Potential for 3rd Glass Pane	++++	+++_	++++	++++	++++	++++	++++
Notes	Dependent on geometry and material	Difficult to lock in position and seal cavity	Thermal Bridges / Cannot be fully reversible	Simplicity of design / Feasible assembly	Difficult assembly due to tolerances in sliding	Difficult assembly due to tolerances in sliding / Thermal bridges/ Visible frame	Difficult assembly due to tolerances in sliding

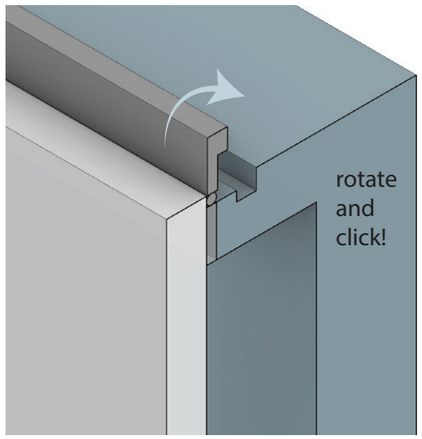
Design Option / Evaluation Criteria	 1. Interlocking Gasket	2. “Tetris” Lock	3. Pushed Embedded Lock	 4. “Tupper” Lock	5. Sliding Embedded Lock A	 6. Sliding Embedded Lock B	7. Sliding Embedded Lock C
Optical Quality	+++	++	+++	+++	+++	+	++
Feasibility of Assembly	+++	++	+++	++++	+	+	+
Thermal Bridges	+++	+++	+	++++	+++	++	++
Simplicity of Design	++++	++	+++	++++	+++	+	+++
Potential for Full Reversibility	++++	+	+	++	++	+	+
Potential for 3rd Glass Pane	++++	+++_	++++	++++	++++	++++	++++
Notes	Feasible depend on geometry and material	Difficult to lock in position and seal cavity	Thermal Bridges / Cannot be fully reversible	Simplicity of design / Feasible assembly	Difficult assembly due to tolerances in sliding	Difficult assembly due to tolerances in sliding / Thermal bridges/ Visible frame	Difficult assembly due to tolerances in sliding

Further Development of Prevailing Designs

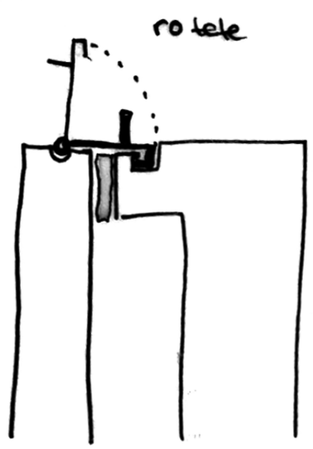


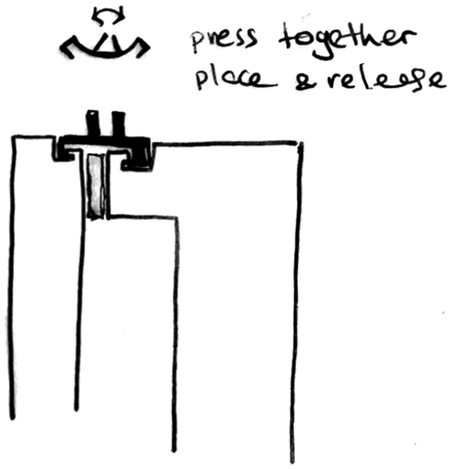
Interlocking Gasket

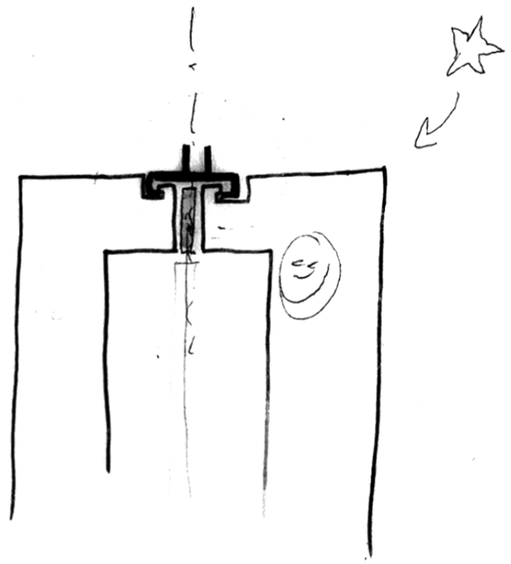




“Tupper” Lock





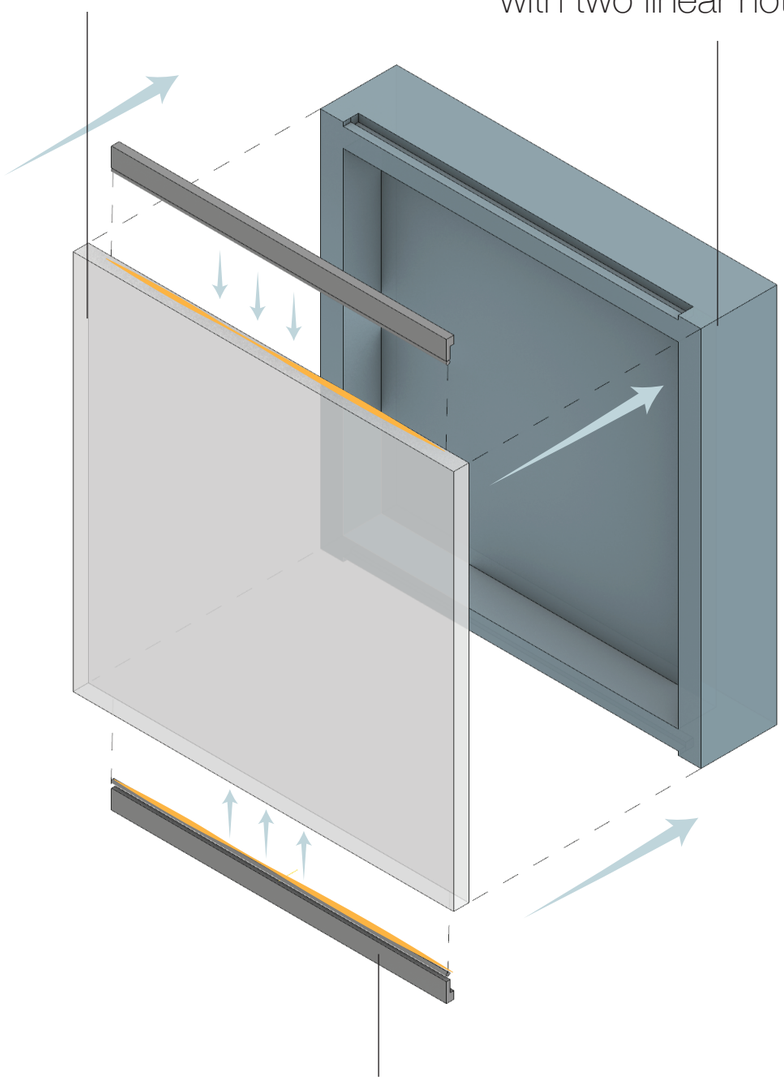


Final Design Development

Float Glass Pane

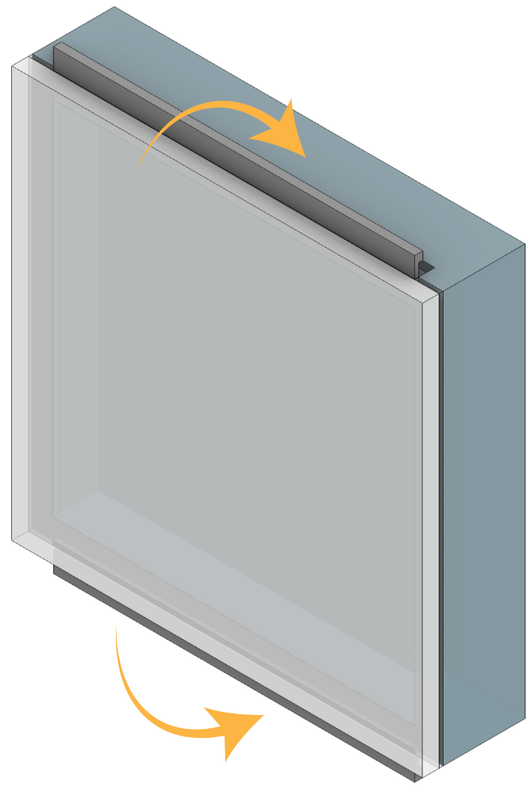
Cast Glass Pane

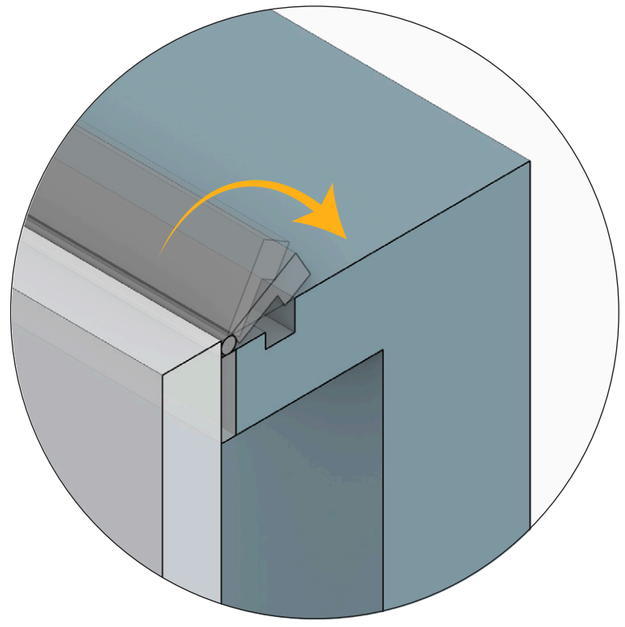
with two linear notches



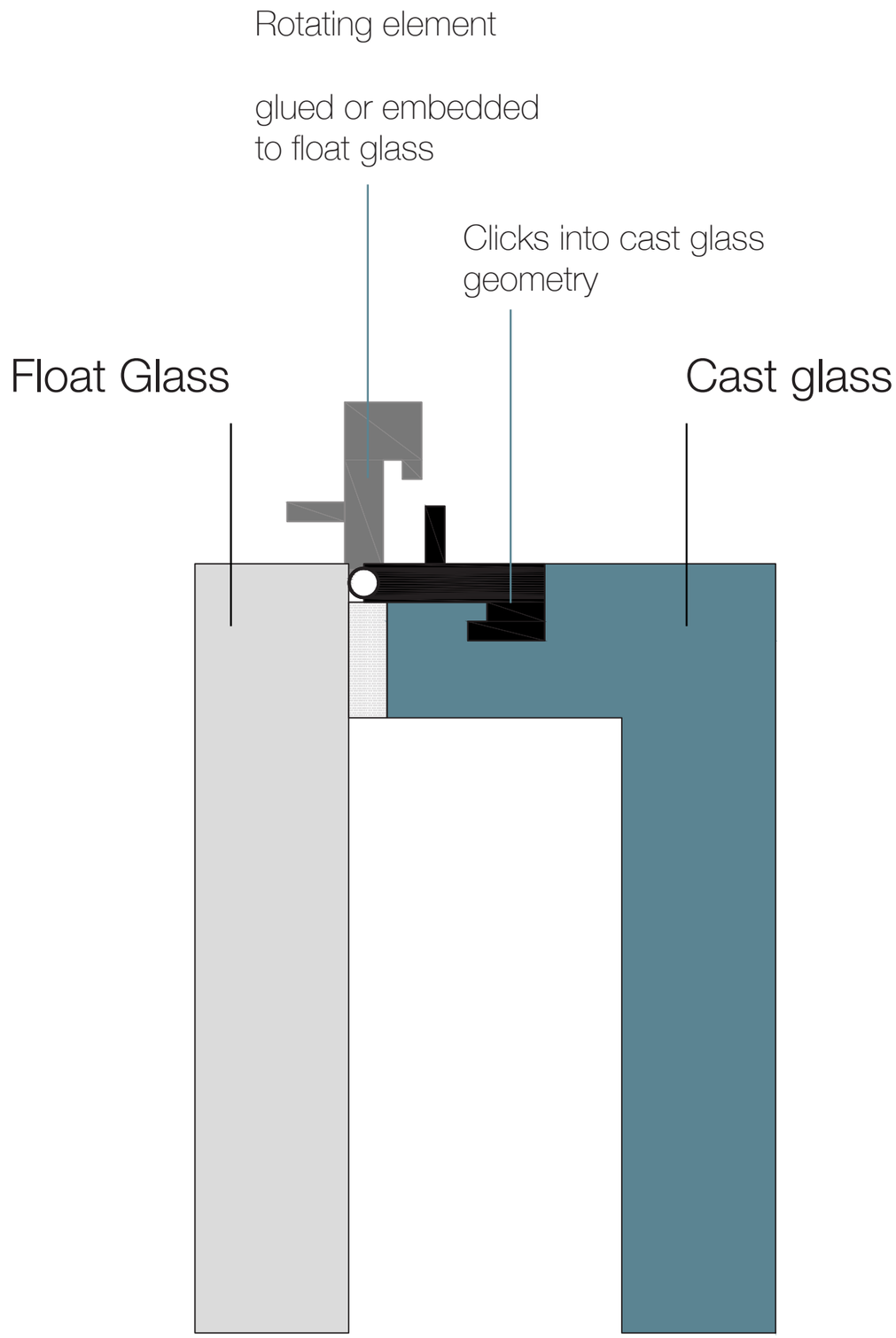
Rotating Flaps

glued or embedded
in float glass

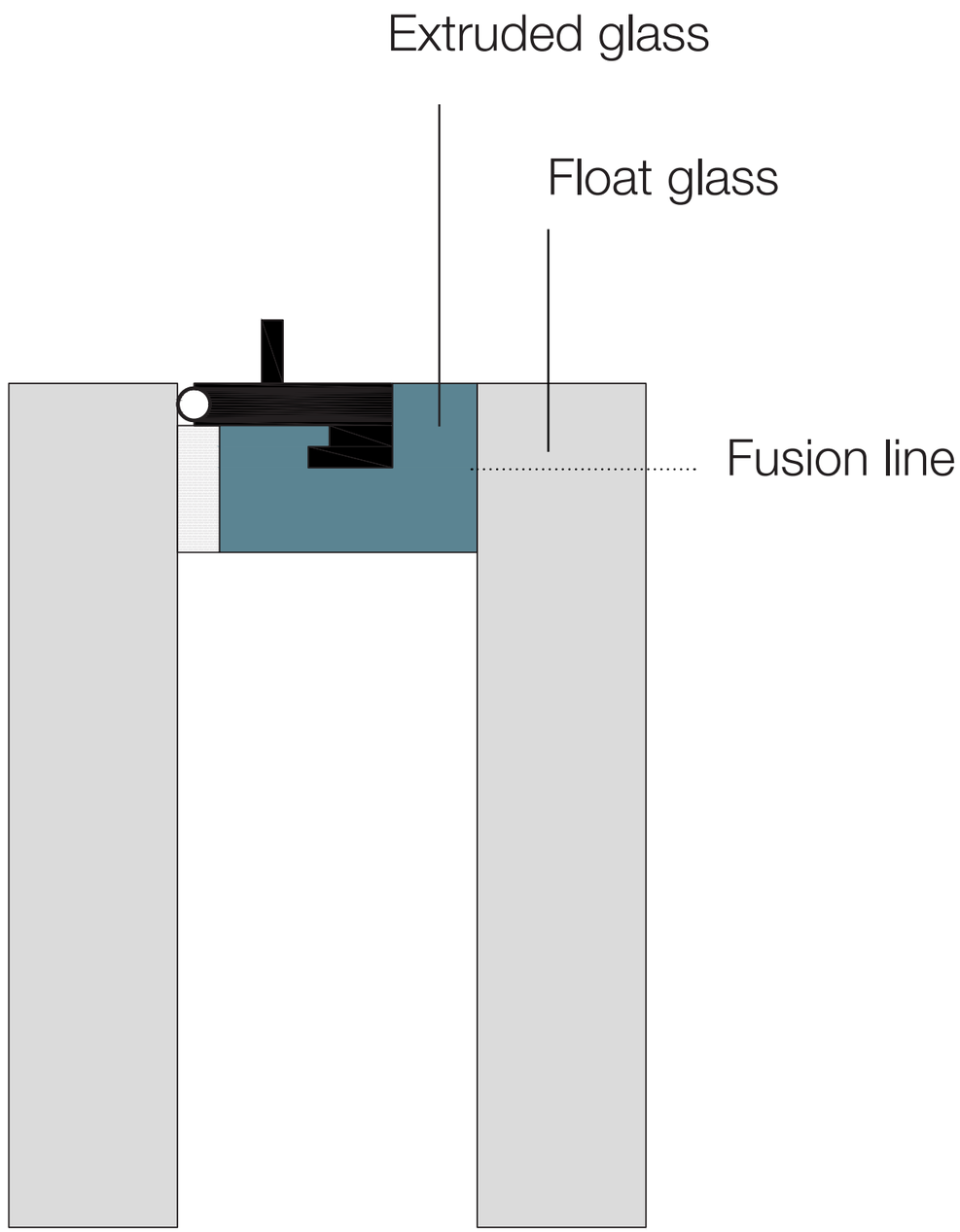




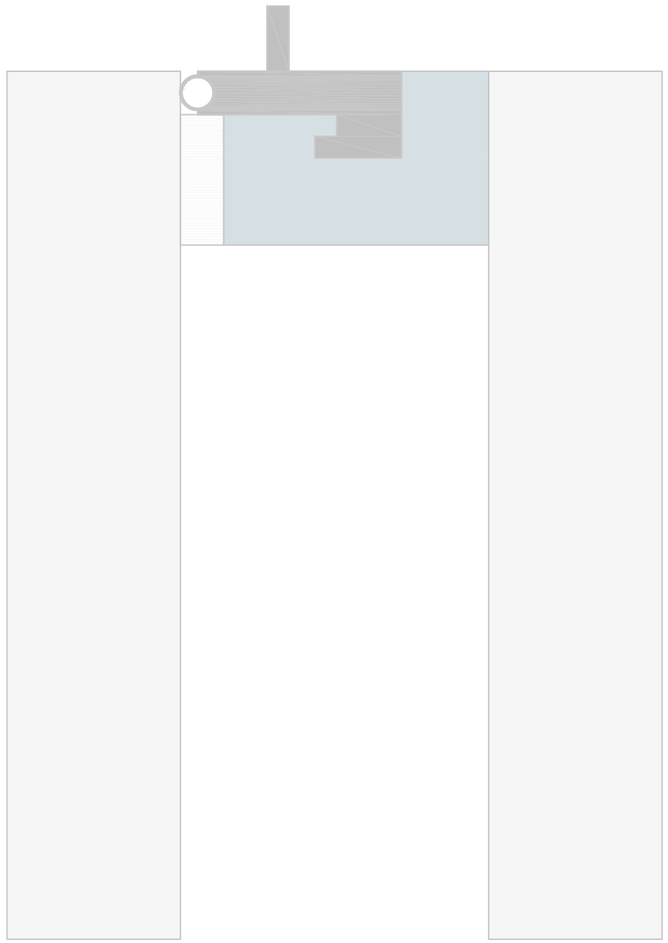
rotate and click!


Rotating element
glued or embedded
to float glass
Clicks into cast glass
geometry
Float Glass
Cast glass

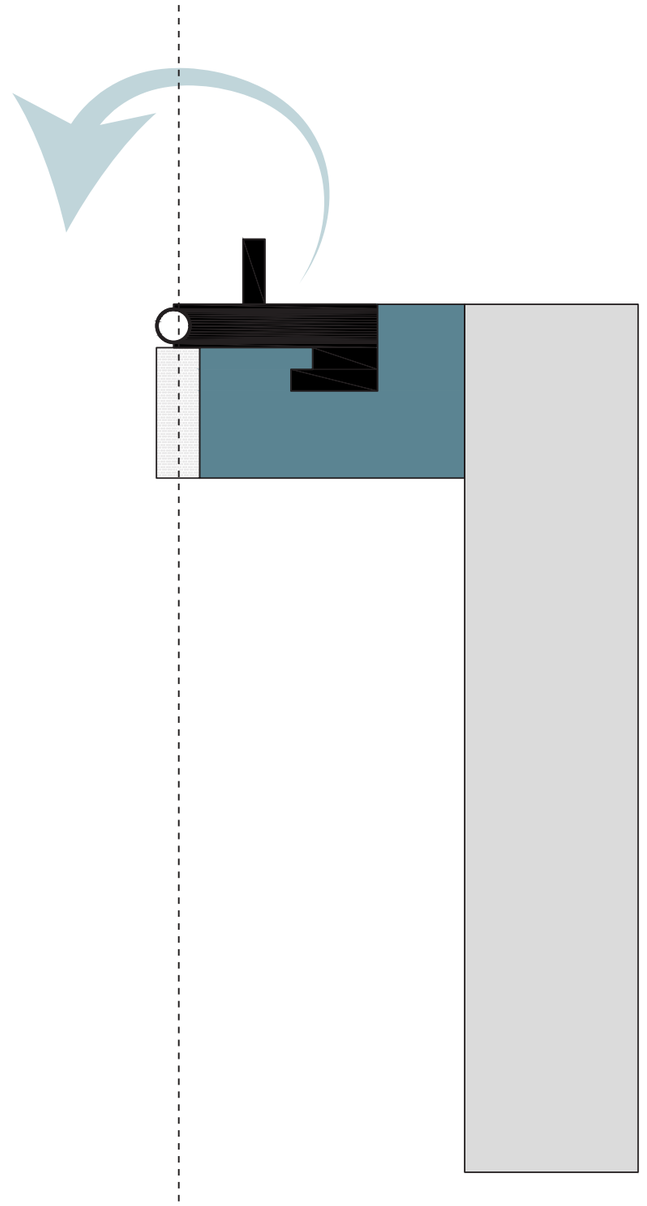
Fusion as alternative to cast glass



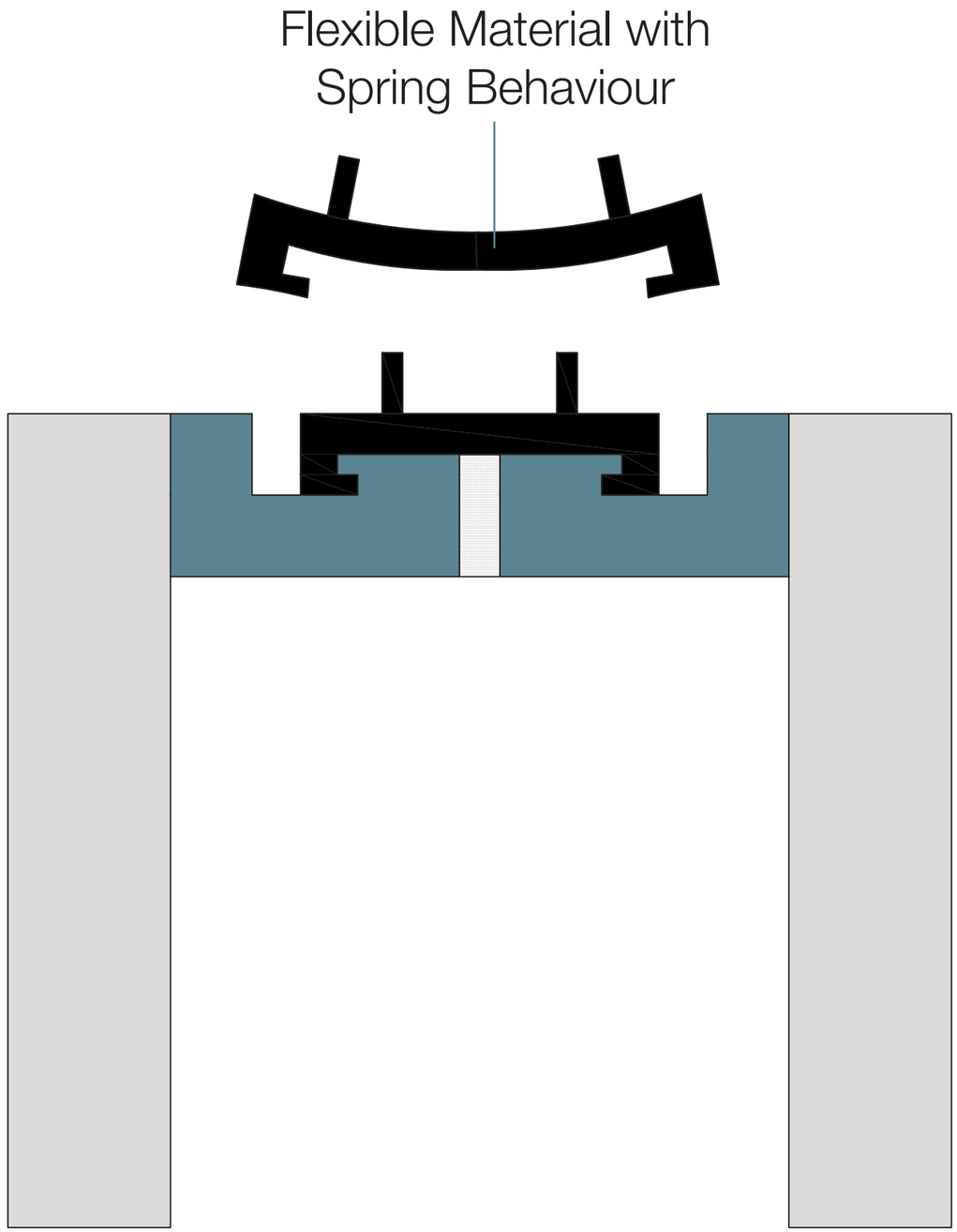
Can we make it fully reversible??



Mirror geometry!

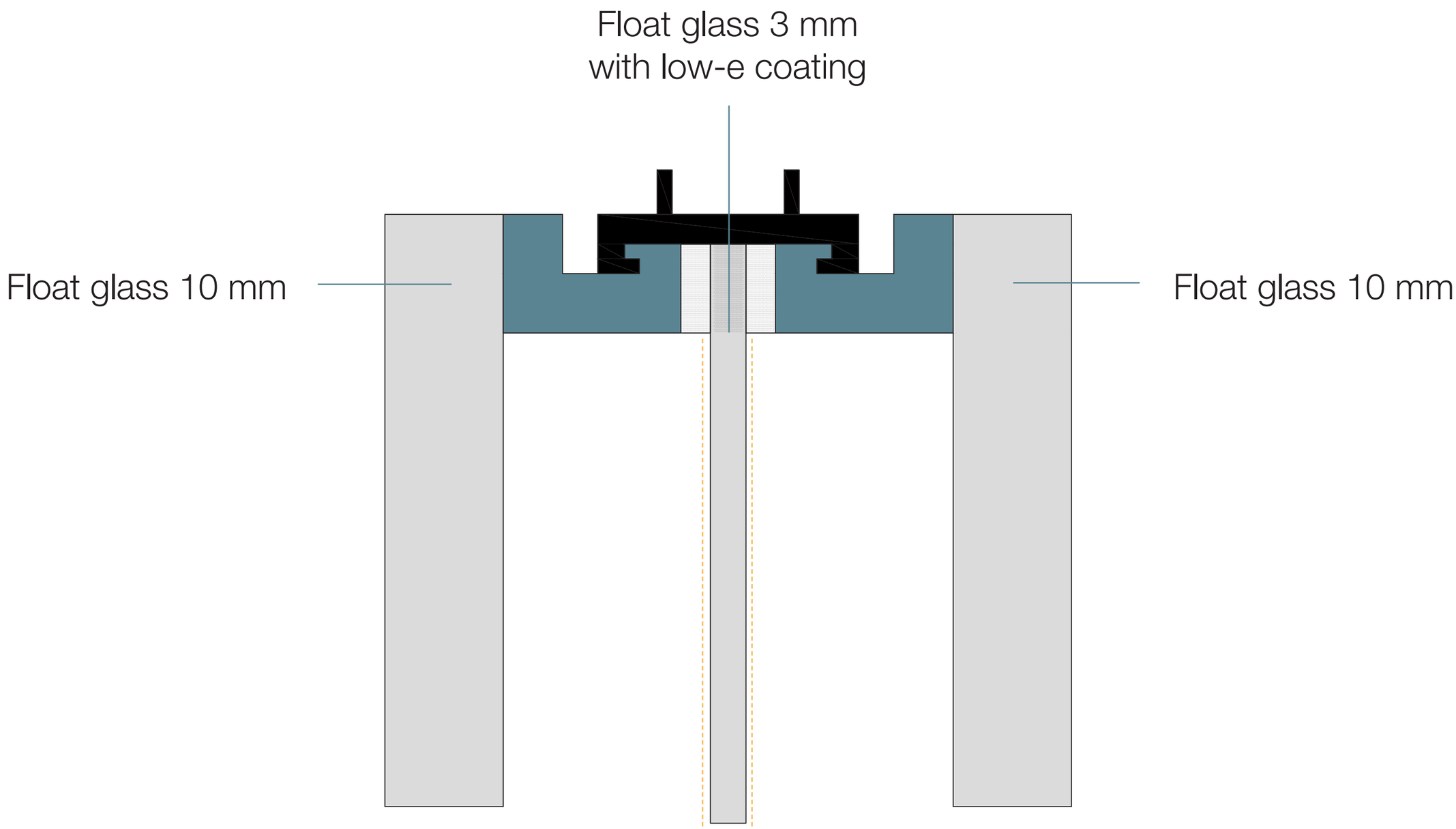


Clamping mechanism



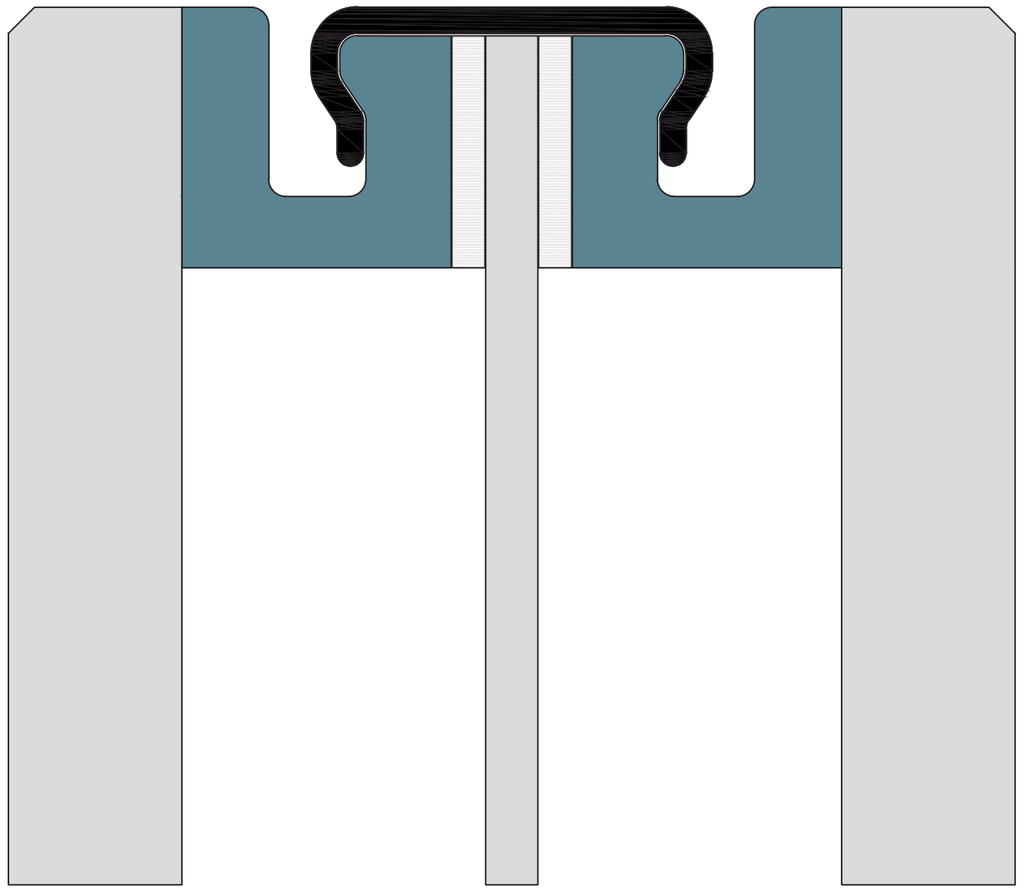
Add third glass pane and coating

u-value = 1.11 W/m2K

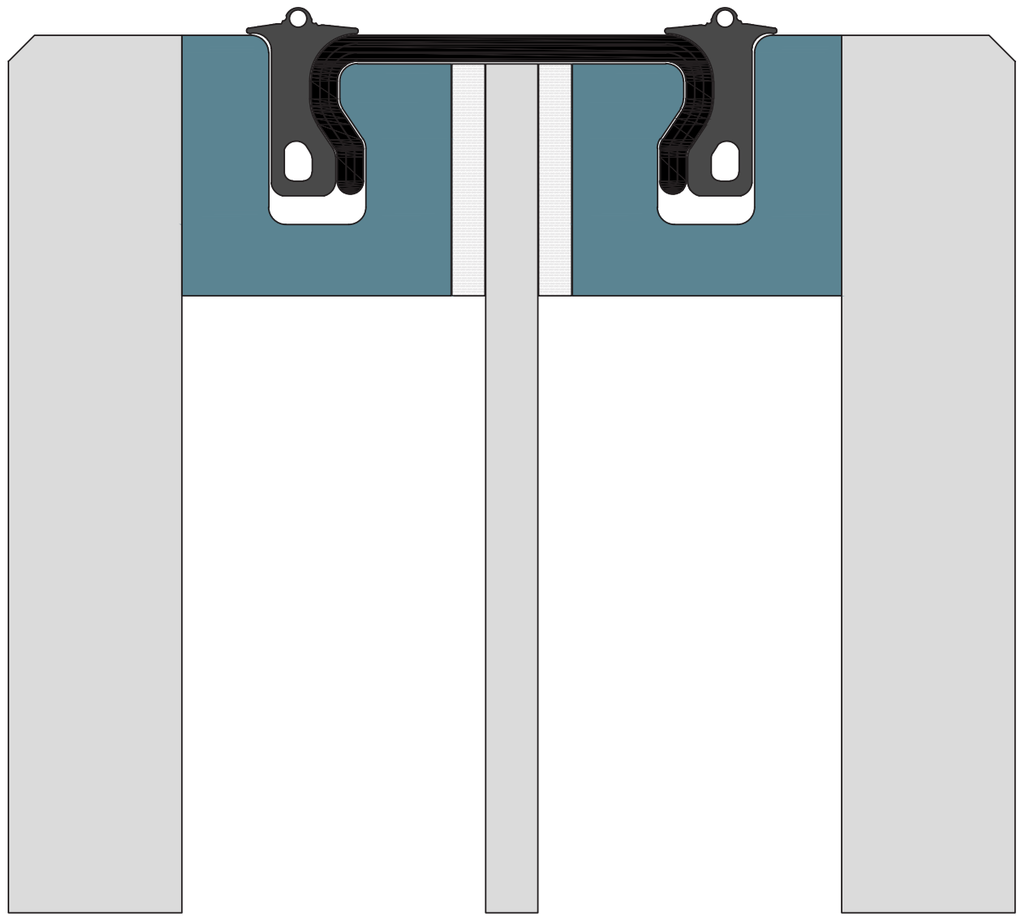


Leave space for tolerances and movements

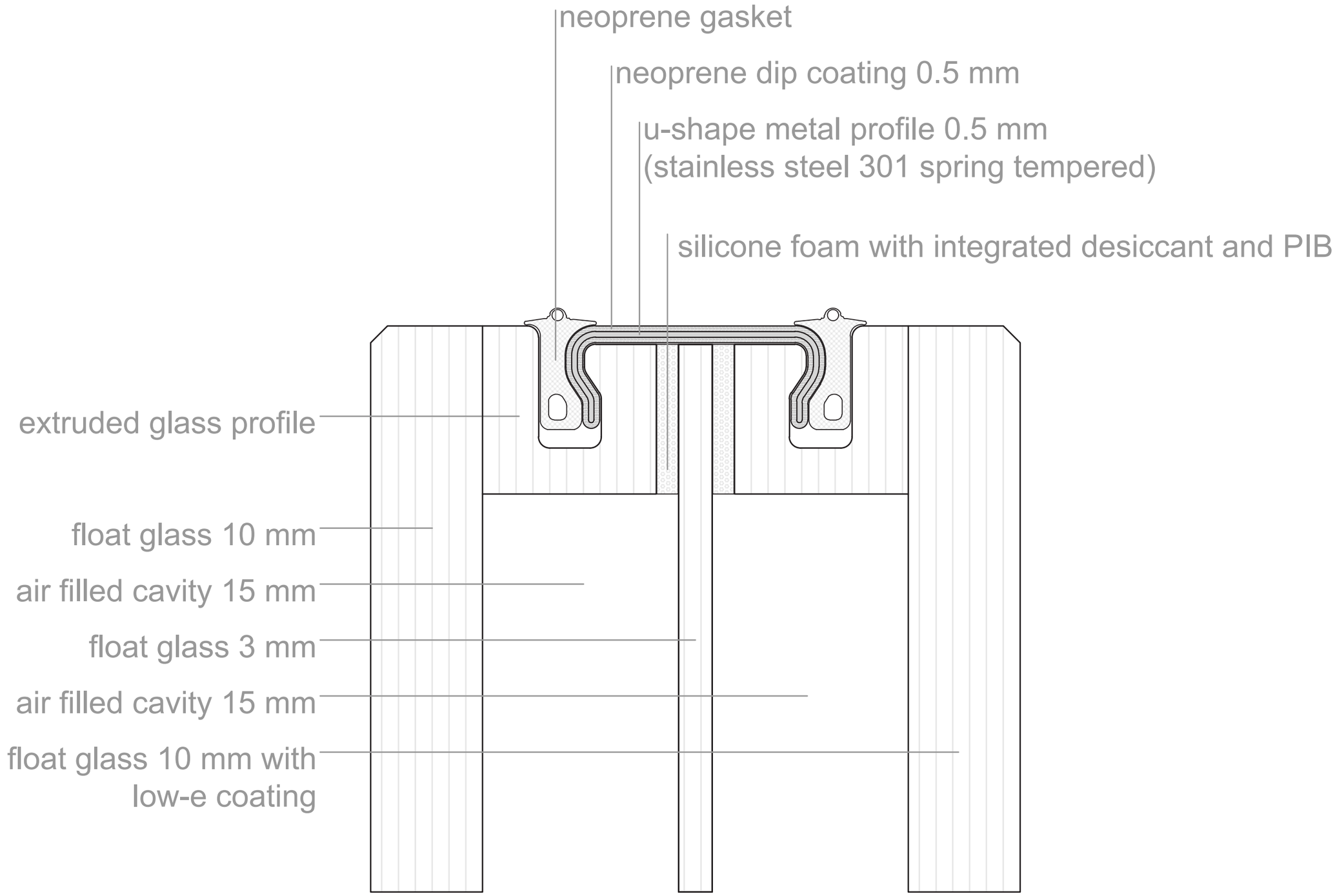
Smoothen glass edges



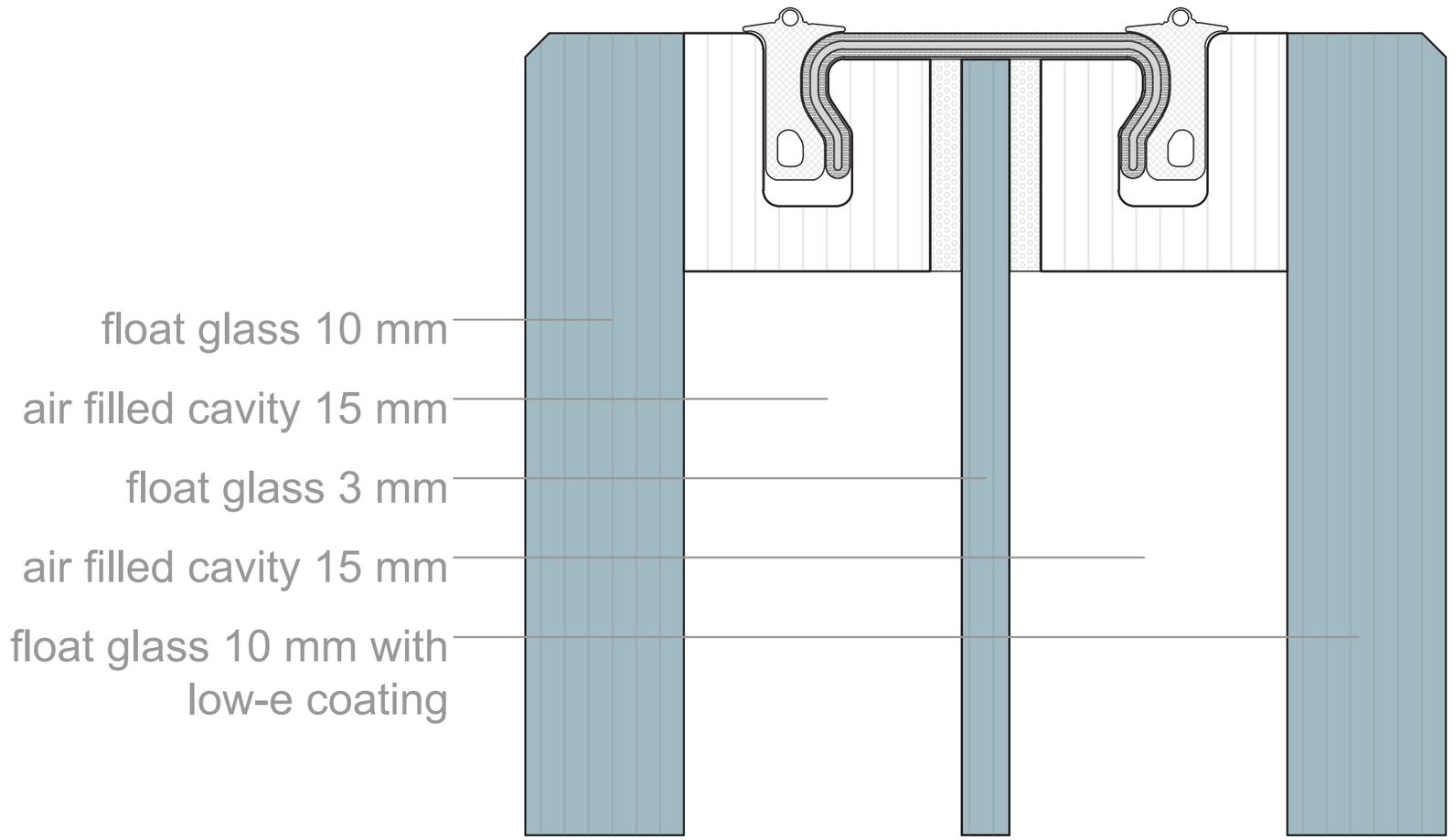
Place gaskets for water and dirt protection



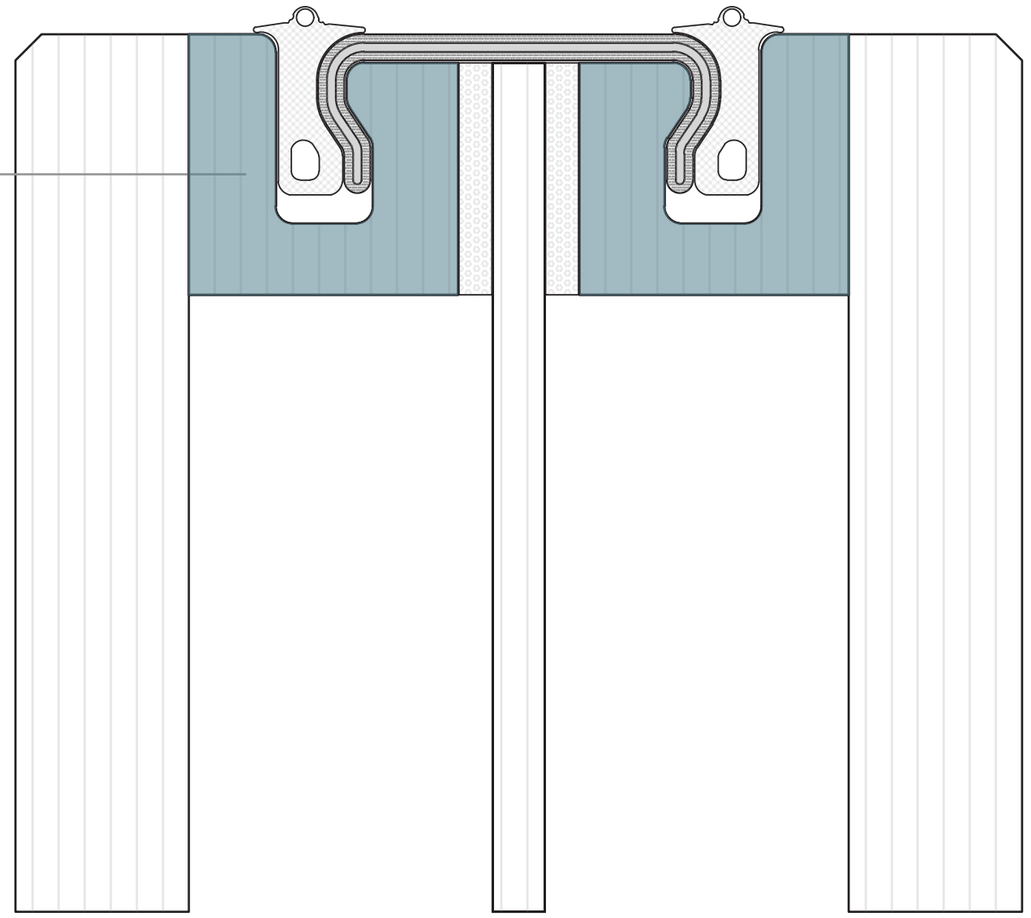
Final Detail

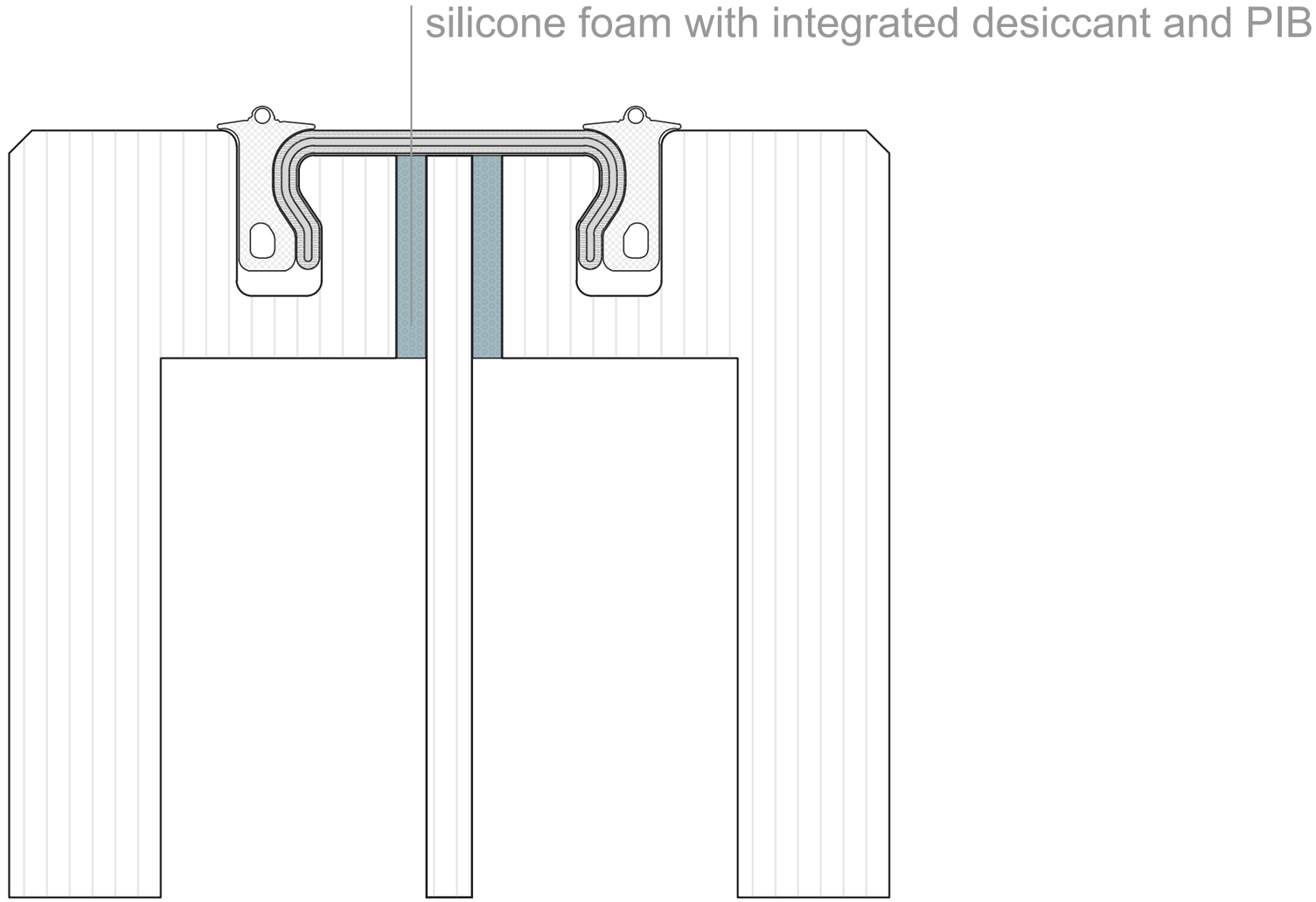


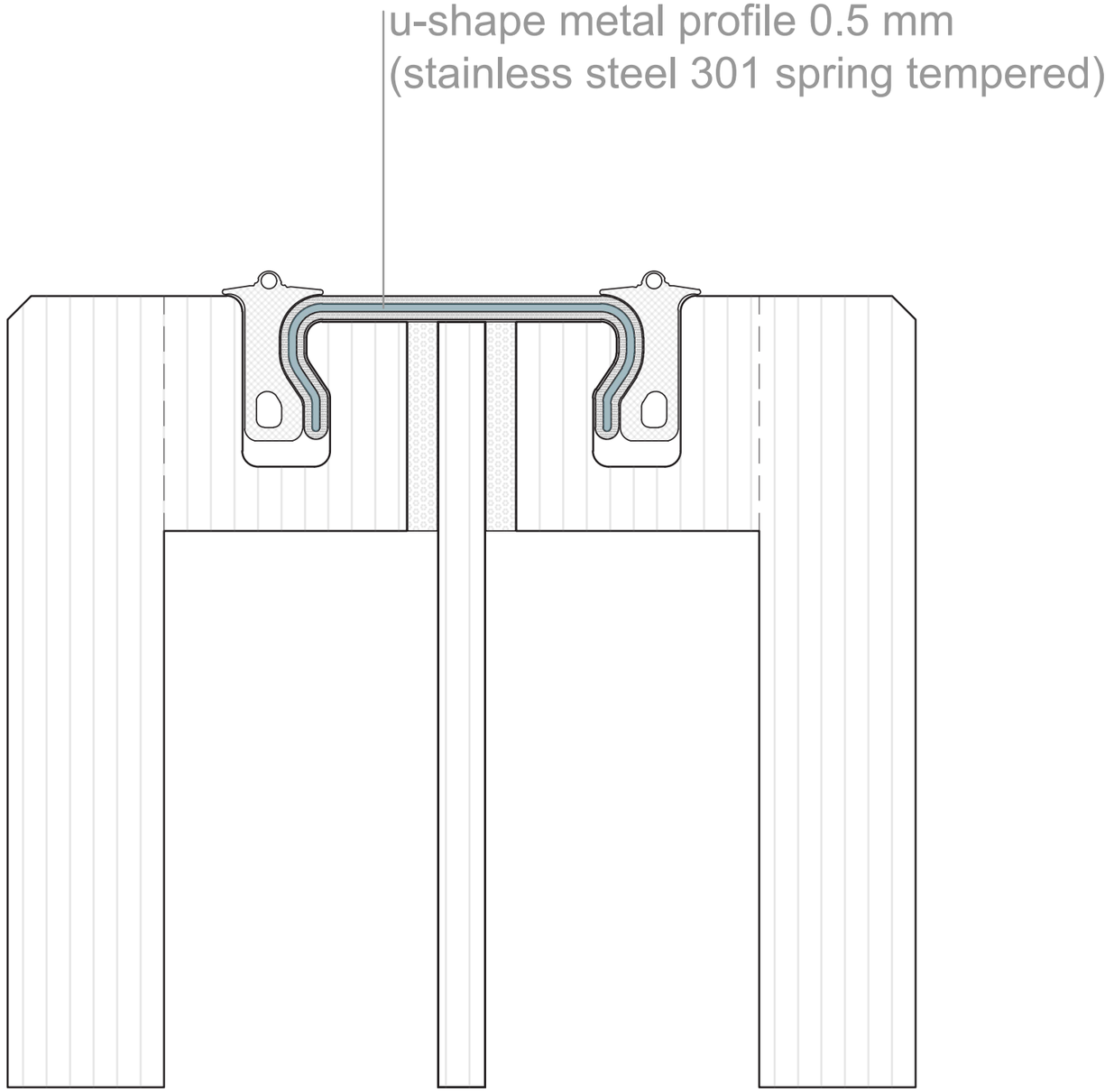
Materials

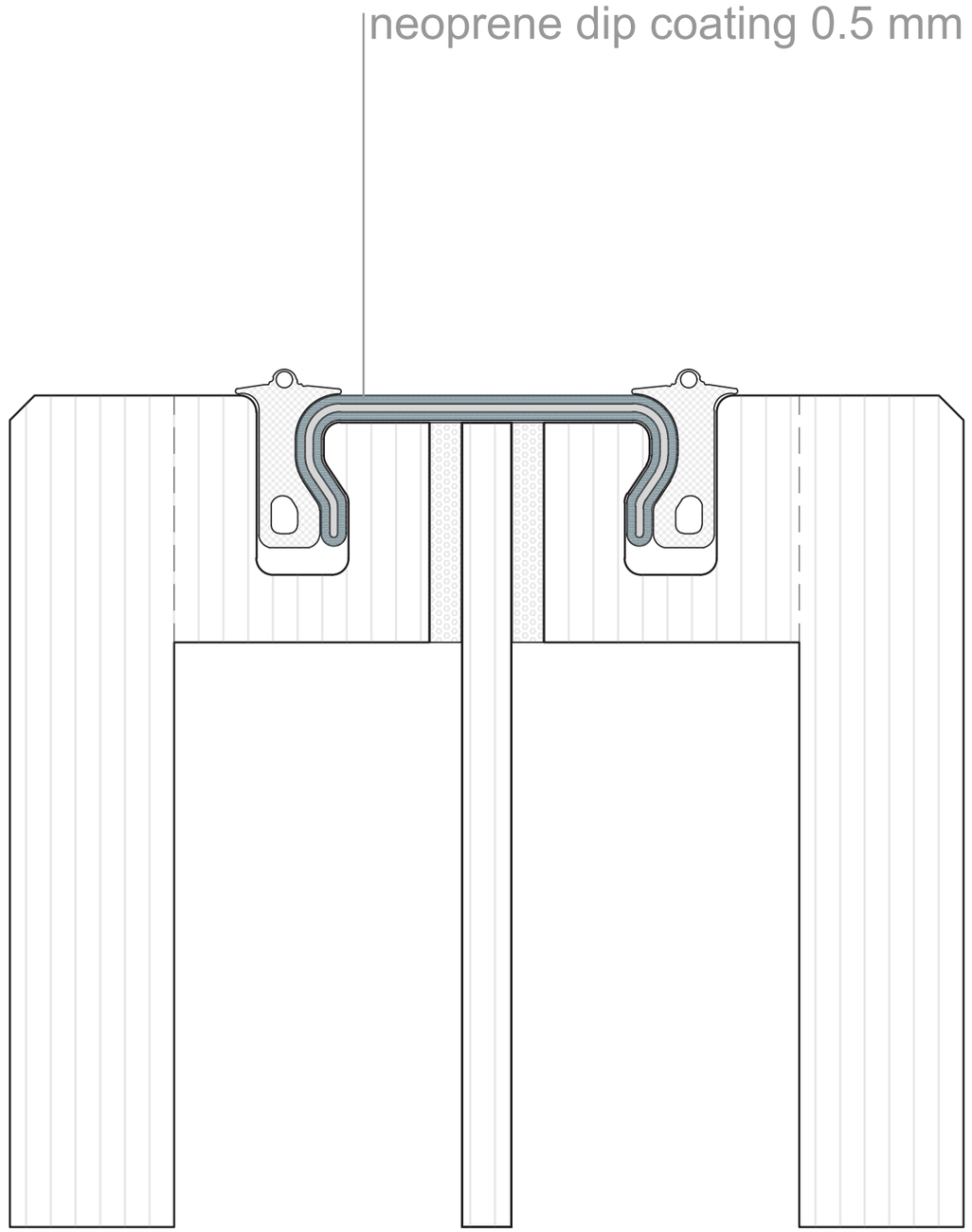

float glass 10 mm
air filled cavity 15 mm
float glass 3 mm
air filled cavity 15 mm
float glass 10 mm with low-e coating

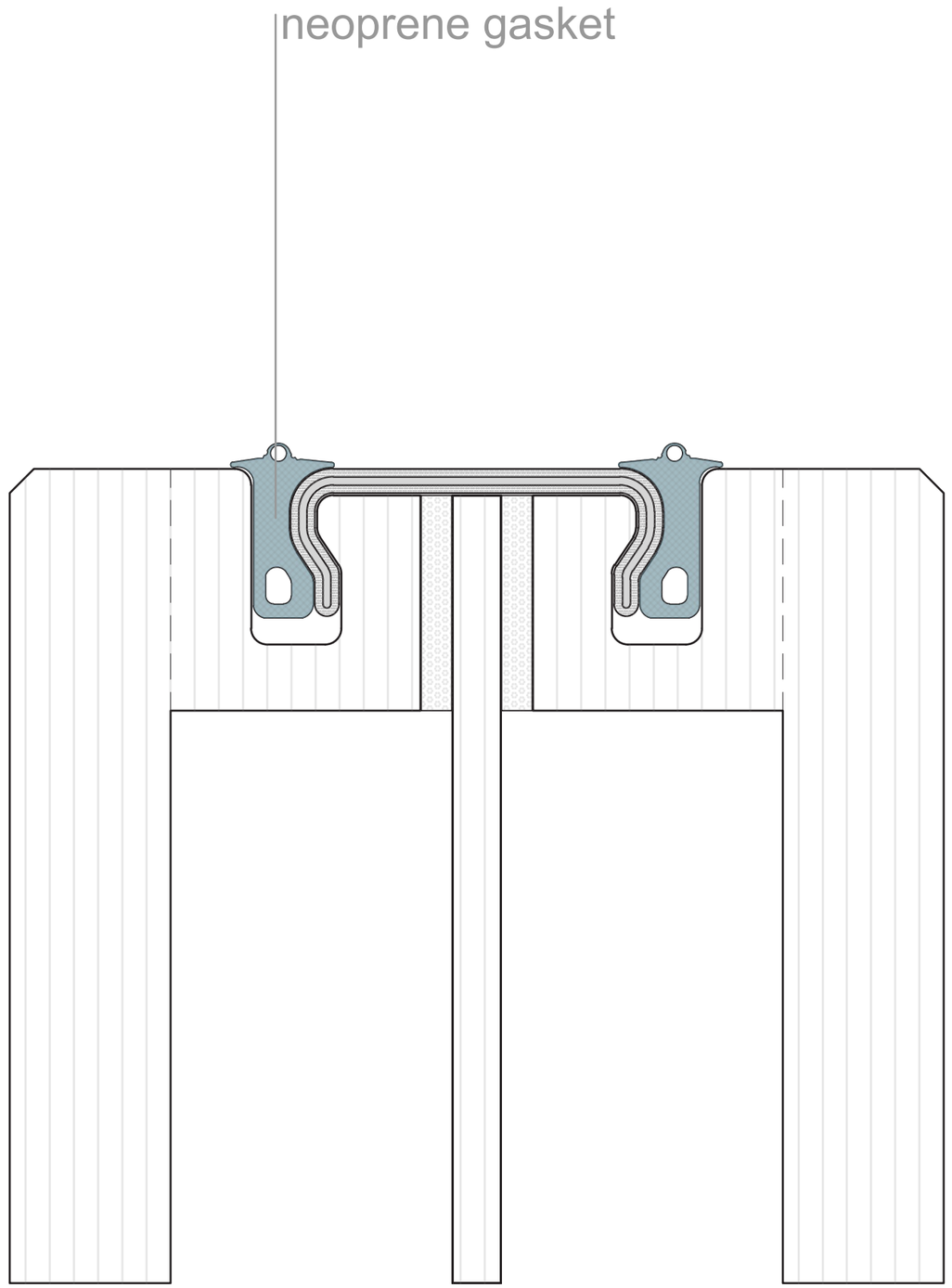
extruded glass profile

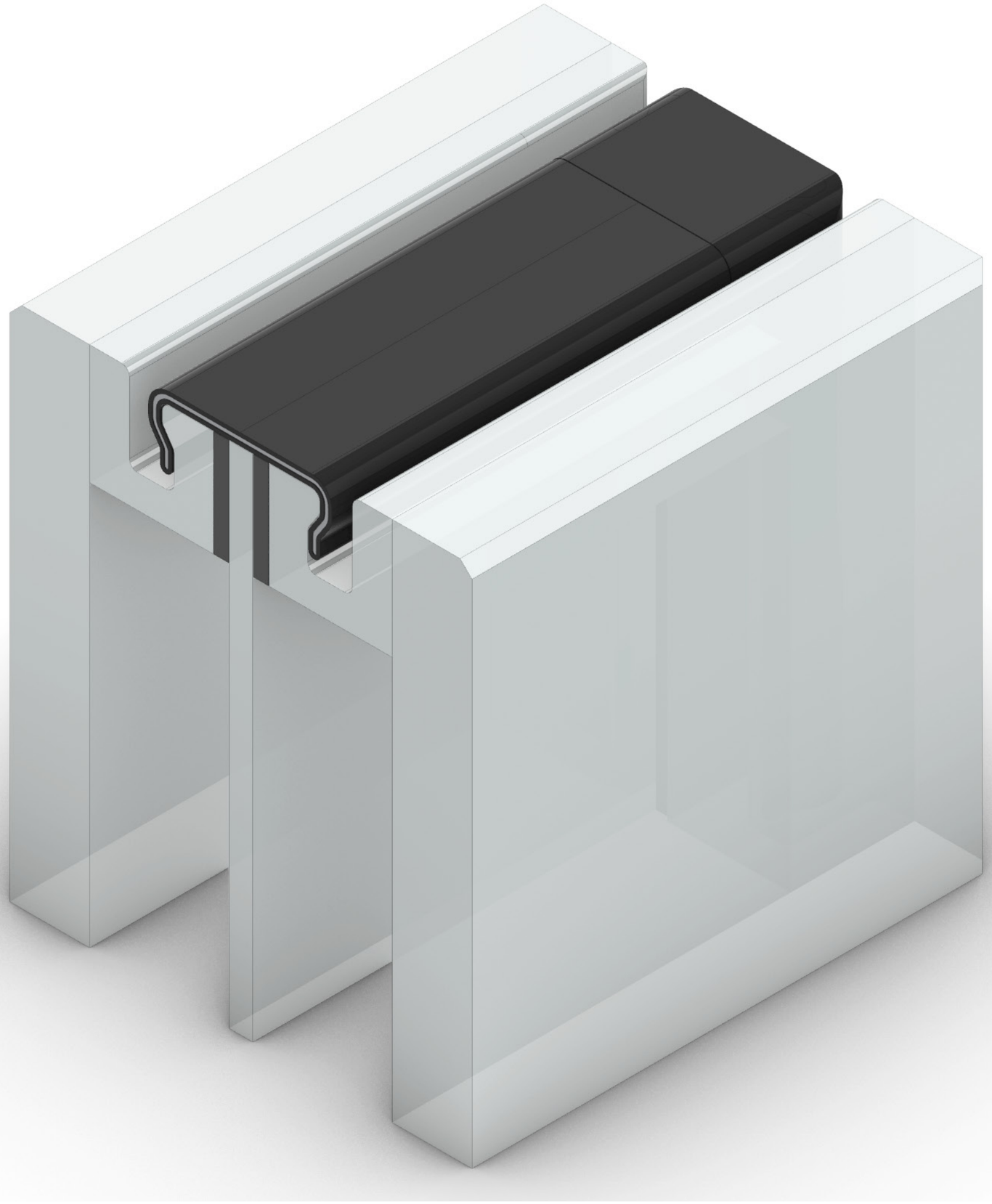


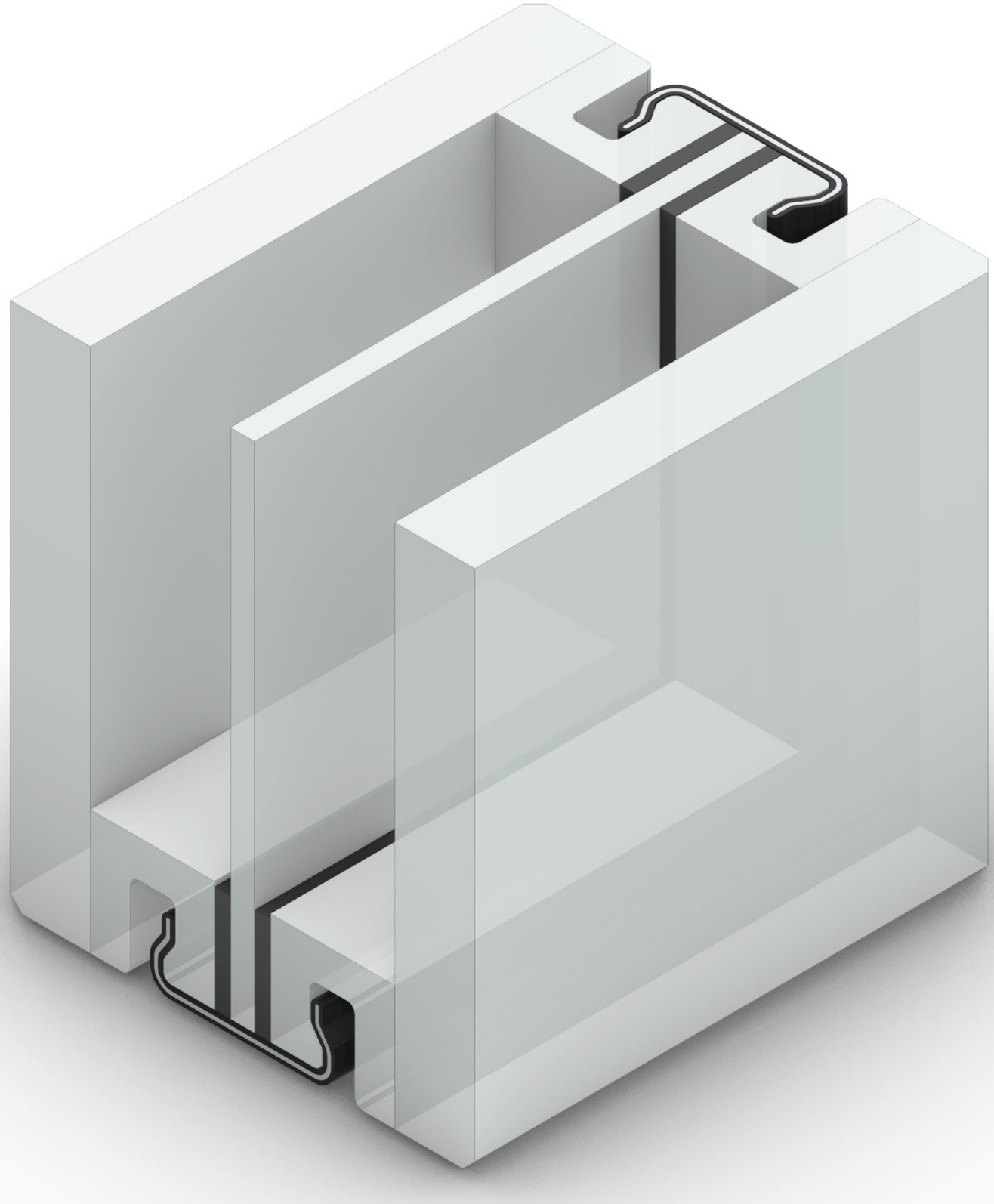

silicone foam with integrated desiccant and PIB


u-shape metal profile 0.5 mm
(stainless steel 301 spring tempered)


neoprene dip coating 0.5 mm


neoprene gasket

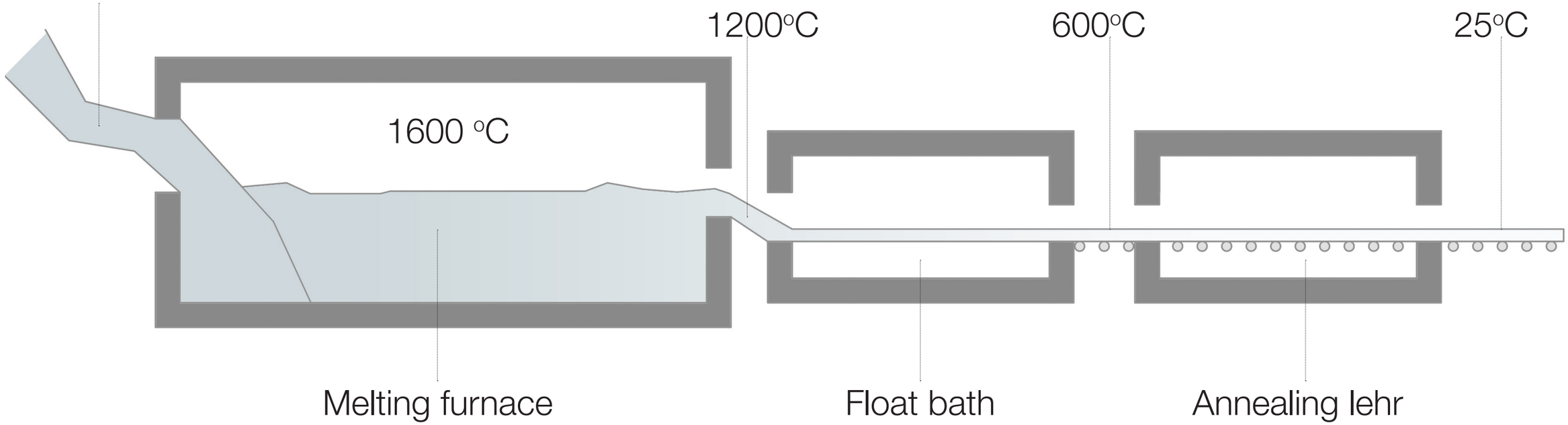




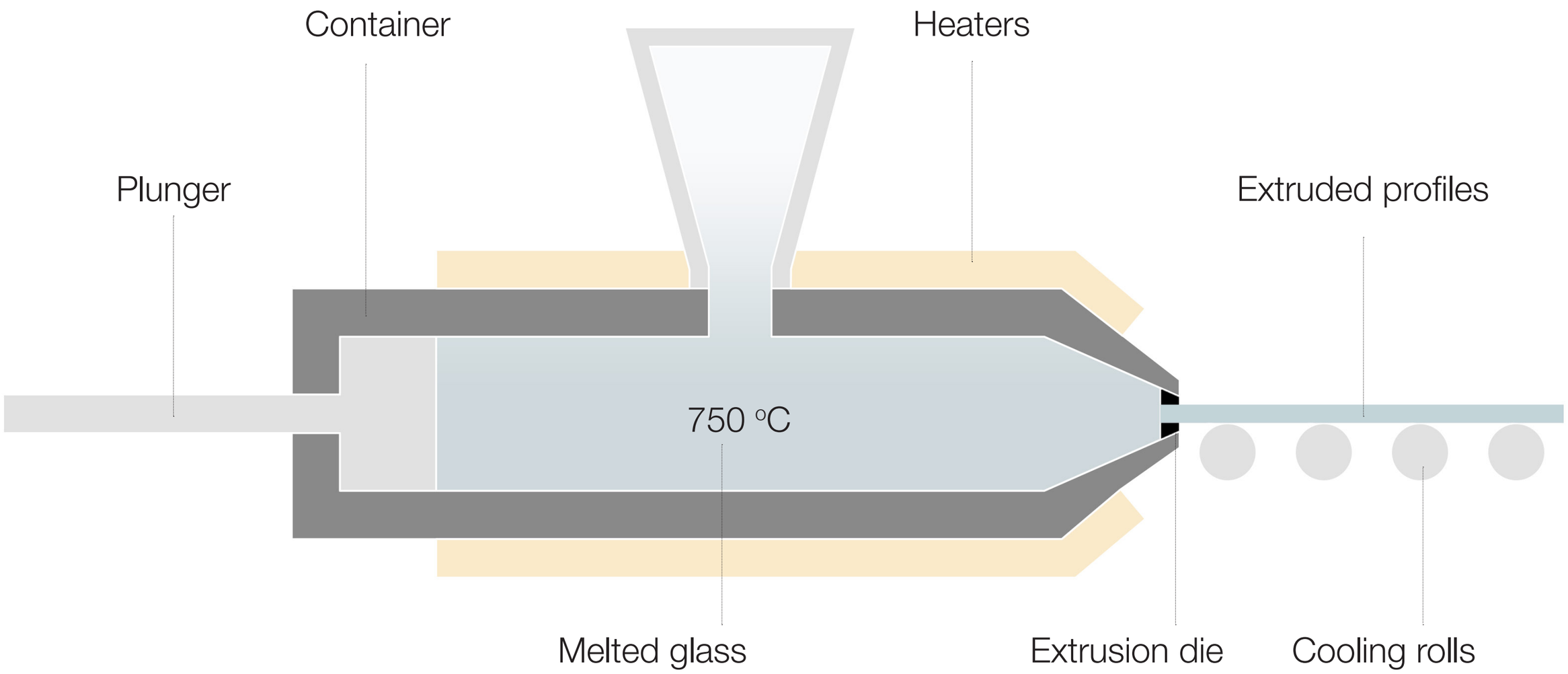
Glass Manufacturing

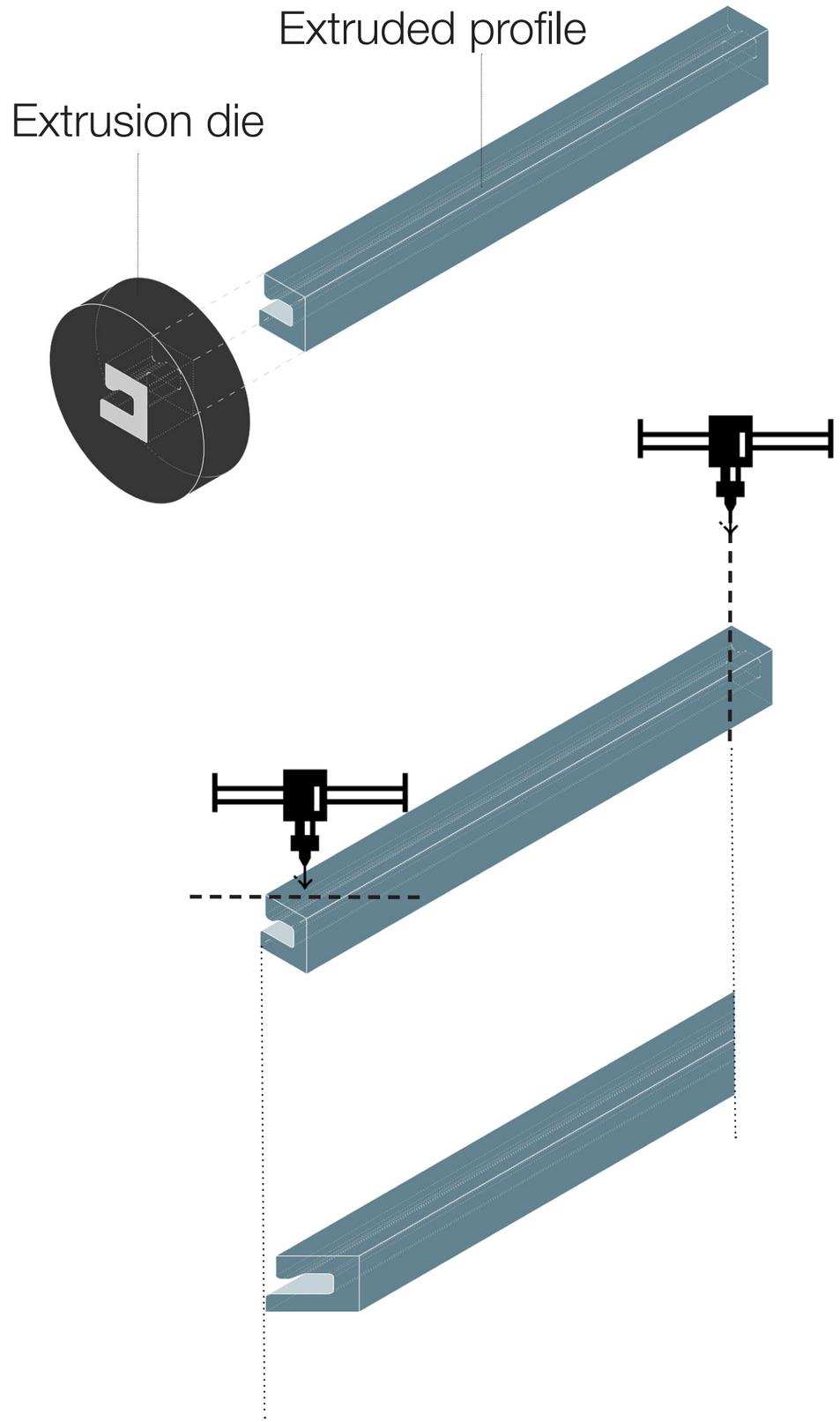
1. Float Glass Panes

Raw materials

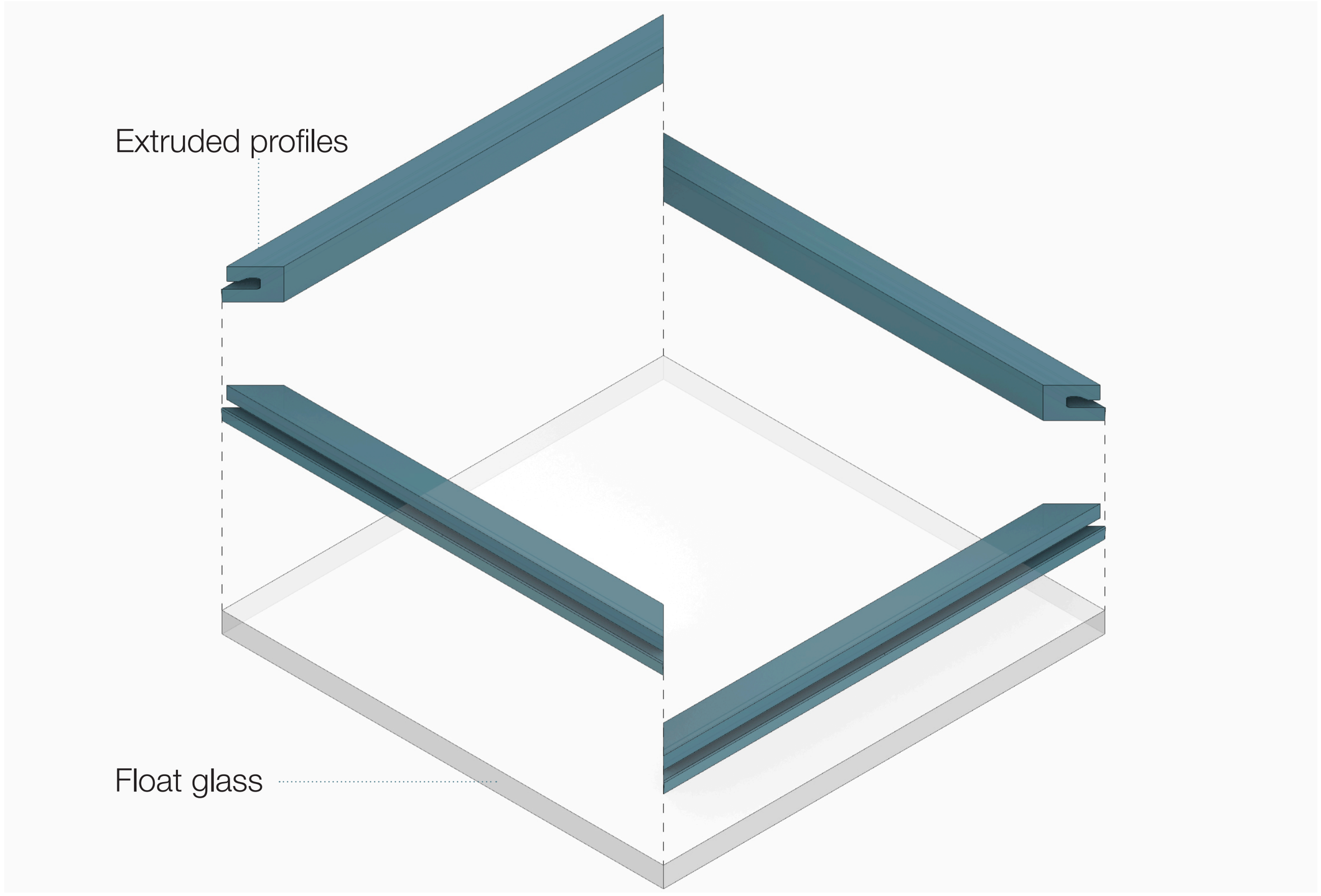


2. Extruded Glass Profiles

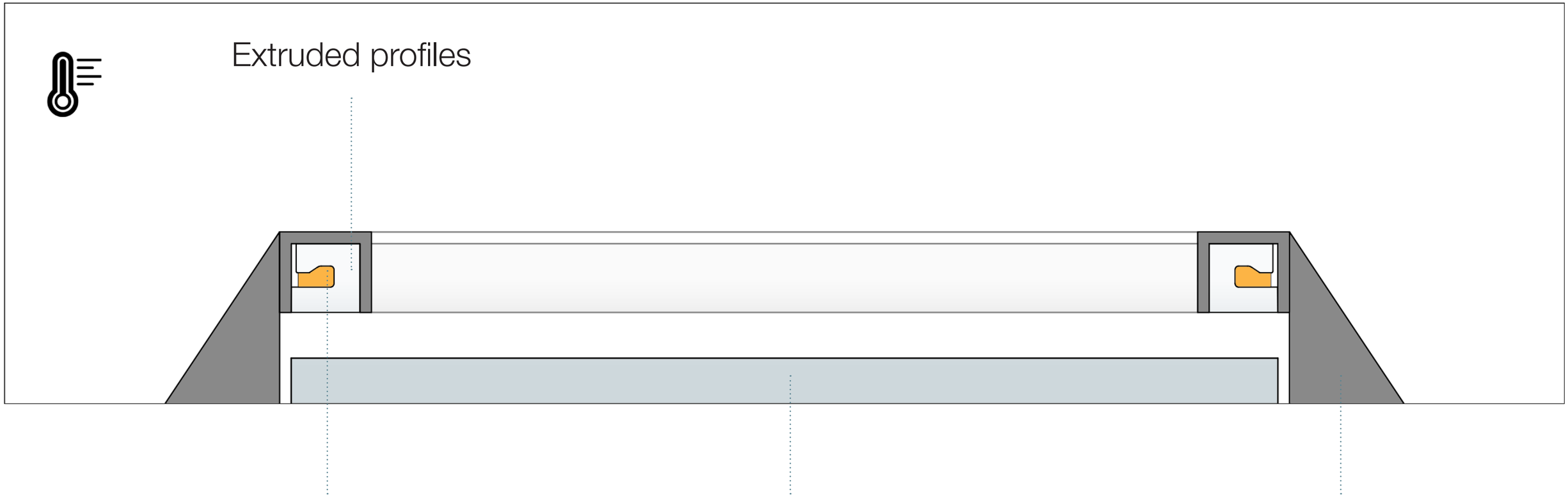



Extruded profile
Extrusion die

3. Glass Tack Fusion

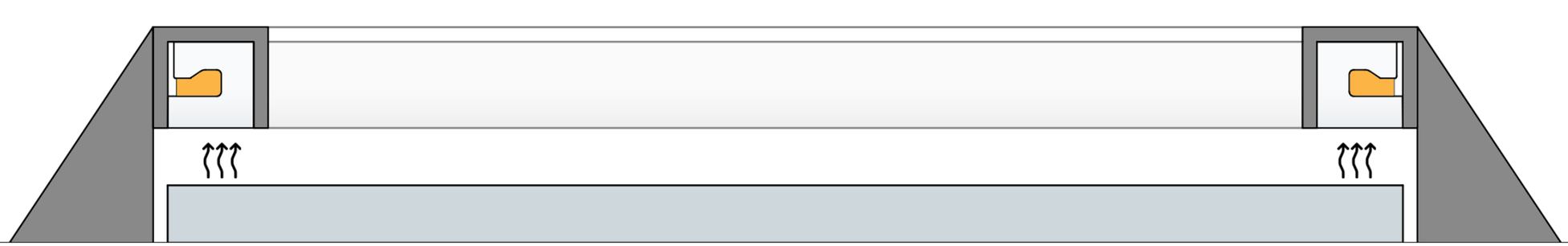


Place inside oven and place supports



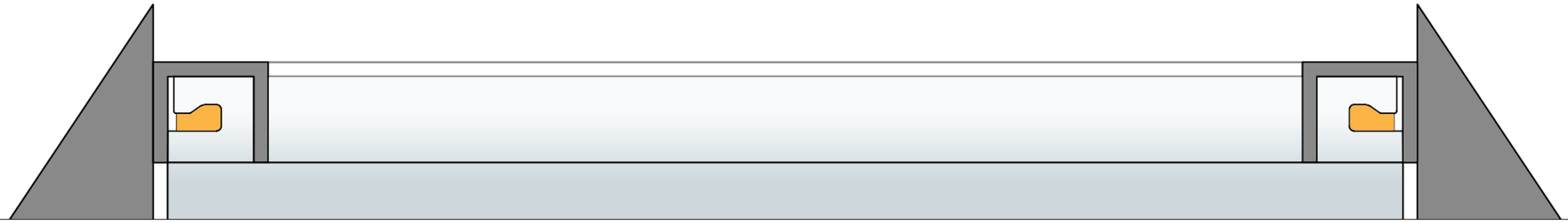
Heat up oven to 650 °C

650 °C



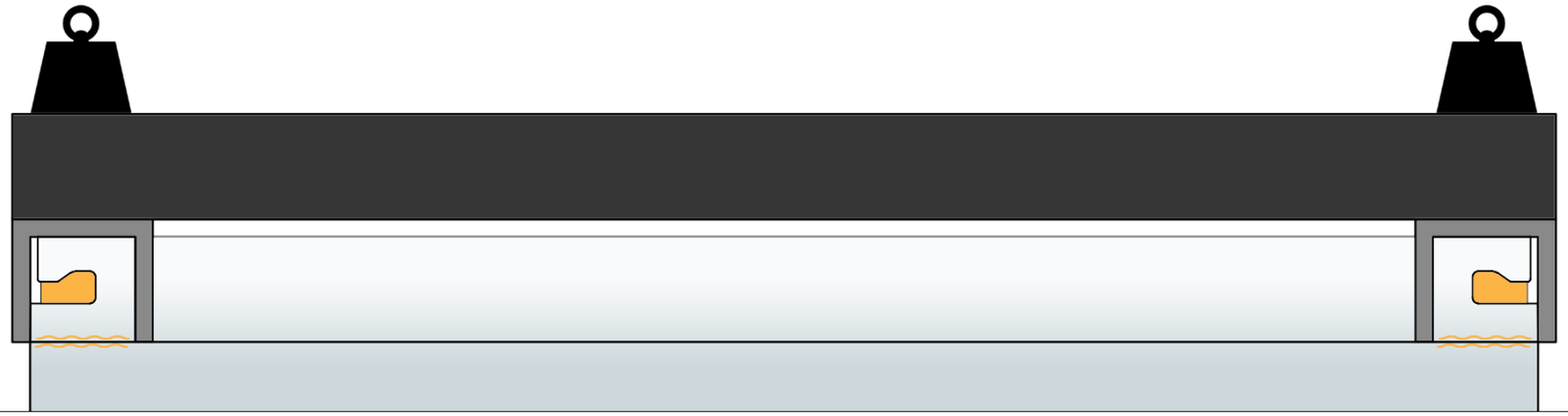
Lower extruded glass

650 °C



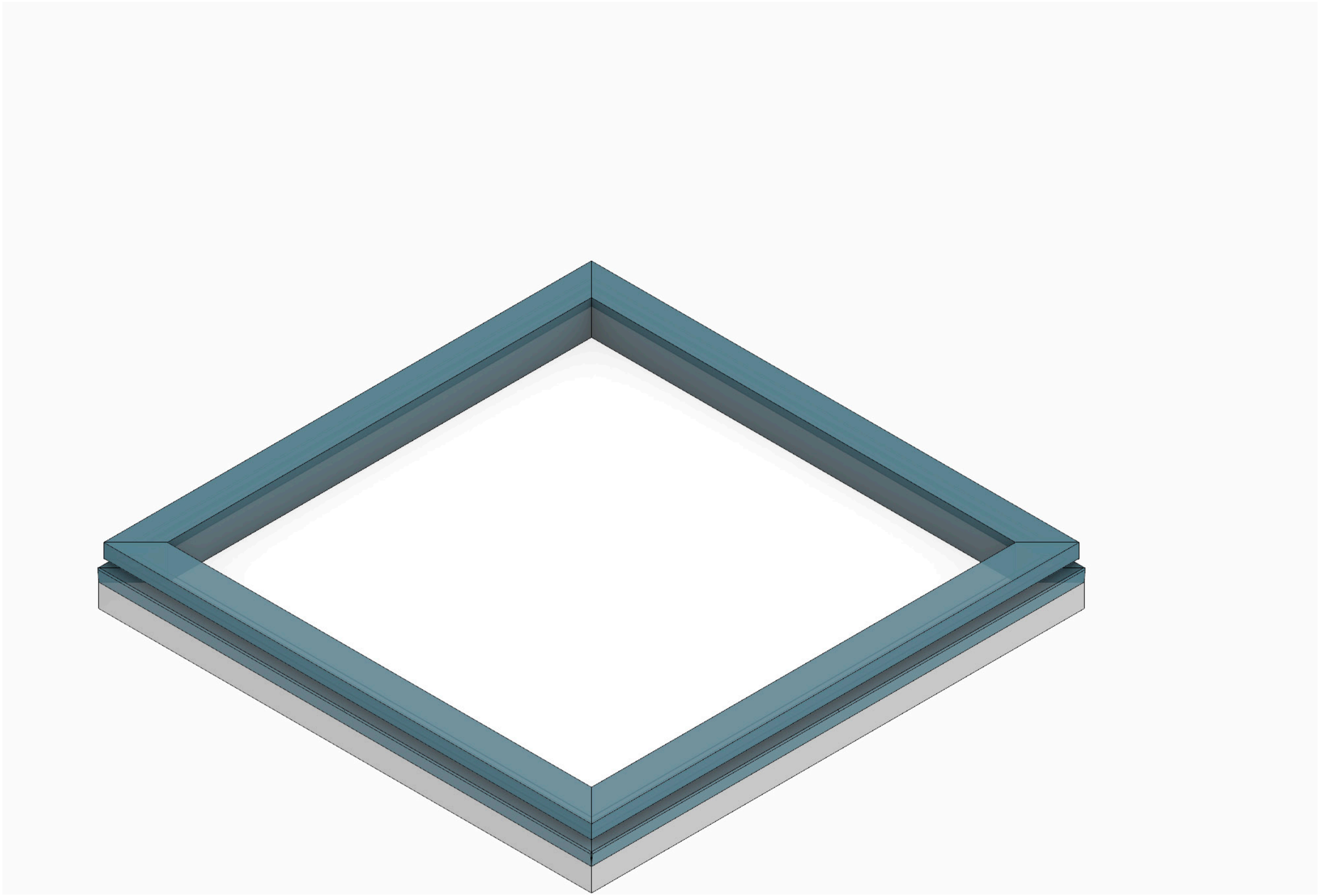
Place press on top of extruded glass

650 °C

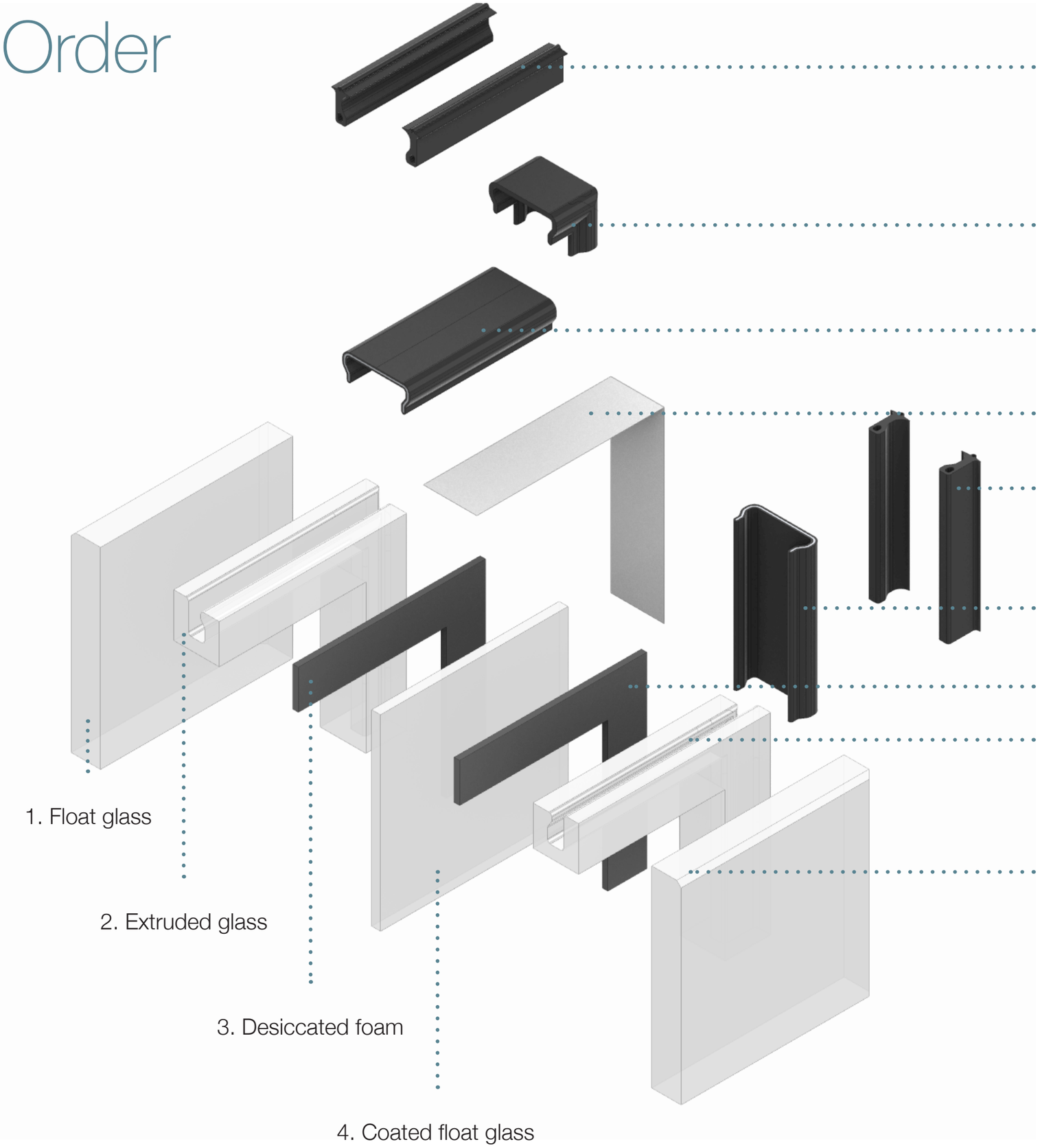


Remove press and supports

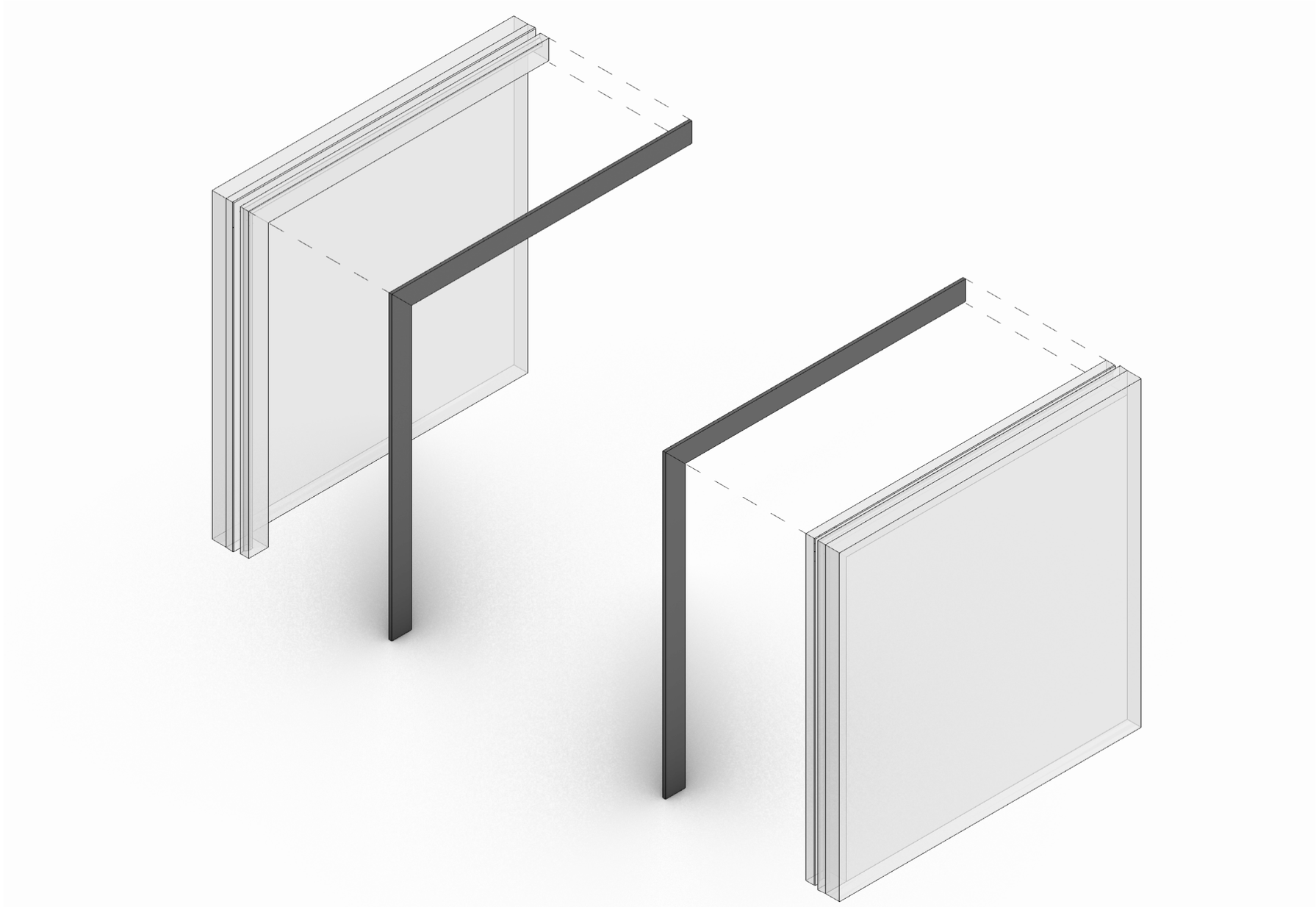
Let glass cool down



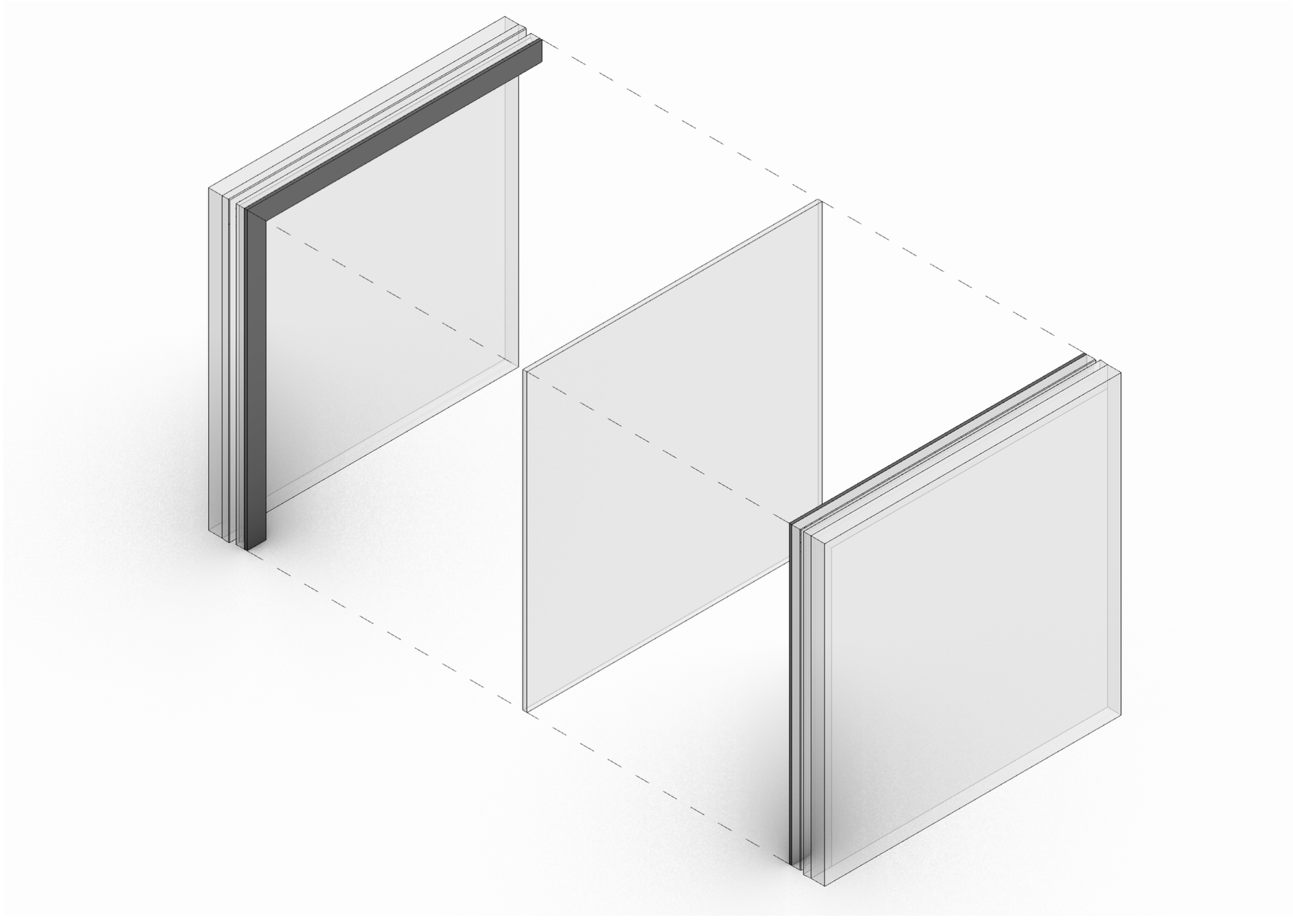
Assembly Order



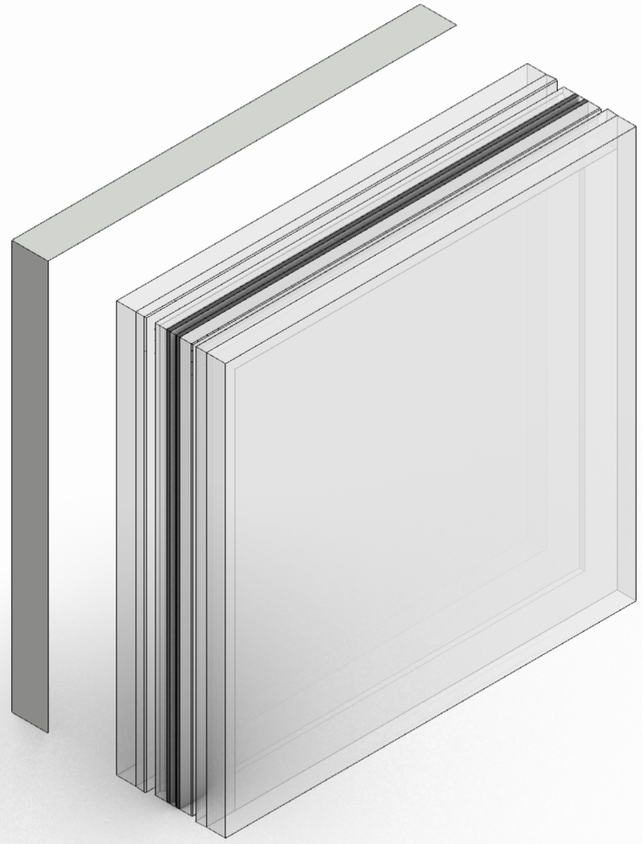
5. Application of silicone foam with integrated desiccant



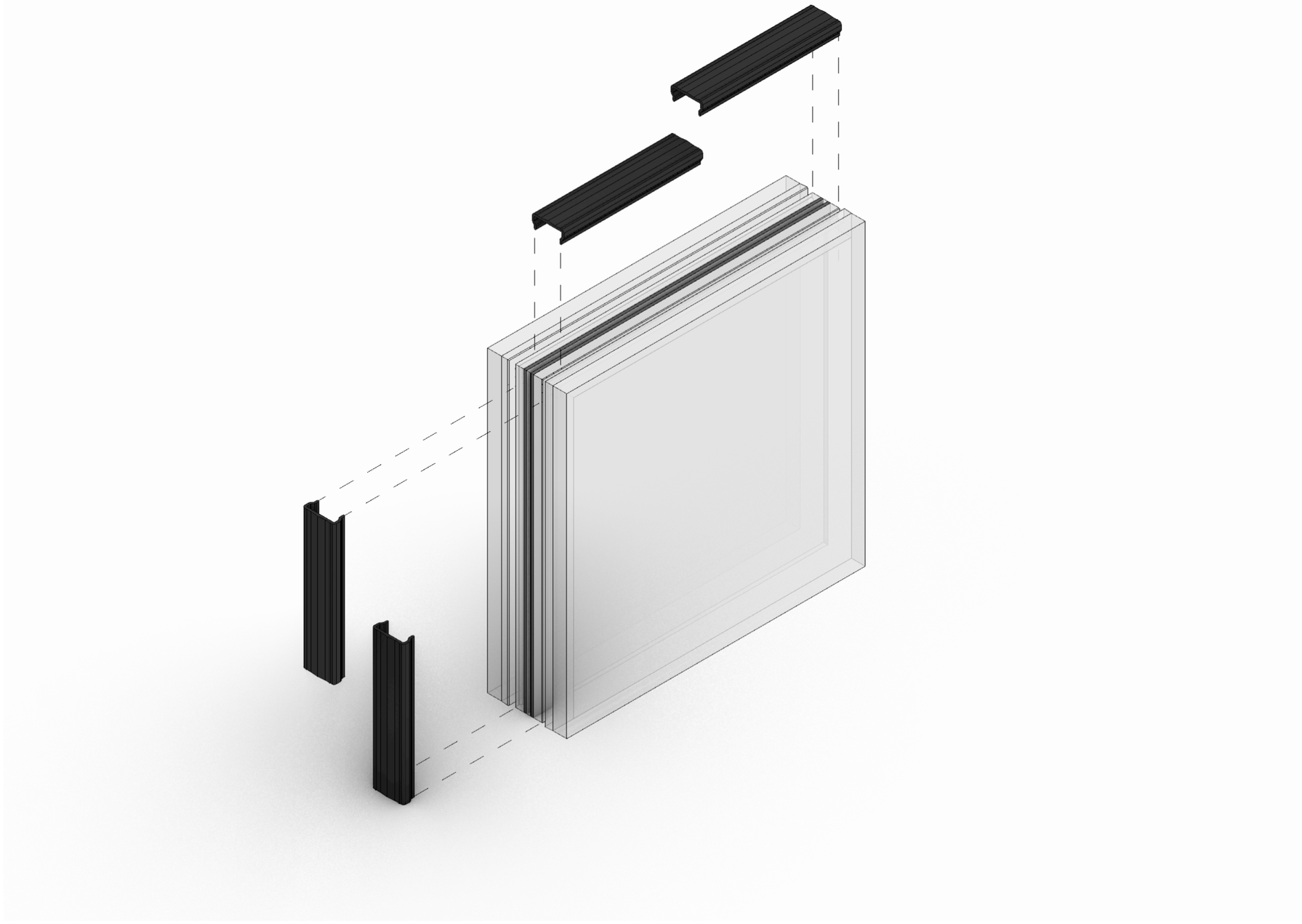
6. Addition of third glass pane



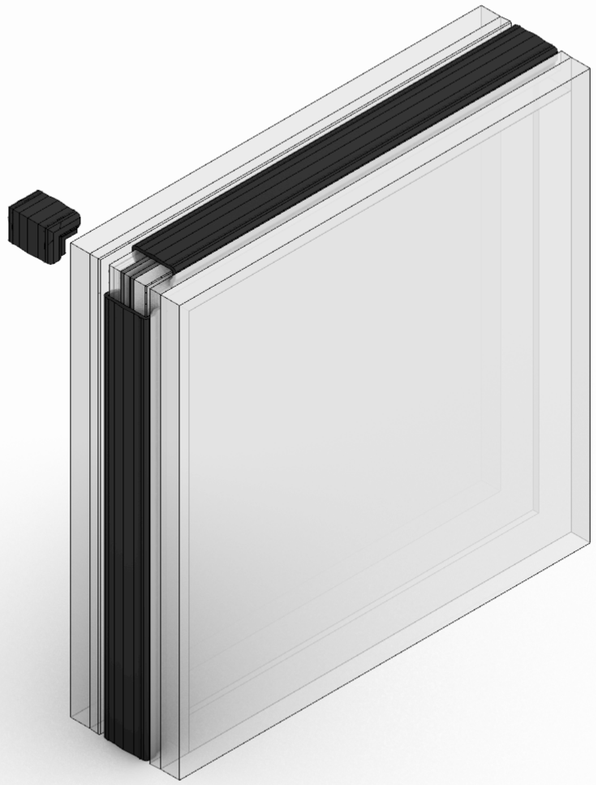
7. Application of aluminum tape around edge seal



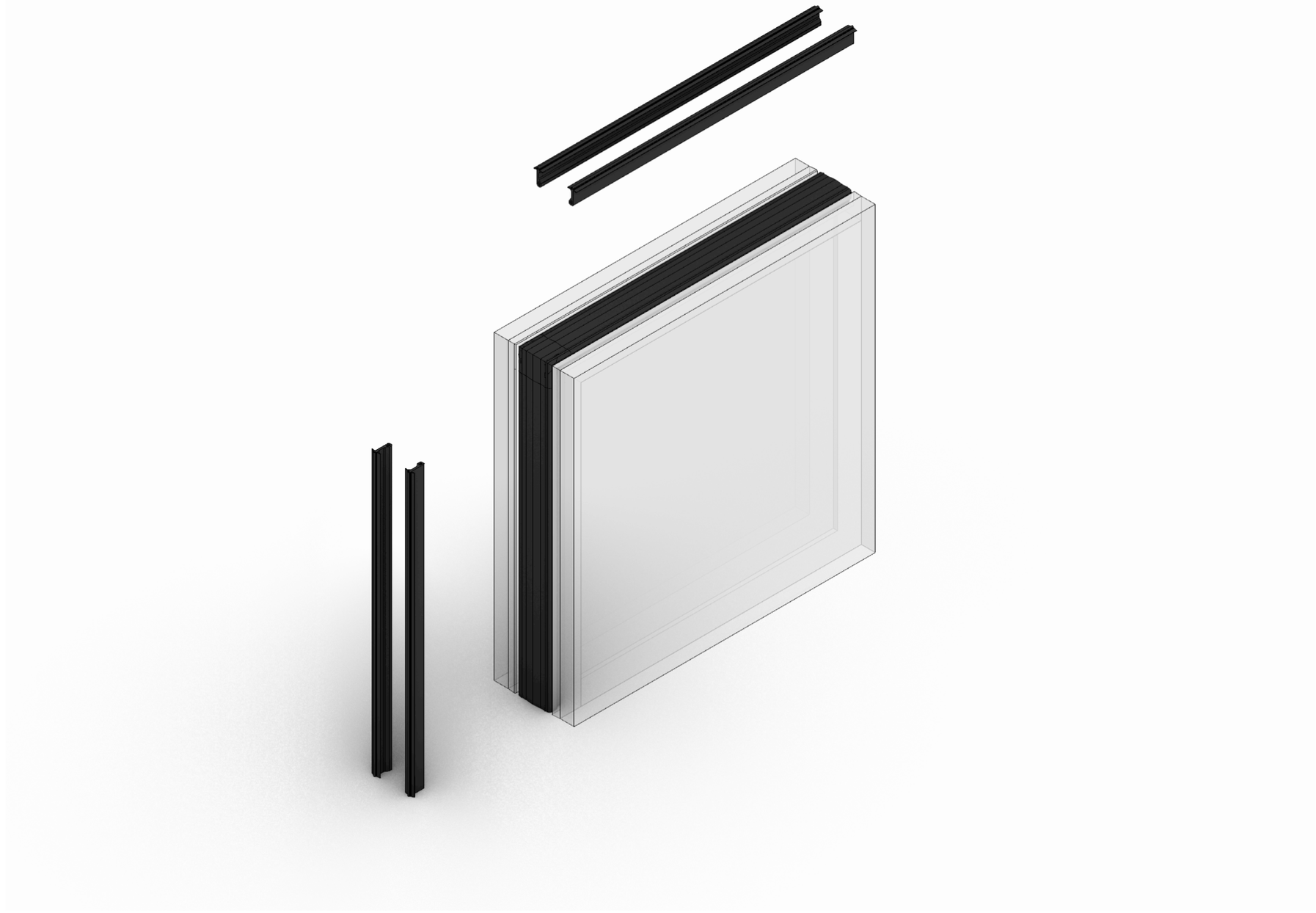
8. Application of spring clips

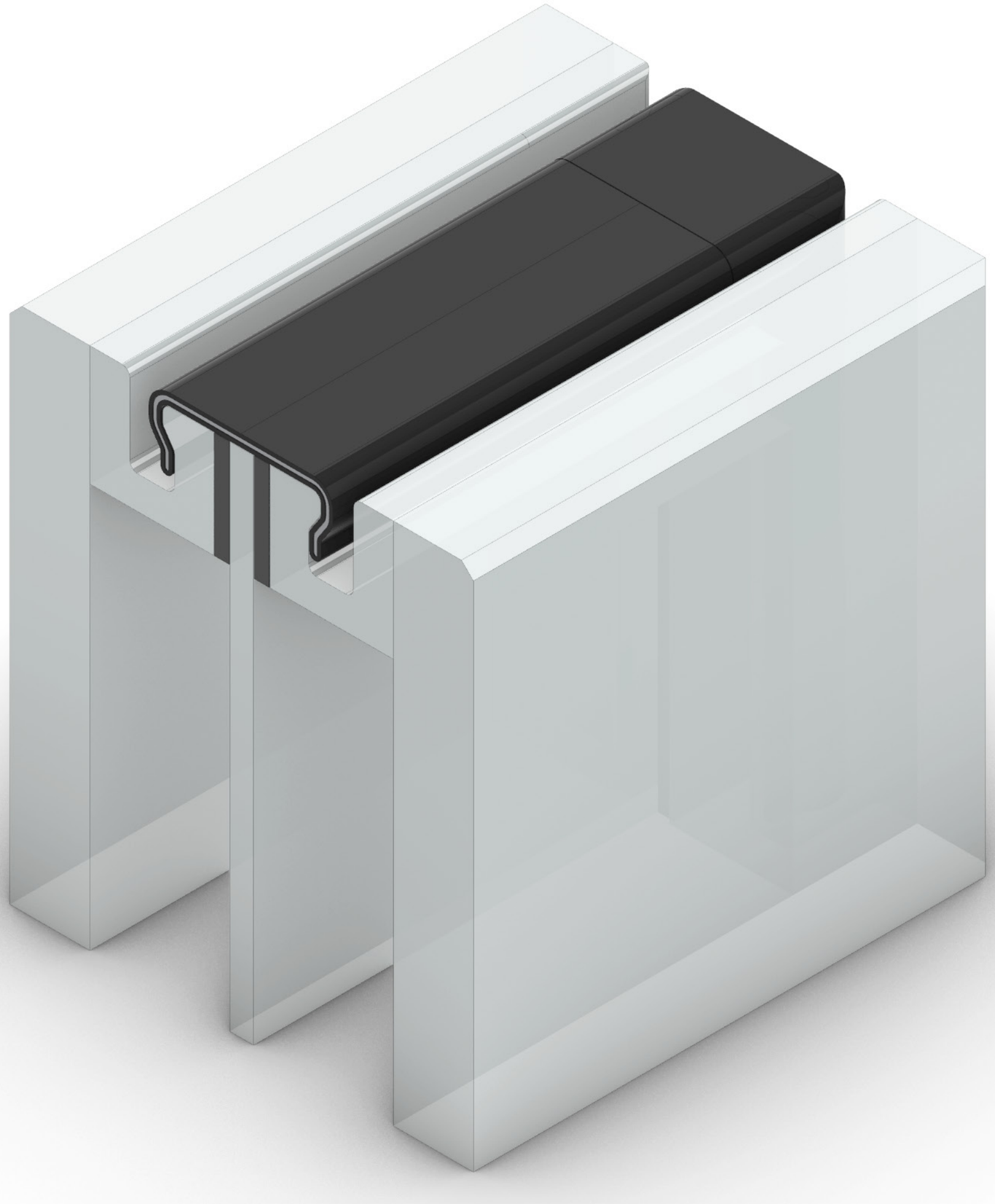


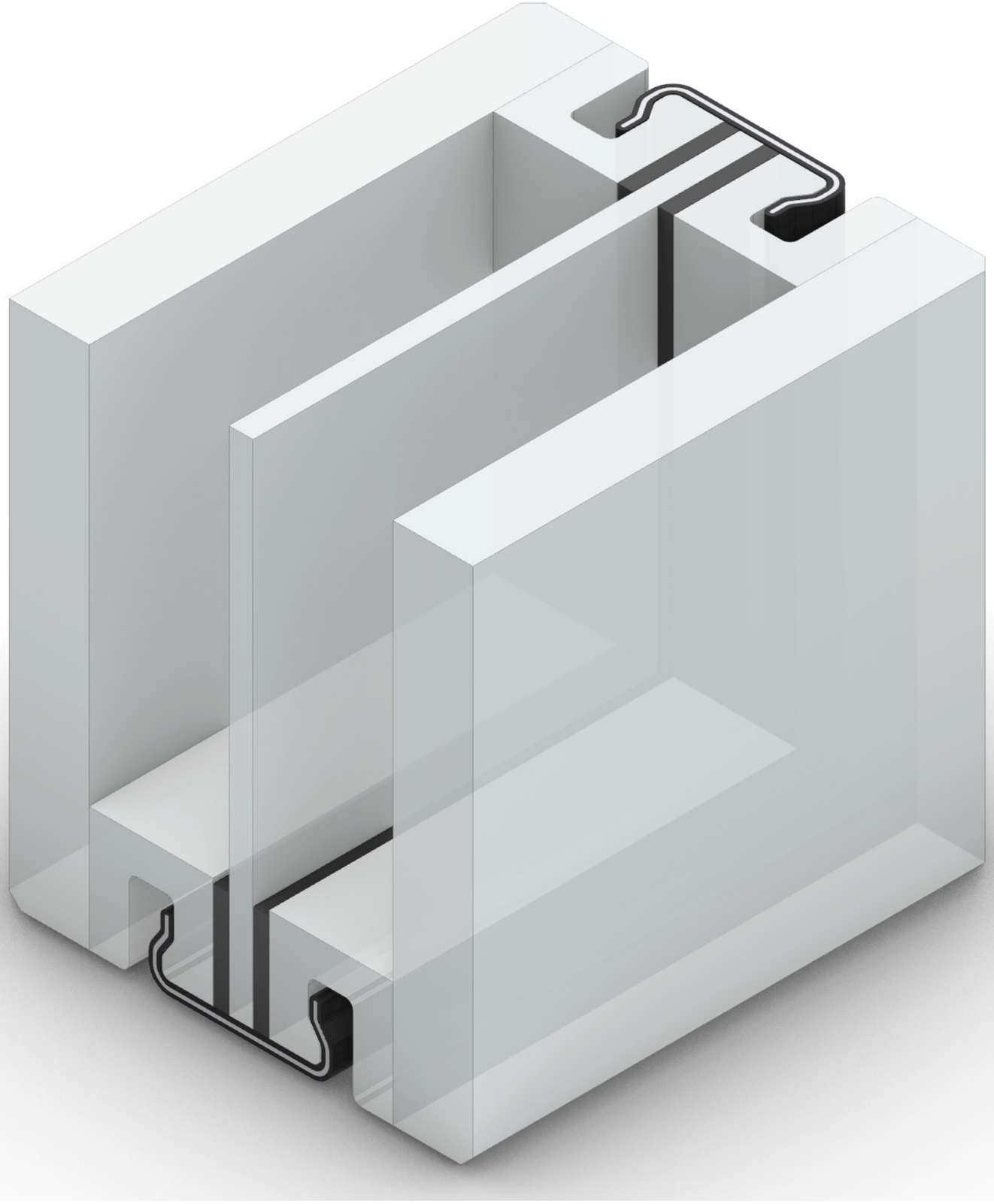
9. Fixing of corner pieces



10. Application of neoprene gaskets







causes of failure

causes of failure

1. edge seal failure

causes of failure

1. edge seal failure

2. coating’s reduced performance

causes of failure

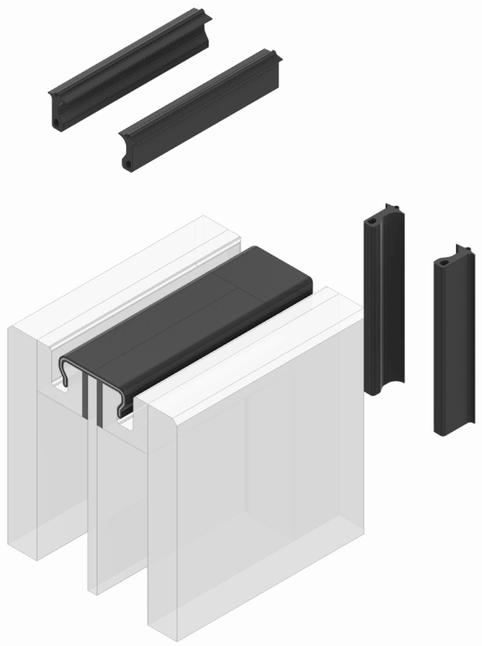
1. edge seal failure

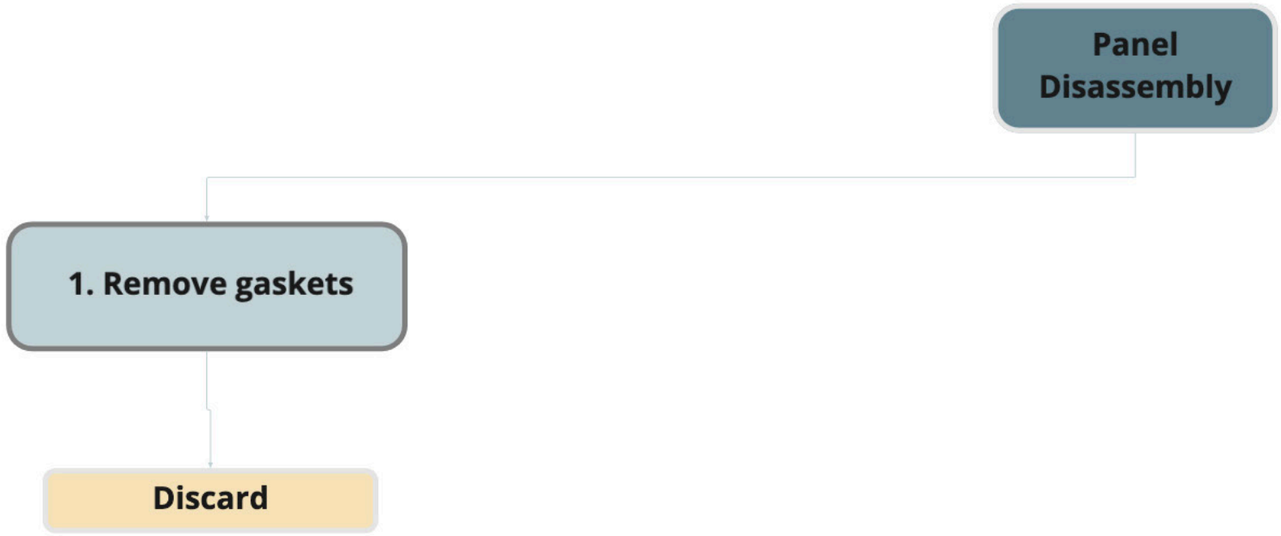
2. coating’s reduced performance

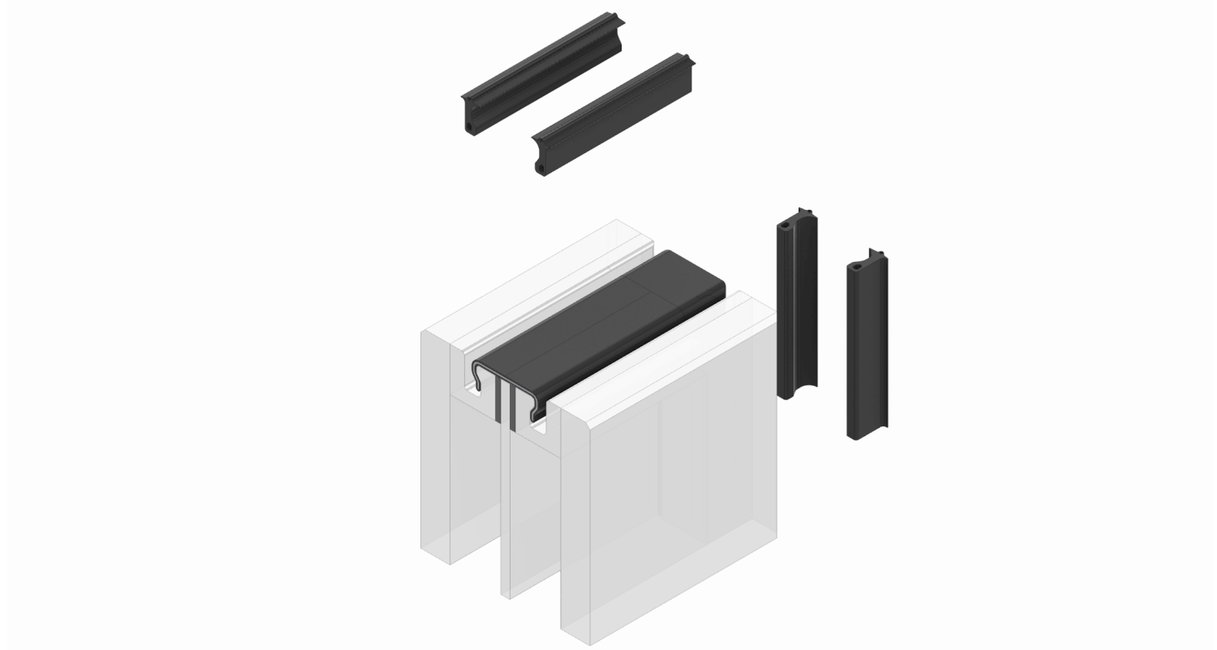
3. glass breakage

Panel Disassembly

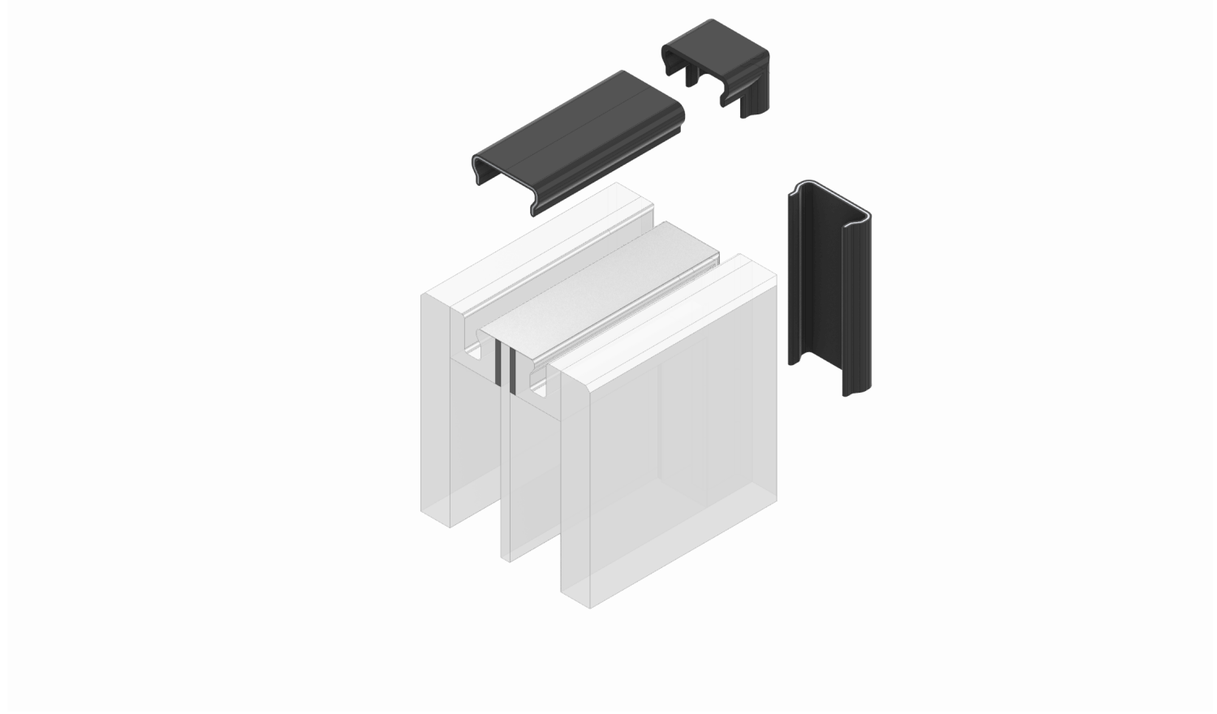
1. Remove gaskets

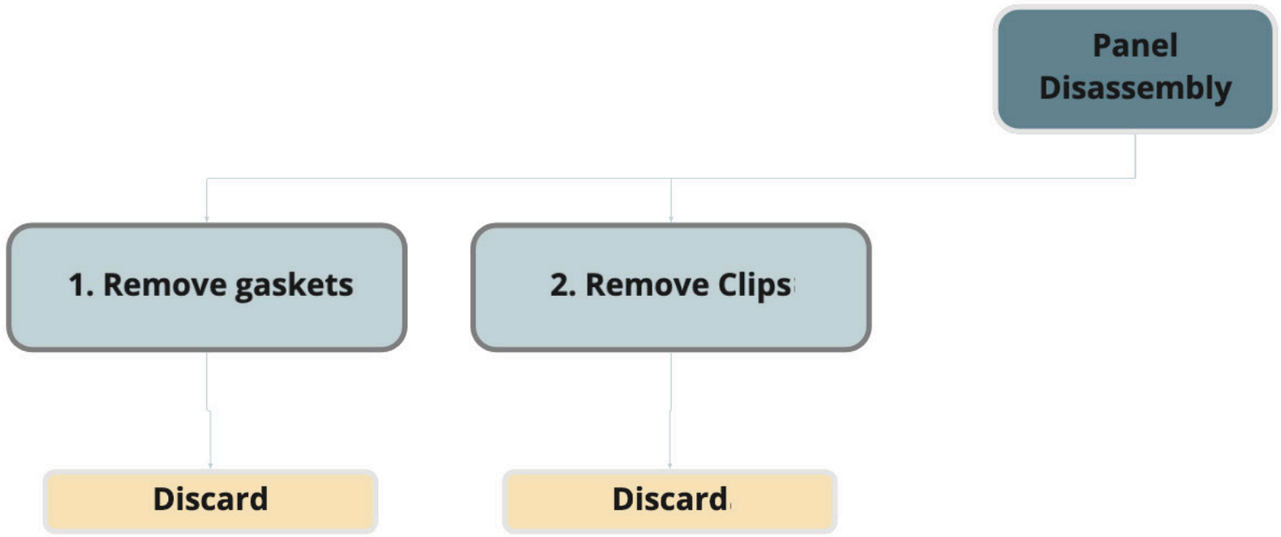


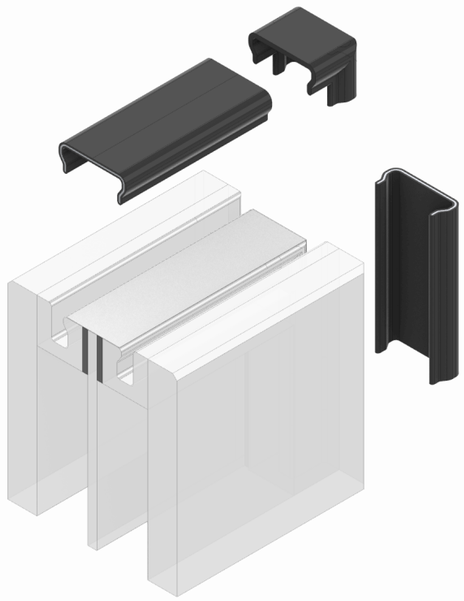

Panel Disassembly
1. Remove gaskets
Discard

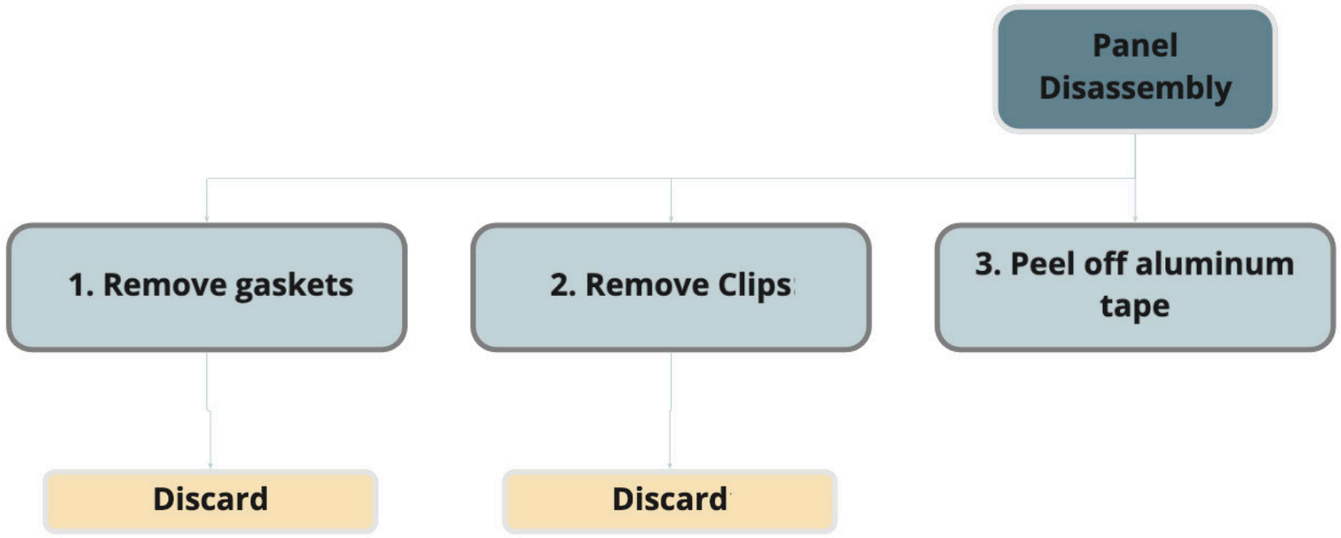


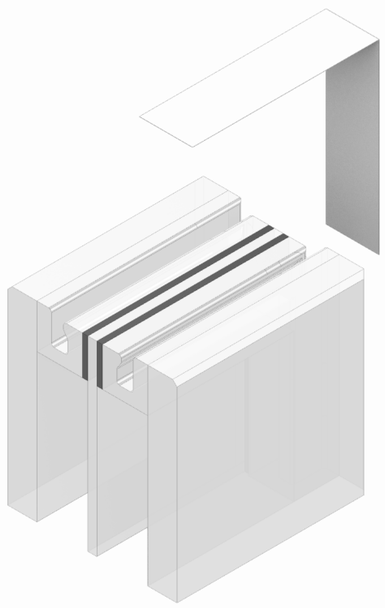

Panel Disassembly
1. Remove gaskets
2. Remove Clips
Discard

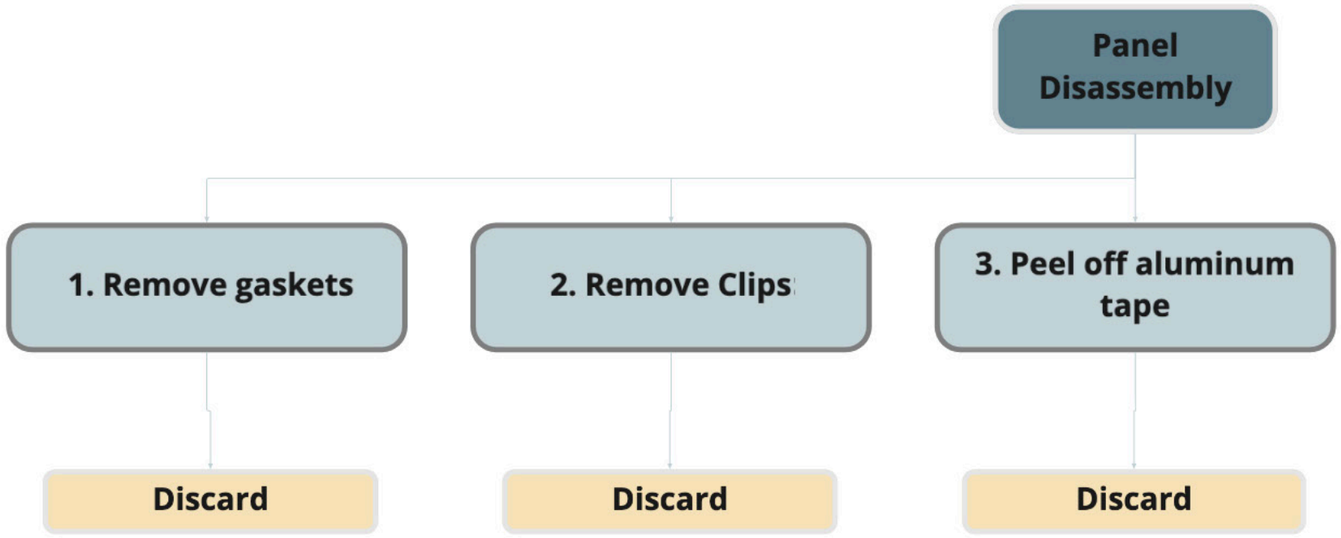


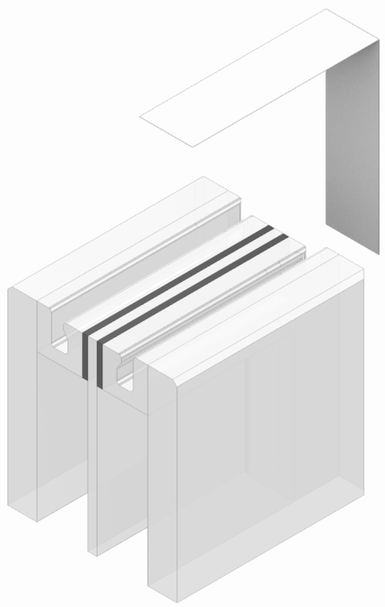

Panel Disassembly
1. Remove gaskets
2. Remove Clips
Discard
Discard

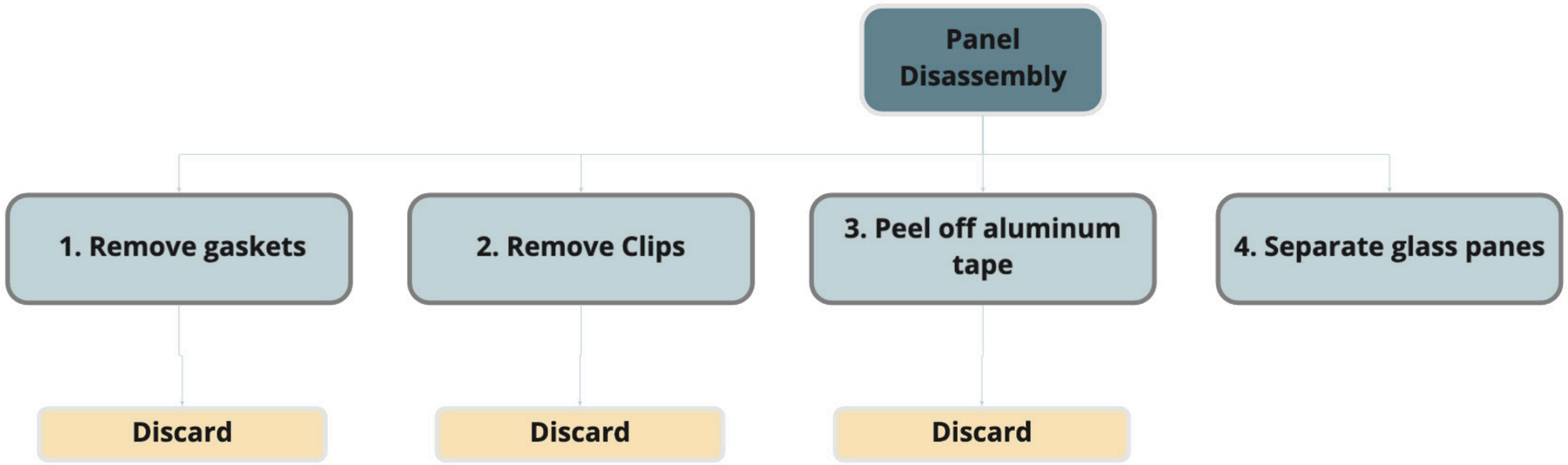


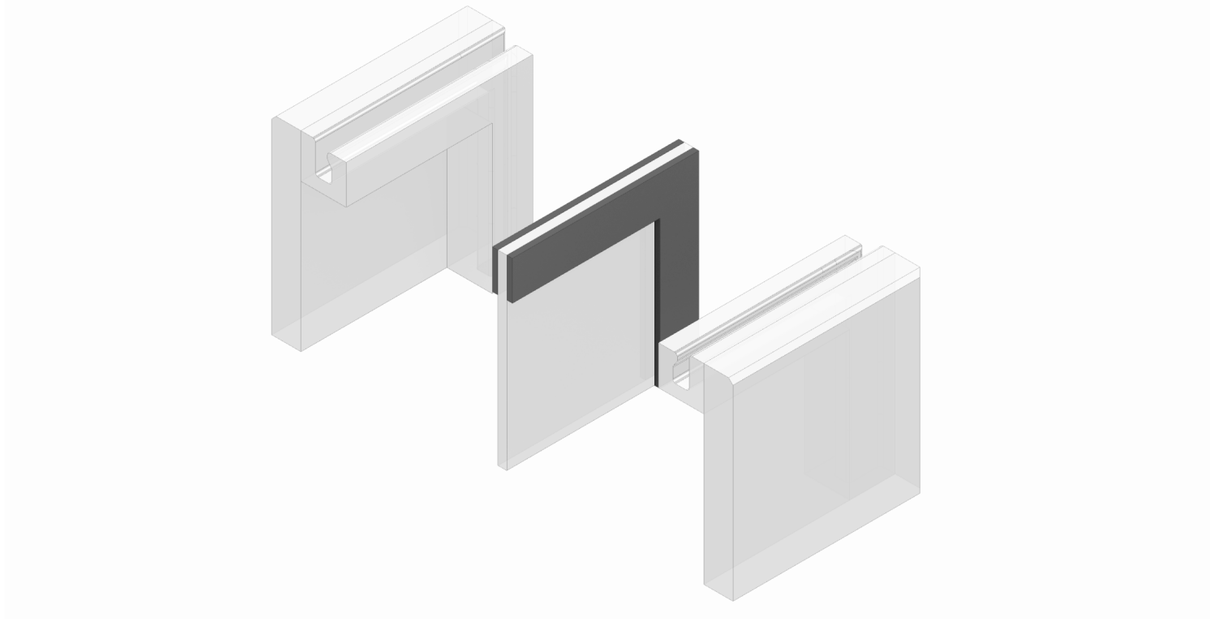

Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
Discard
Discard

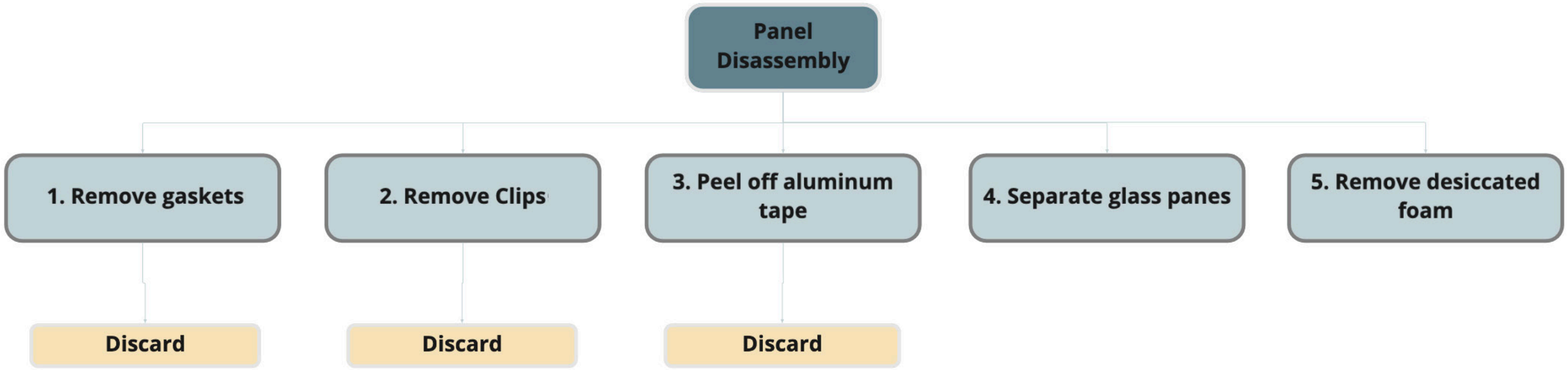


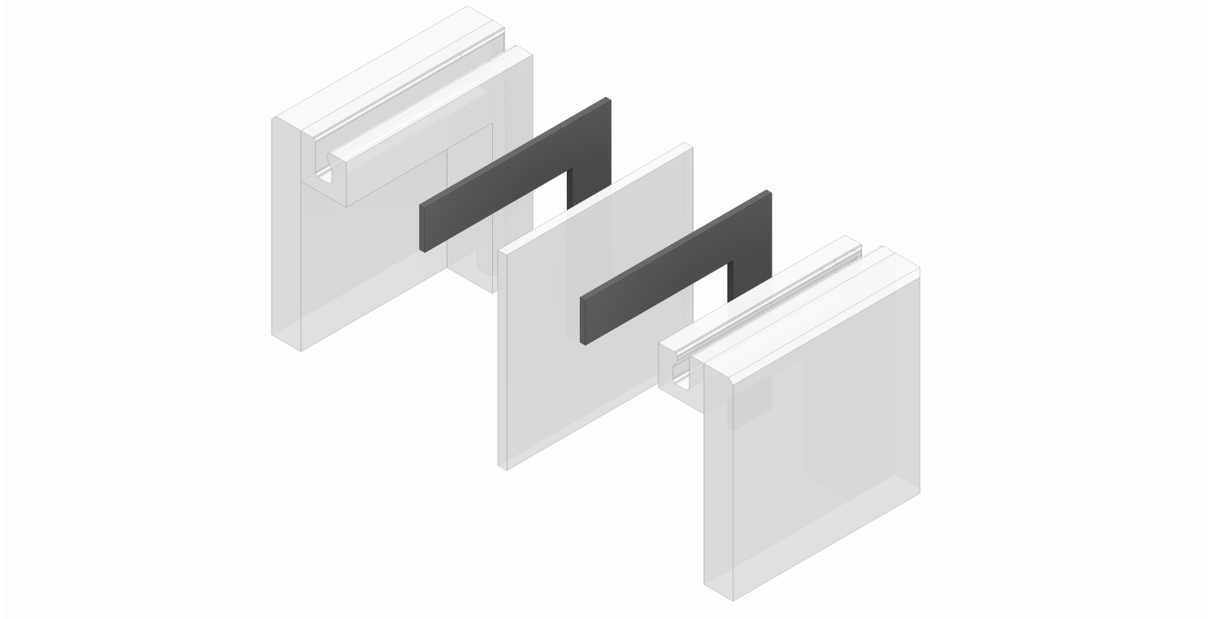

Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
Discard
Discard
Discard

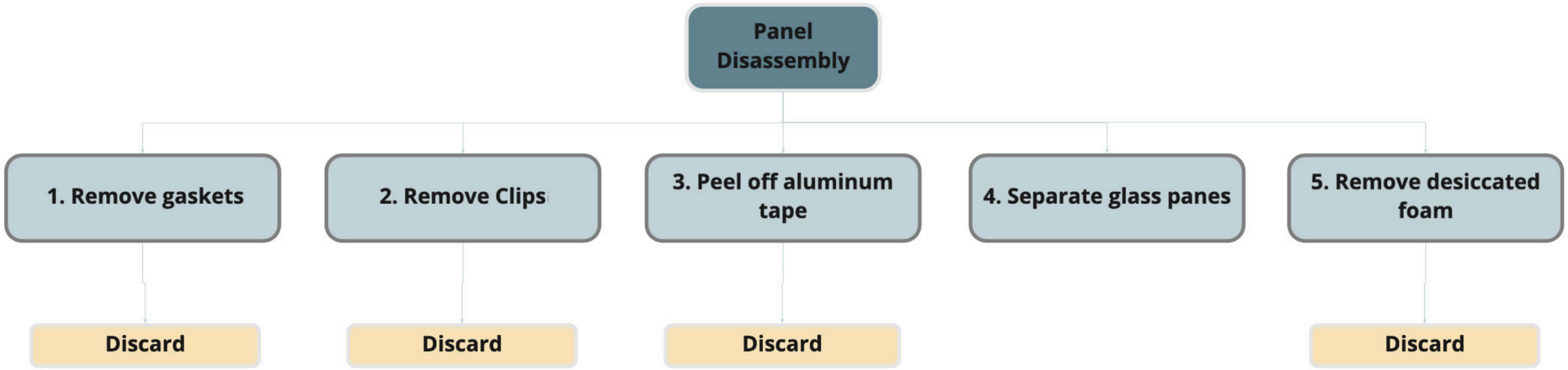


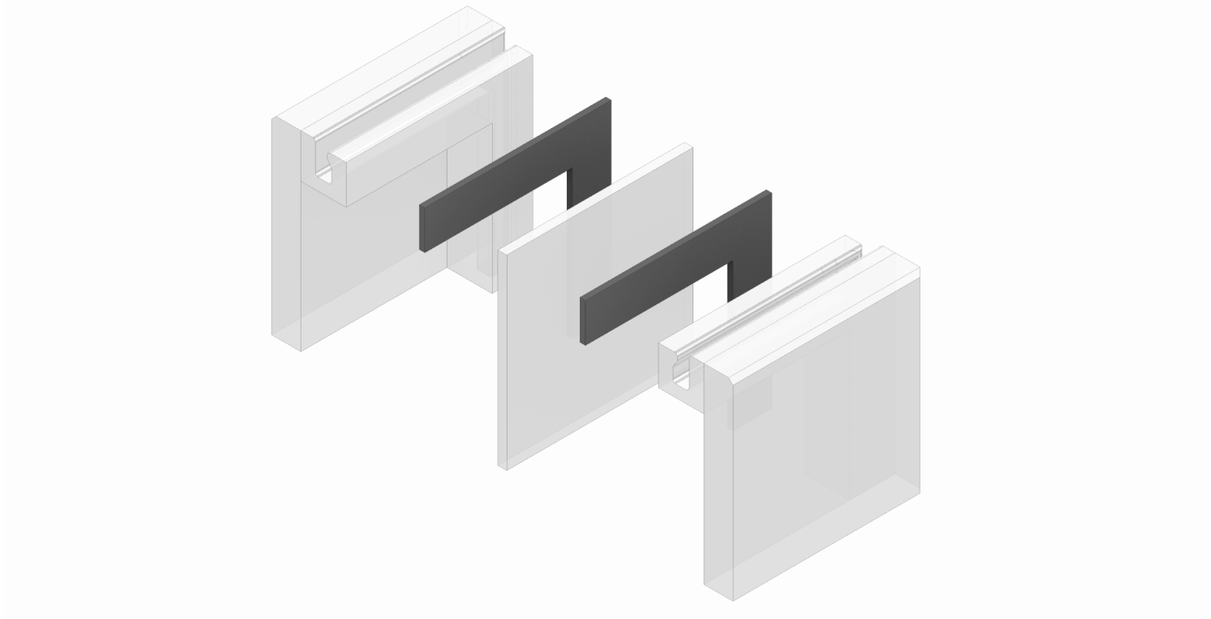

Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
Discard
Discard
Discard

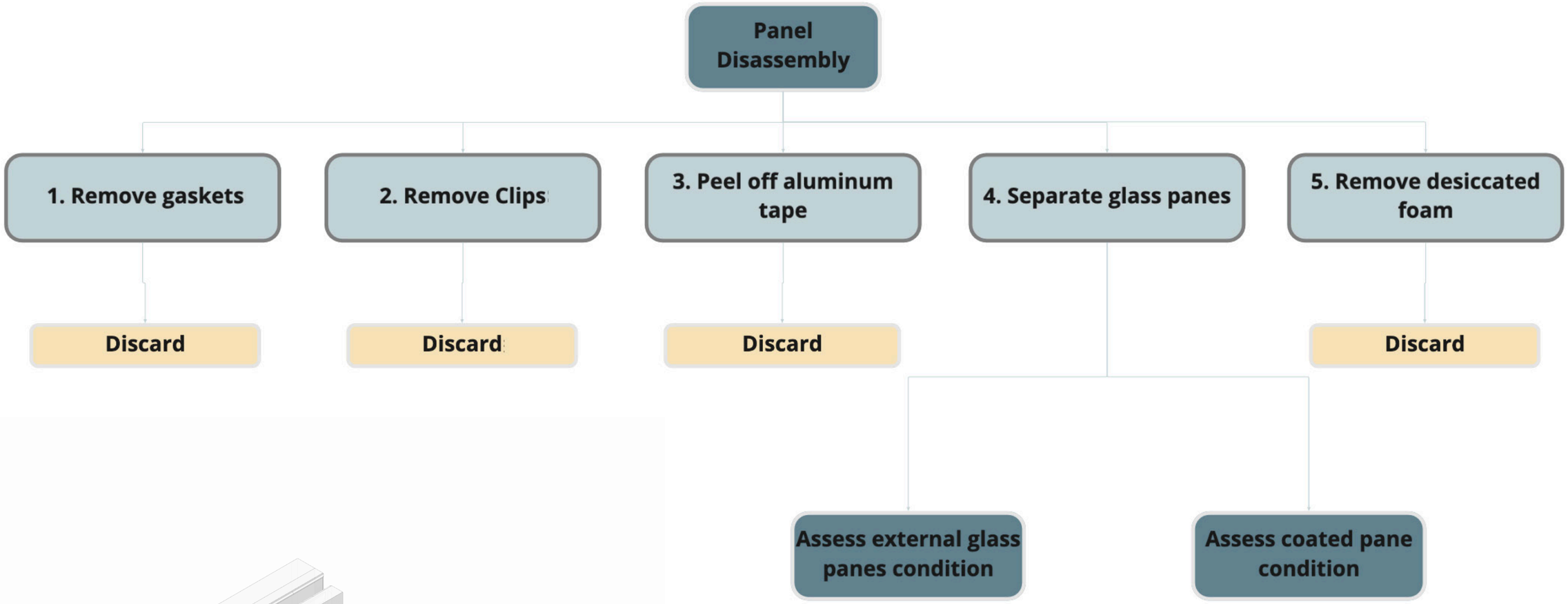


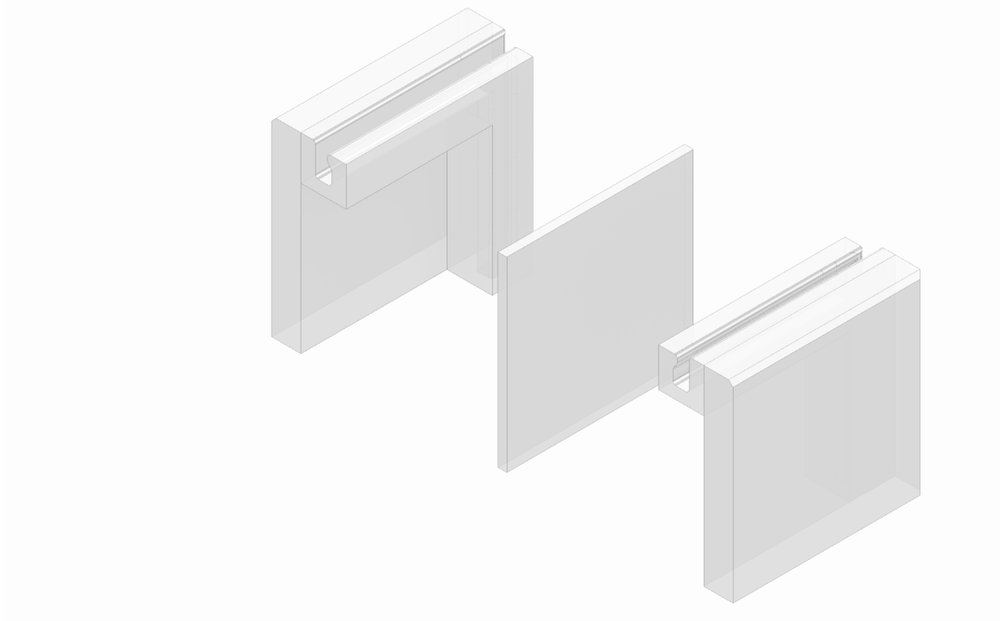

Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
5. Remove desiccated foam
Discard
Discard
Discard

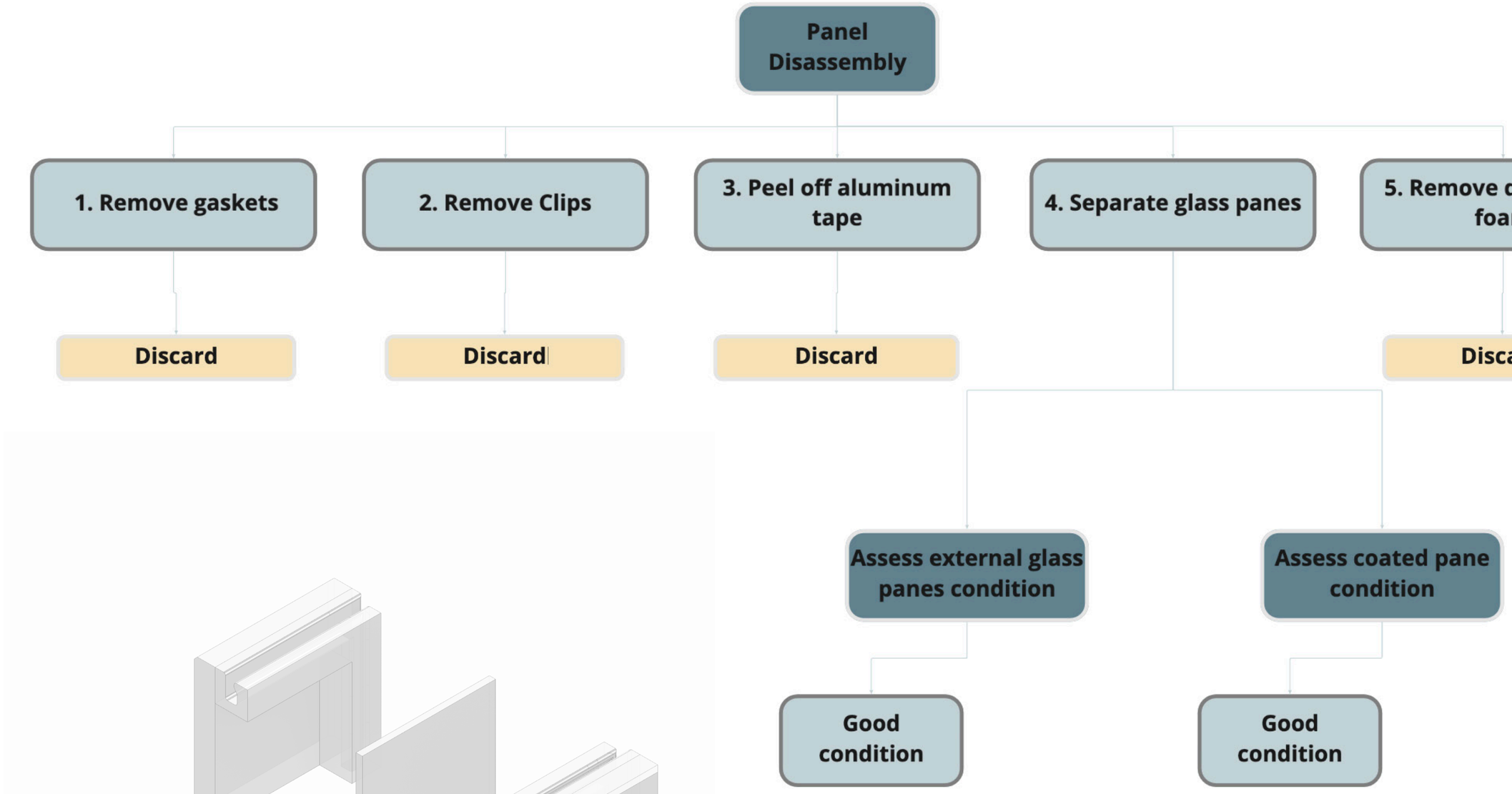


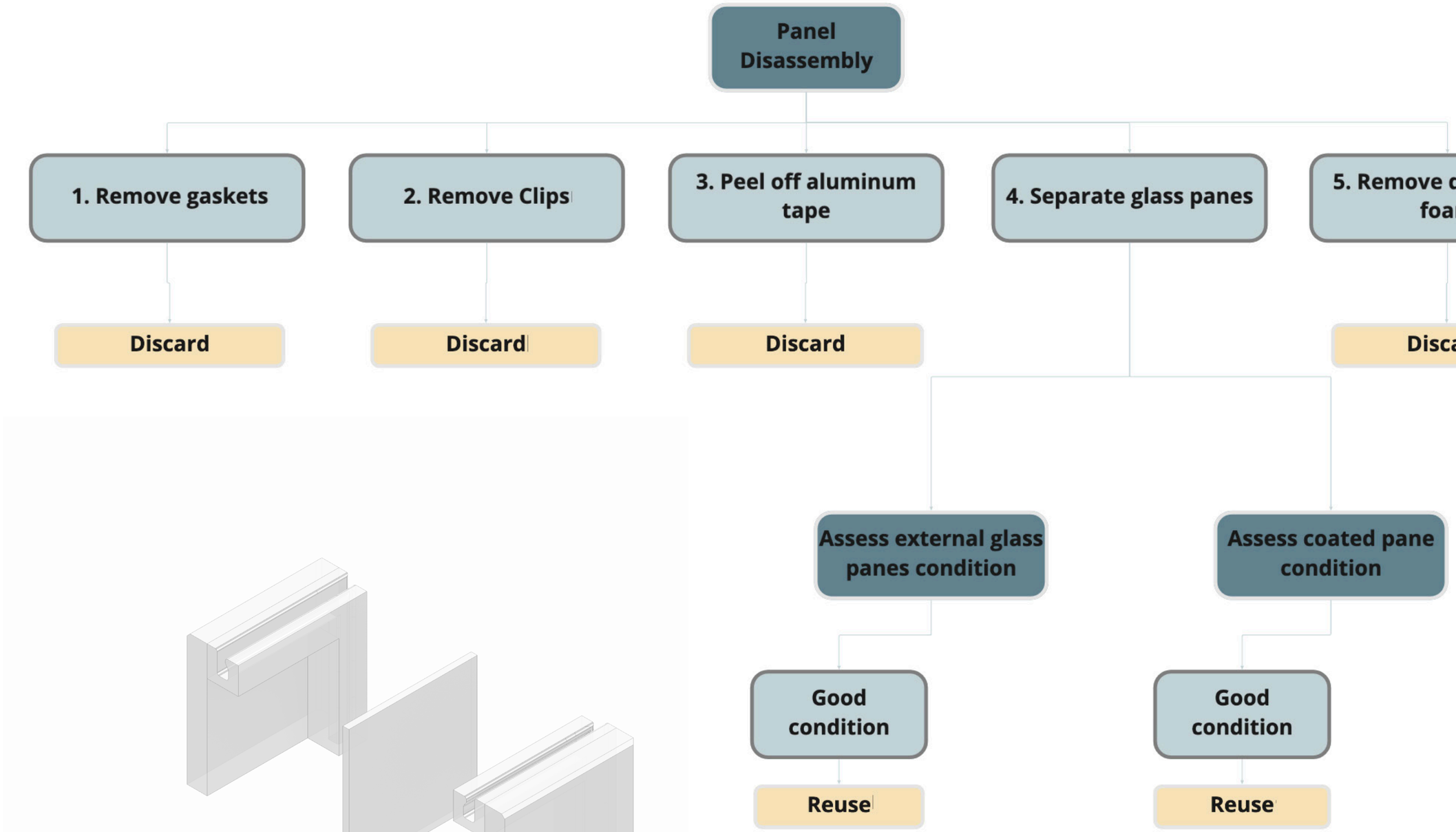

Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
5. Remove desiccated foam
Discard
Discard
Discard
Discard

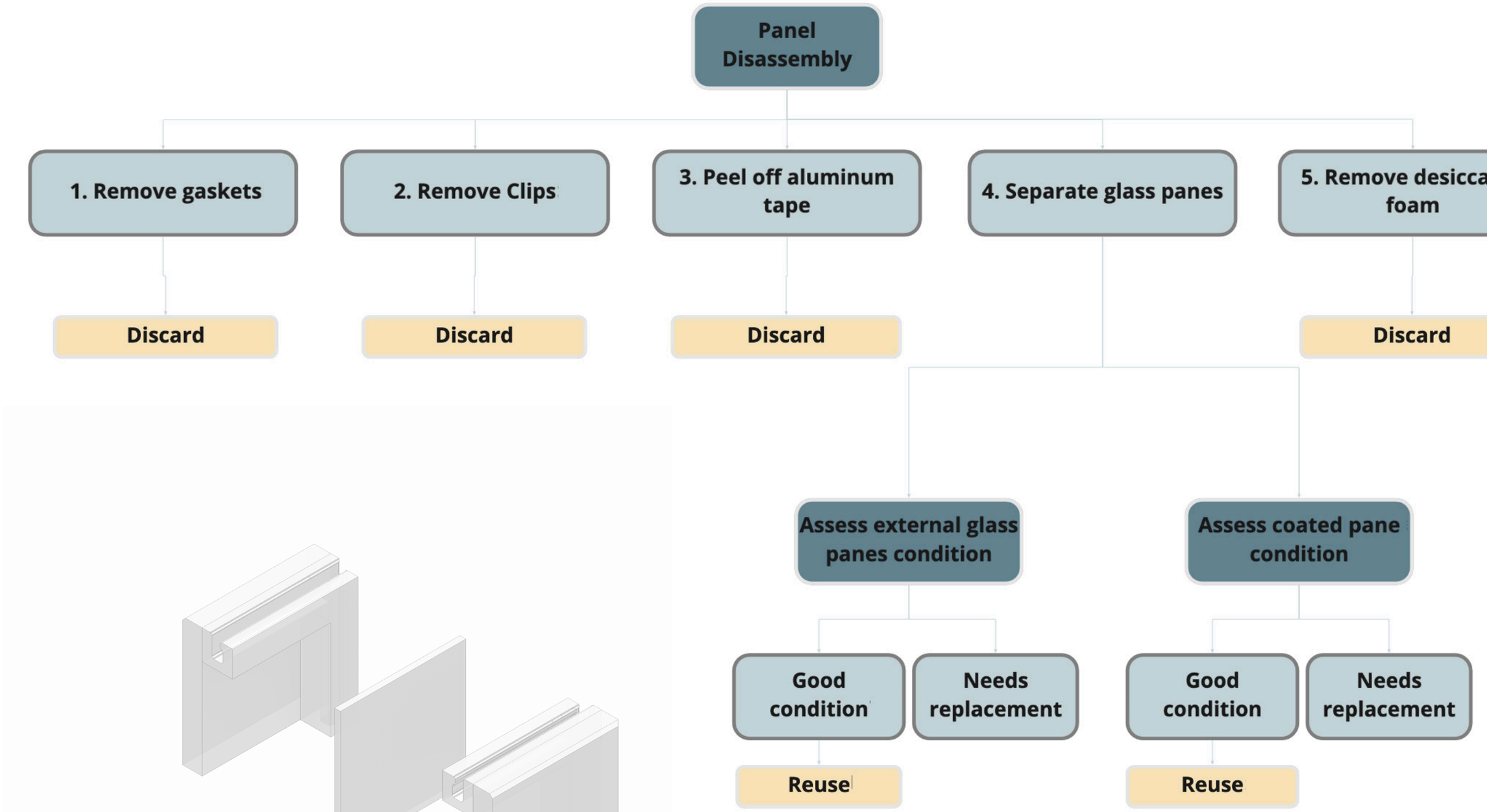


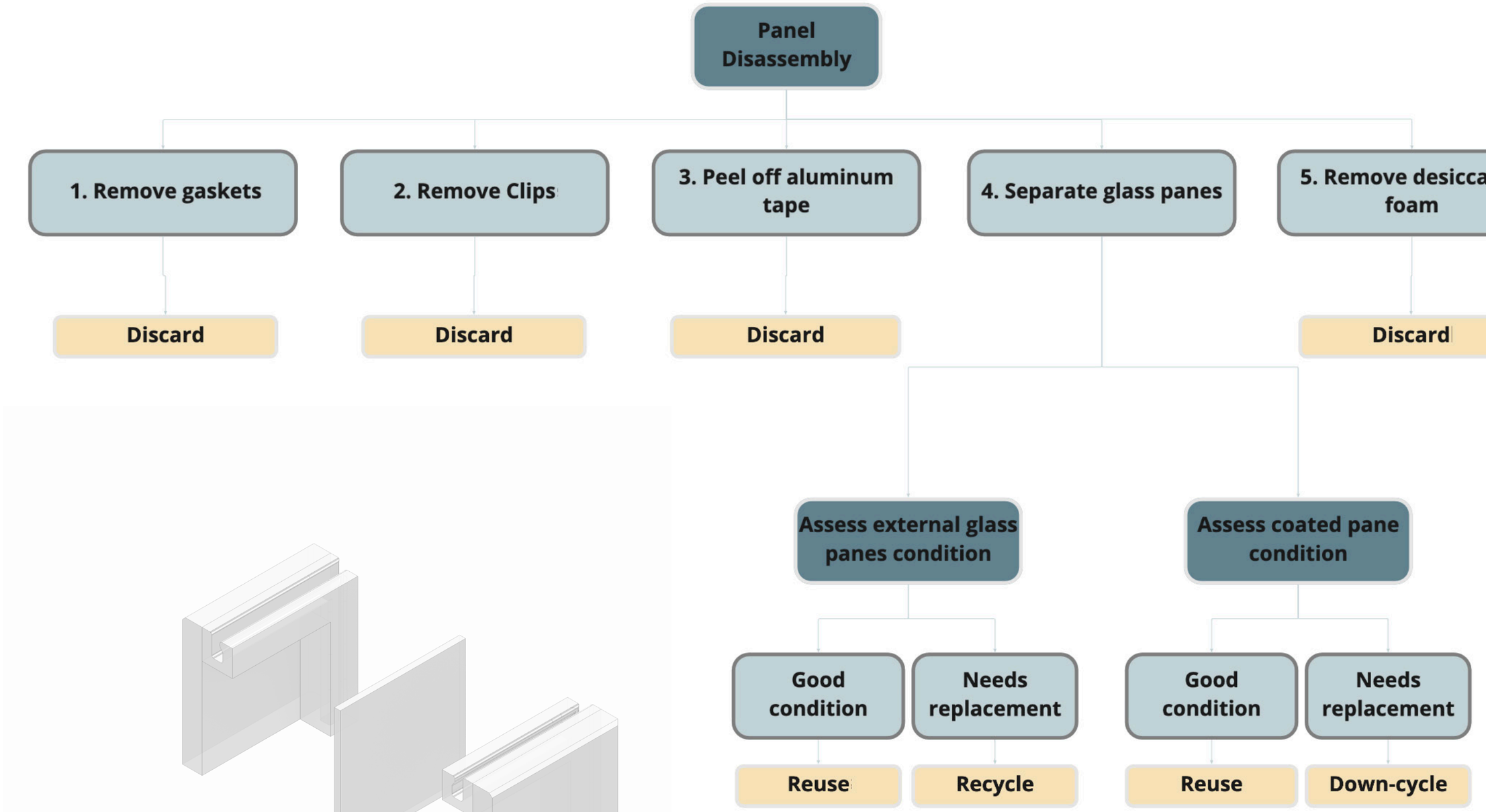

Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
5. Remove desiccated foam
Discard
Discard
Discard
Discard
Assess external glass panes condition
Assess coated pane condition

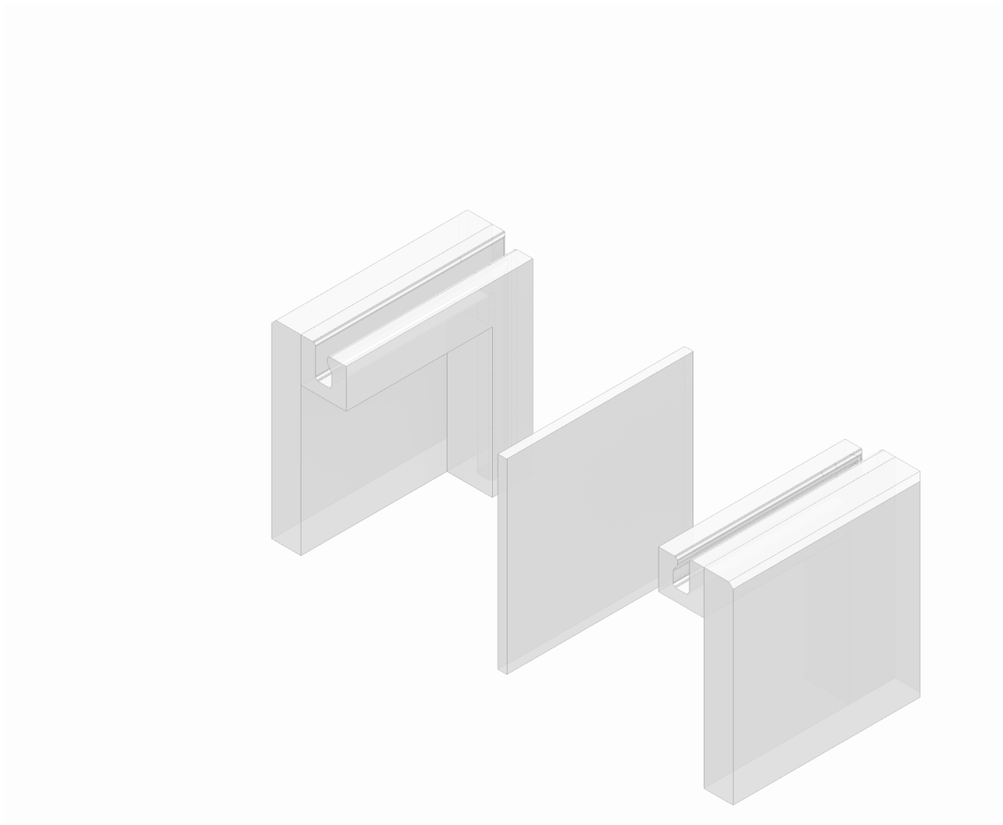



Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
5. Remove desiccated foam
Discard
Discard
Discard
Discard
Assess external glass panes condition
Assess coated pane condition
Good condition
Good condition


Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
5. Remove desiccated foam
Discard
Discard
Discard
Discard
Assess external glass panes condition
Assess coated pane condition
Good condition
Good condition
Reuse
Reuse


Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
5. Remove desiccated foam
Discard
Discard
Discard
Discard
Assess external glass panes condition
Assess coated pane condition
Good condition
Needs replacement
Good condition
Needs replacement
Reuse
Reuse


Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
5. Remove desiccated foam
Discard
Discard
Discard
Discard
Assess external glass panes condition
Assess coated pane condition
Good condition
Needs replacement
Good condition
Needs replacement
Reuse
Recycle
Reuse
Down-cycle



Panel Disassembly
1. Remove gaskets
2. Remove Clips
3. Peel off aluminum tape
4. Separate glass panes
5. Remove desiccated foam
Discard
Discard
Discard
Discard
Assess external glass panes condition
Assess coated pane condition
Good condition
Needs replacement
Good condition
Needs replacement
Reuse
Recycle
Reuse
Down-cycle
Refurbishment
Refurbishment

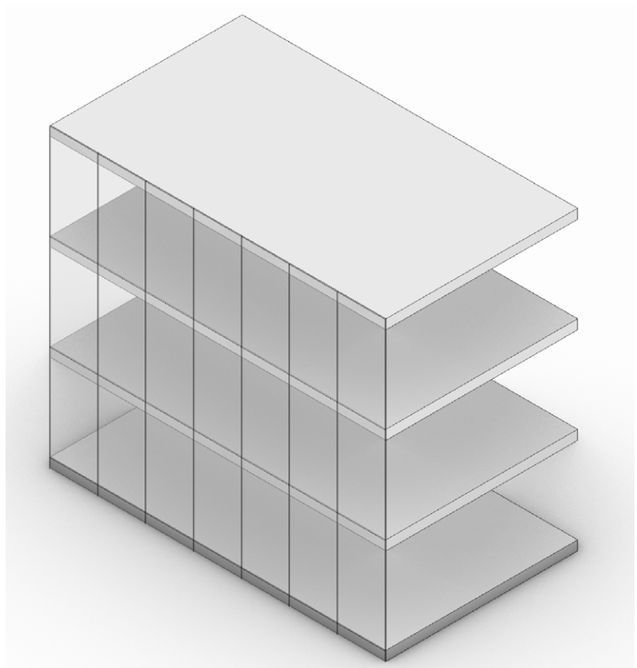
REFURBISHMENT OPTION

Prolong IGU Life time

or

RECYCLING OPTION

Bring Glass Back Into The Loop



Facade Application

Answer to Research Sub-Question:

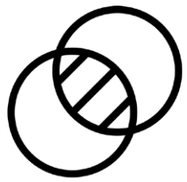
2. What are the current **potential** and **limitations** of implementing a circular design of maximised transparency in:

(b) in a curtain wall facade

Design Criteria

thermal insulation

u-value <1.25 W/m2K

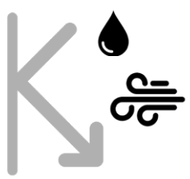


transparency

optically unobstructive
facade connections

demountable

enable reversibility
of the structure



weather proofing

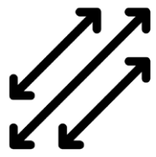
air tight
water tight

load-transfer

floor span height

substructure

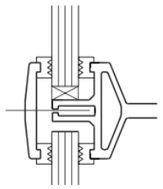
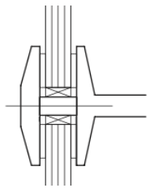
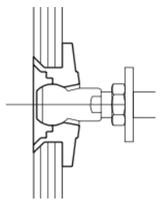
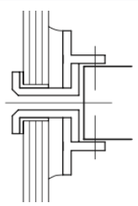
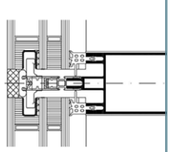
beams

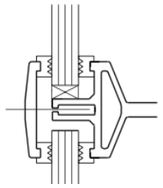
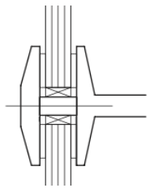
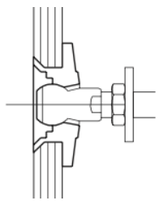
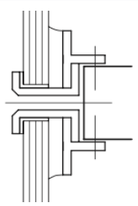
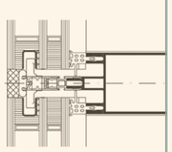


construction feasibility

accommodate tolerances,
thermal expansions,
building movements

Selection of Suitable Facade Connection

	Load-transfer	Reversibility	Transparency	Notes
Linear Clamping Bar 	+++	+++	+	Visible Framing
Point Clamping Plates 	++	+++	++	Less visible than linear clamps
Point Drilled Fixings 	++	+++	++	Stress Concentrations, Requires attention at sealing of IGU, Optically Discrete
Structural Silicone 	+++	-	+++	Difficult disassembly, Reversible with glass contamination
Point Mechanical Clamp Fixing 	++	+++	+++	Hidden Fixings Fully Reversible

	Load-transfer	Reversibility	Transparency	Notes
Linear Clamping Bar 	+++	+++	+	Visible Framing
Point Clamping Plates 	++	+++	++	Less visible than linear clamps
Point Drilled Fixings 	++	+++	++	Stress Concentrations, Requires attention at sealing of IGU, Optically Discrete
Structural Silicone 	+++	-	+++	Difficult disassembly, Reversible with glass contamination
Point Mechanical Clamp Fixing 	++	+++	+++	Hidden Fixings Fully Reversible

Facade Structure Overview

Substructure: Beams

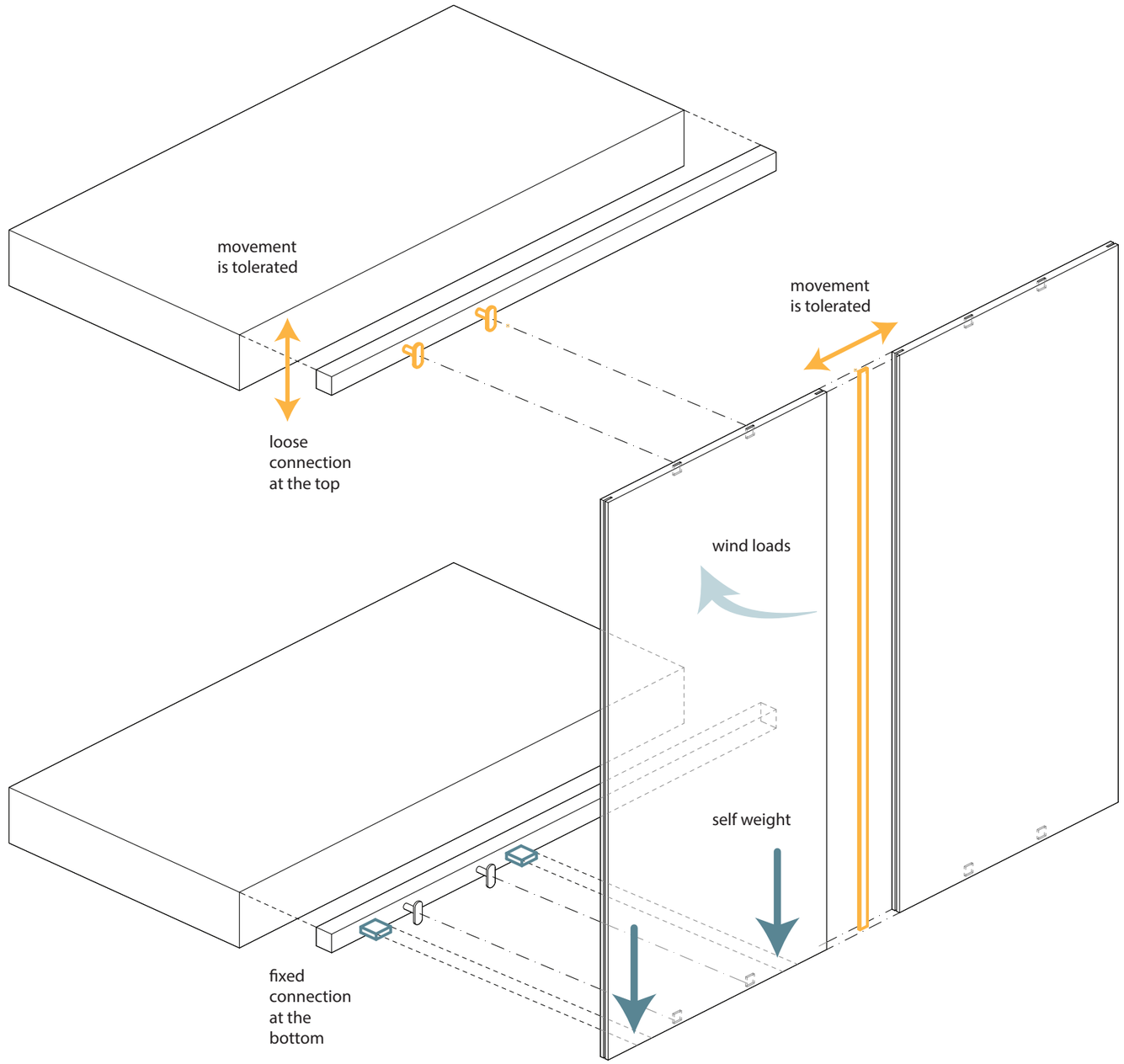
Load Transfer Mechanism: Per Floor

-> In-plane loads:
Transfered through support blocks

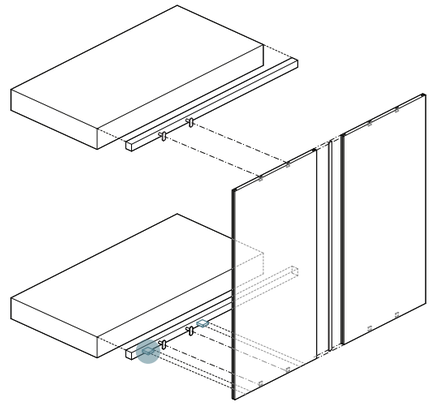
-> Out-of-plane loads:
Transfered by point fixing clamping plates

Movement Tolerance:

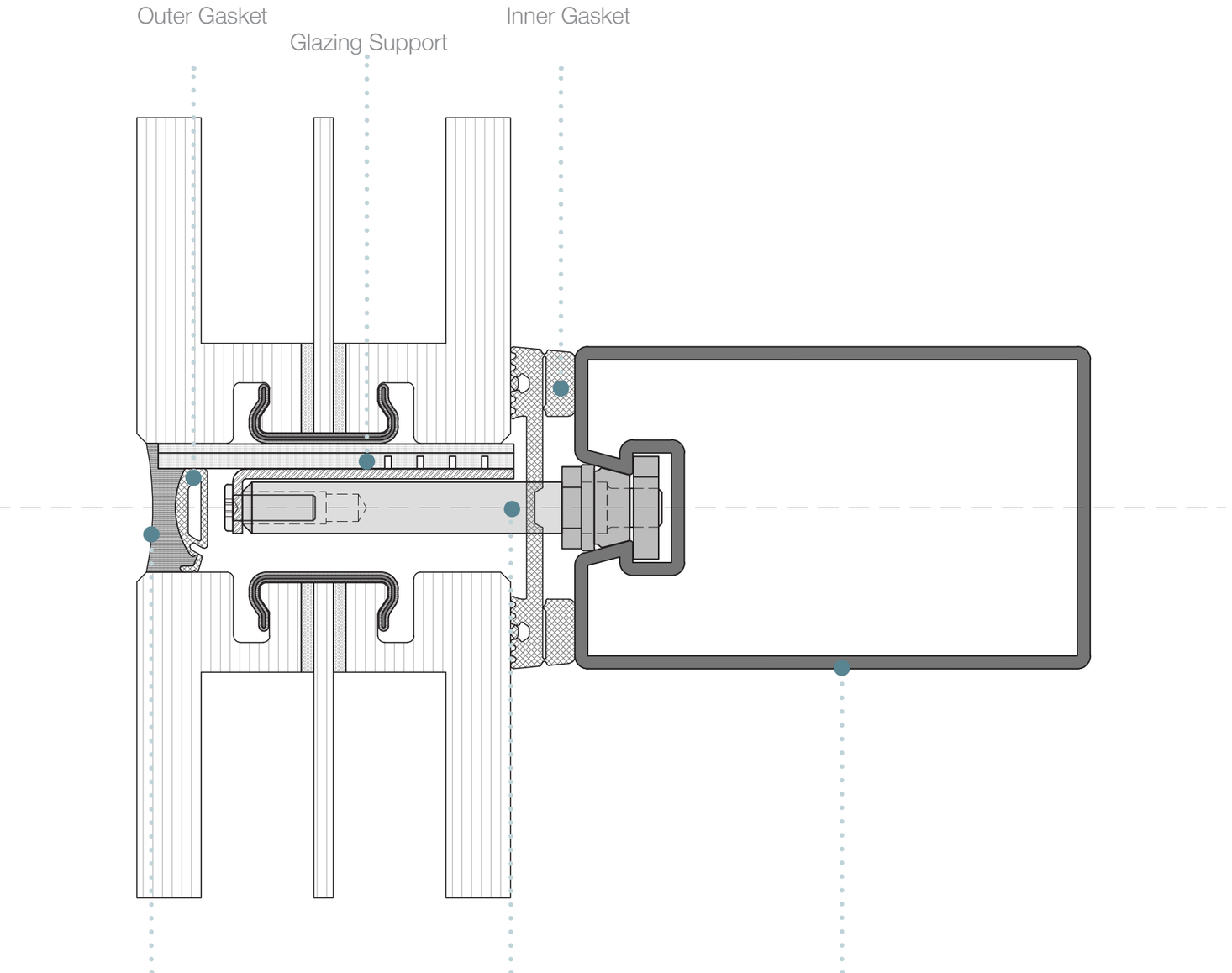
-> Fixed Bottom Connection
-> Loose Top Connection

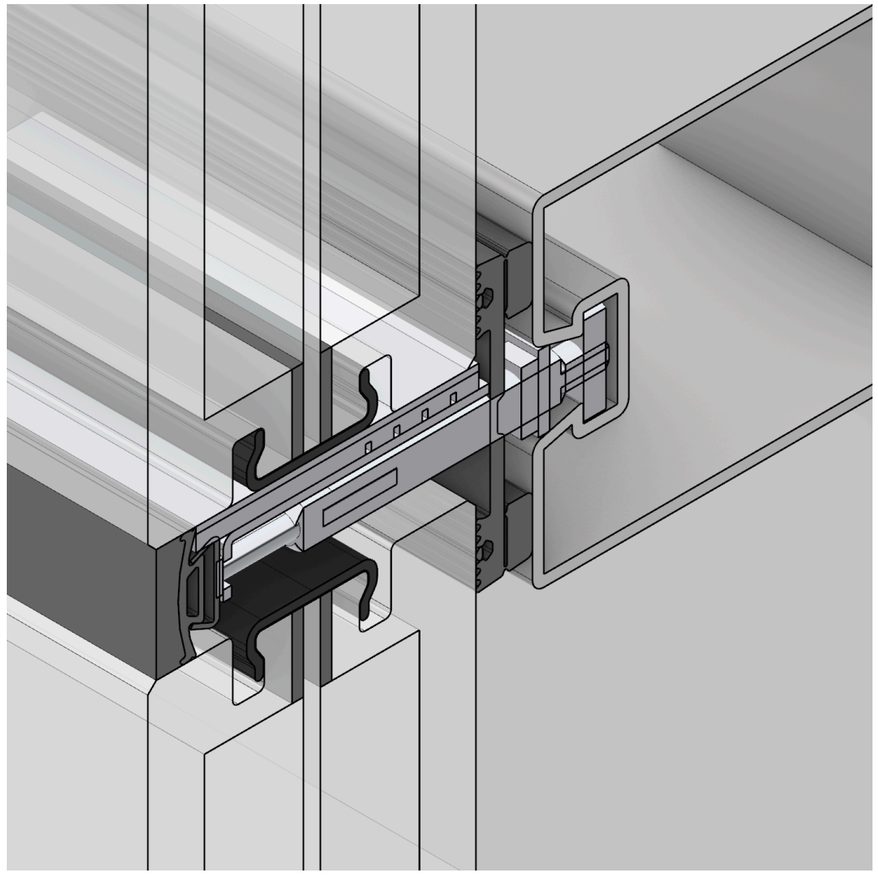


Vertical Connections

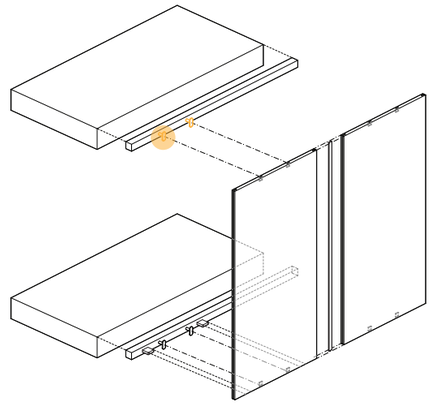


Vertical Section at Facade Support Block

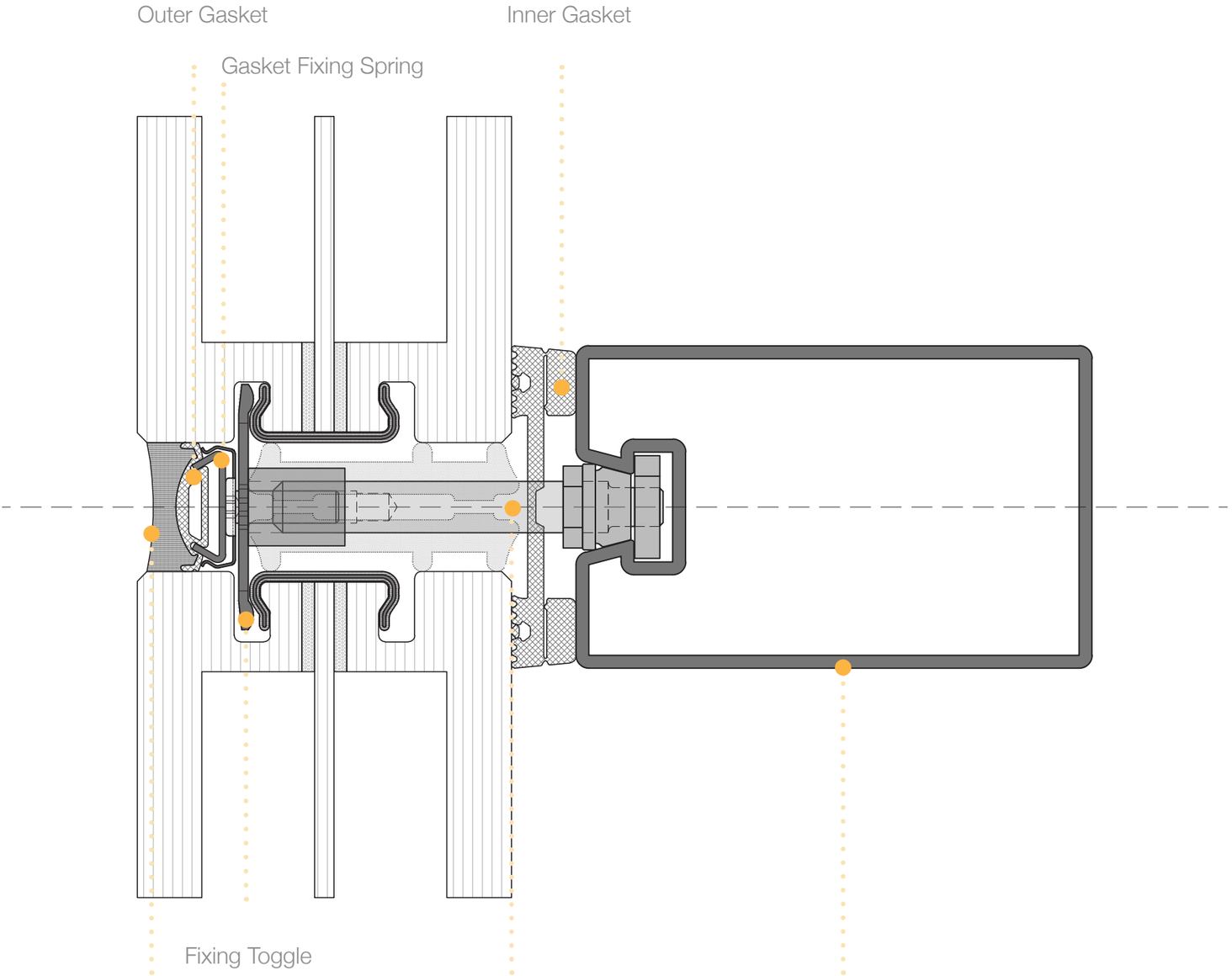


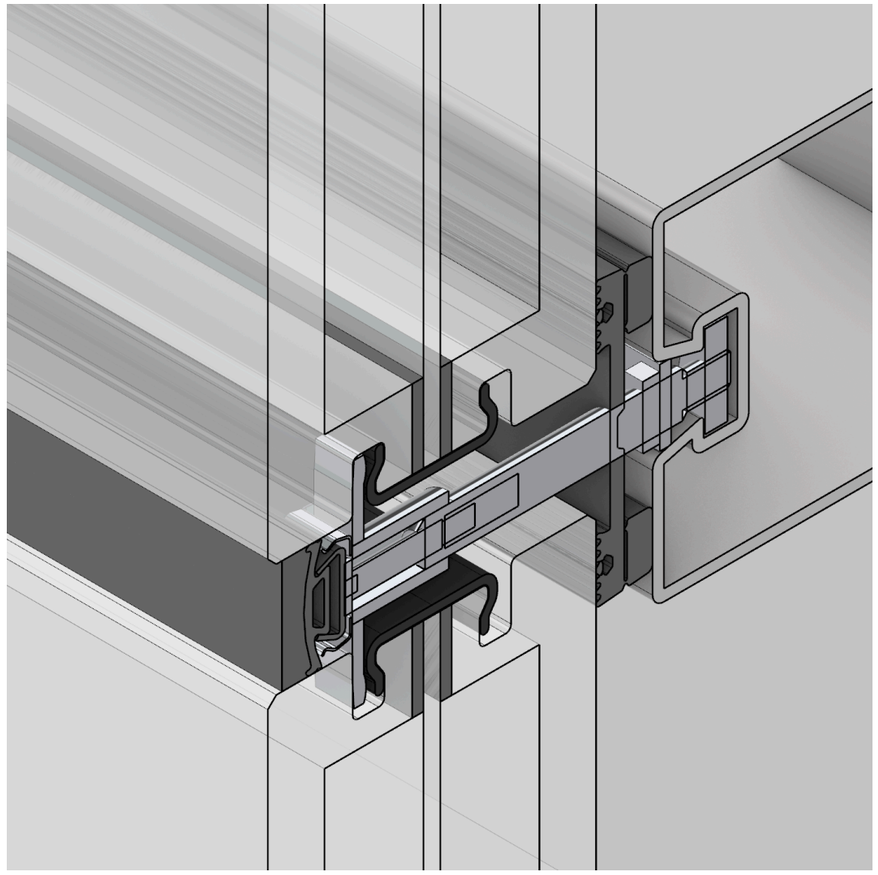


Vertical Connections

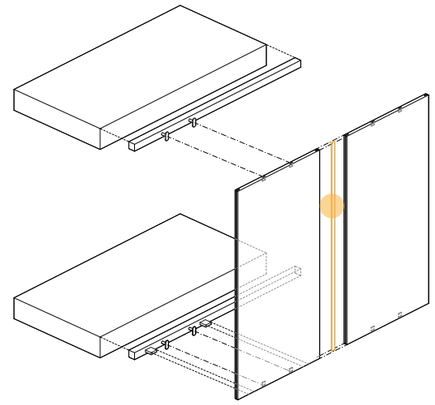


Vertical Section at Facade Clamp Fixing

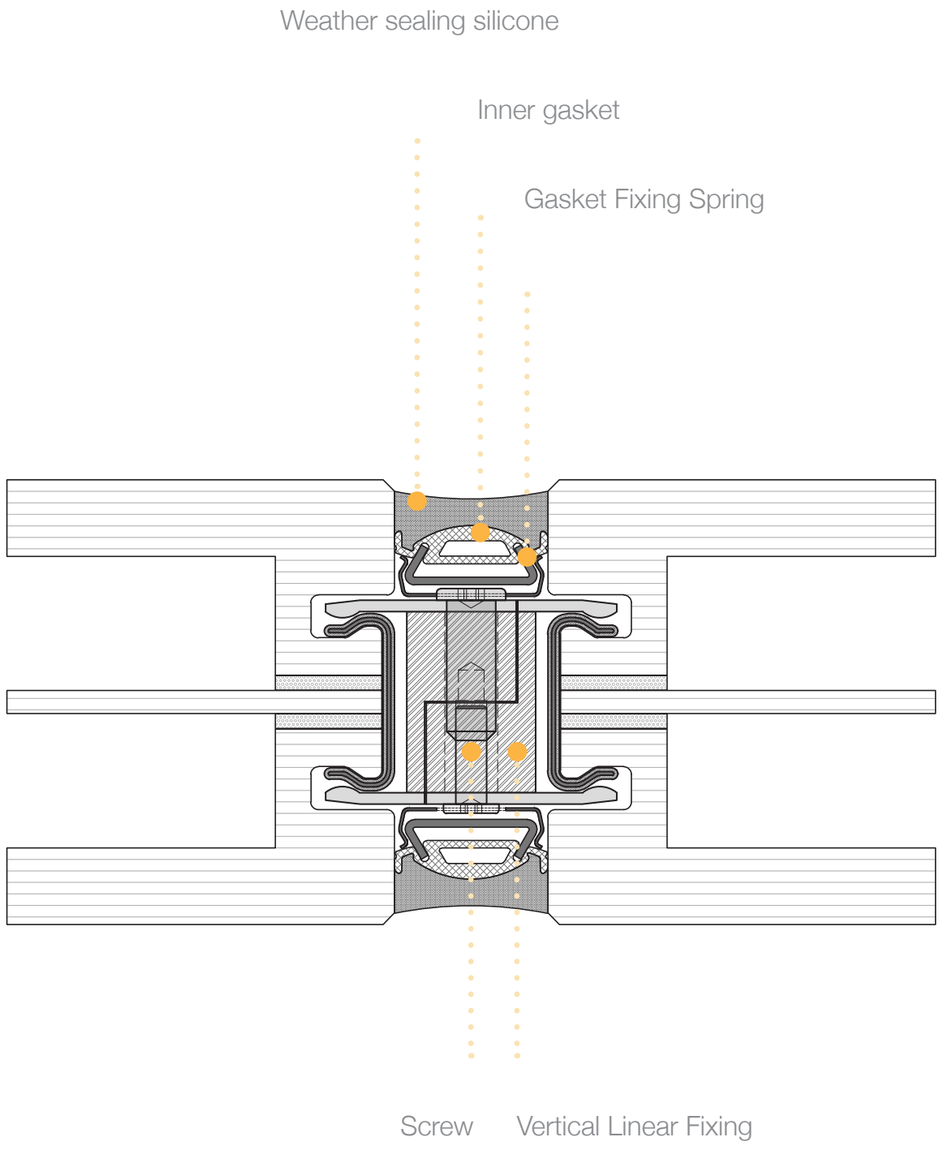


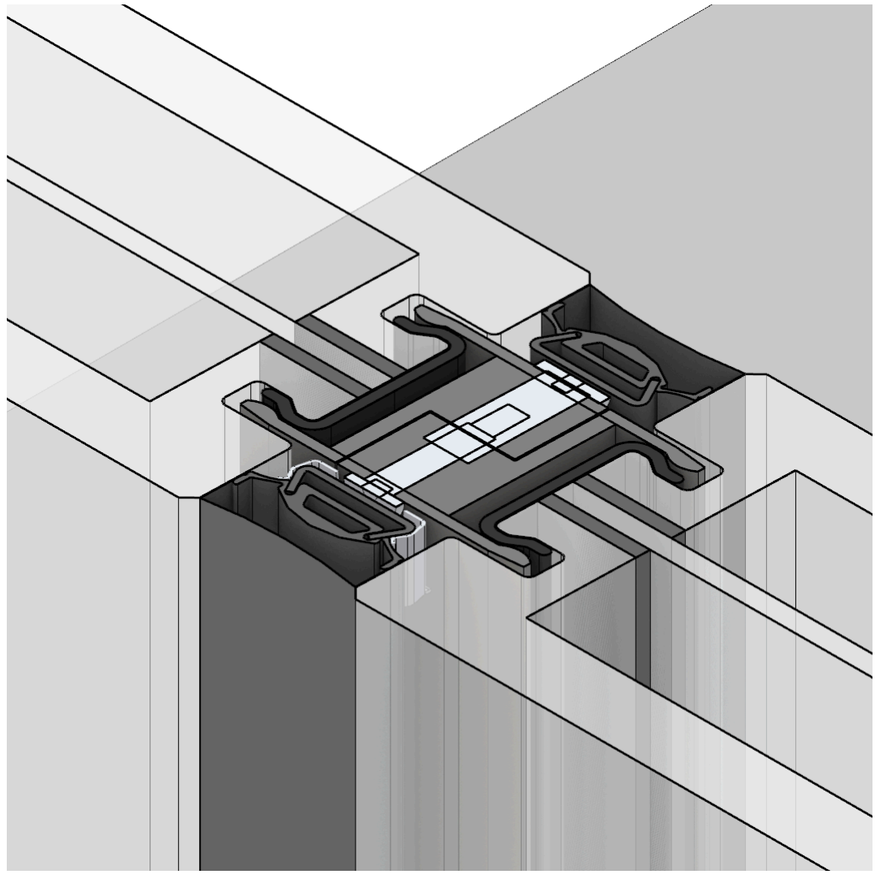


Horizontal Connection



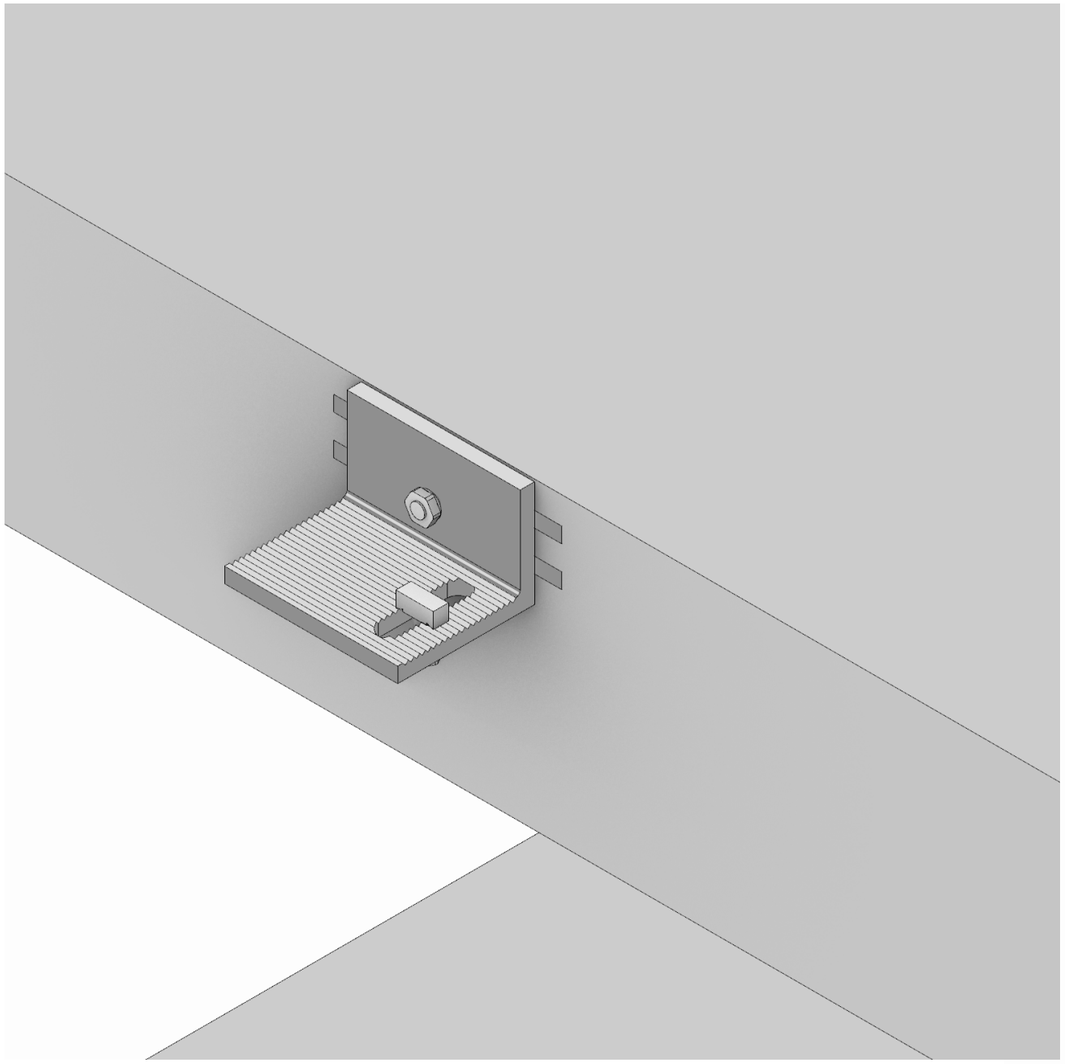
Horizontal Section between Adjacent IGUs

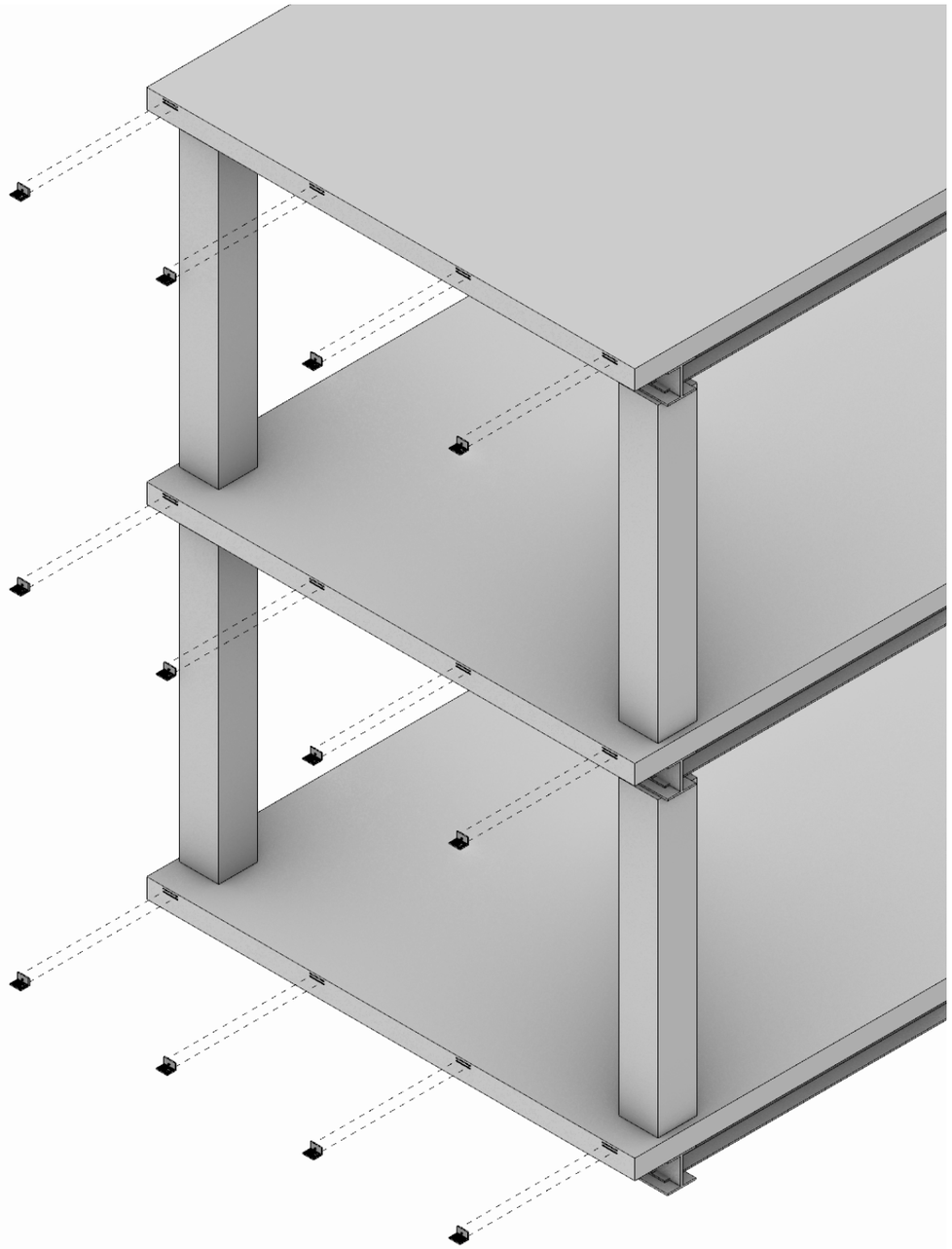




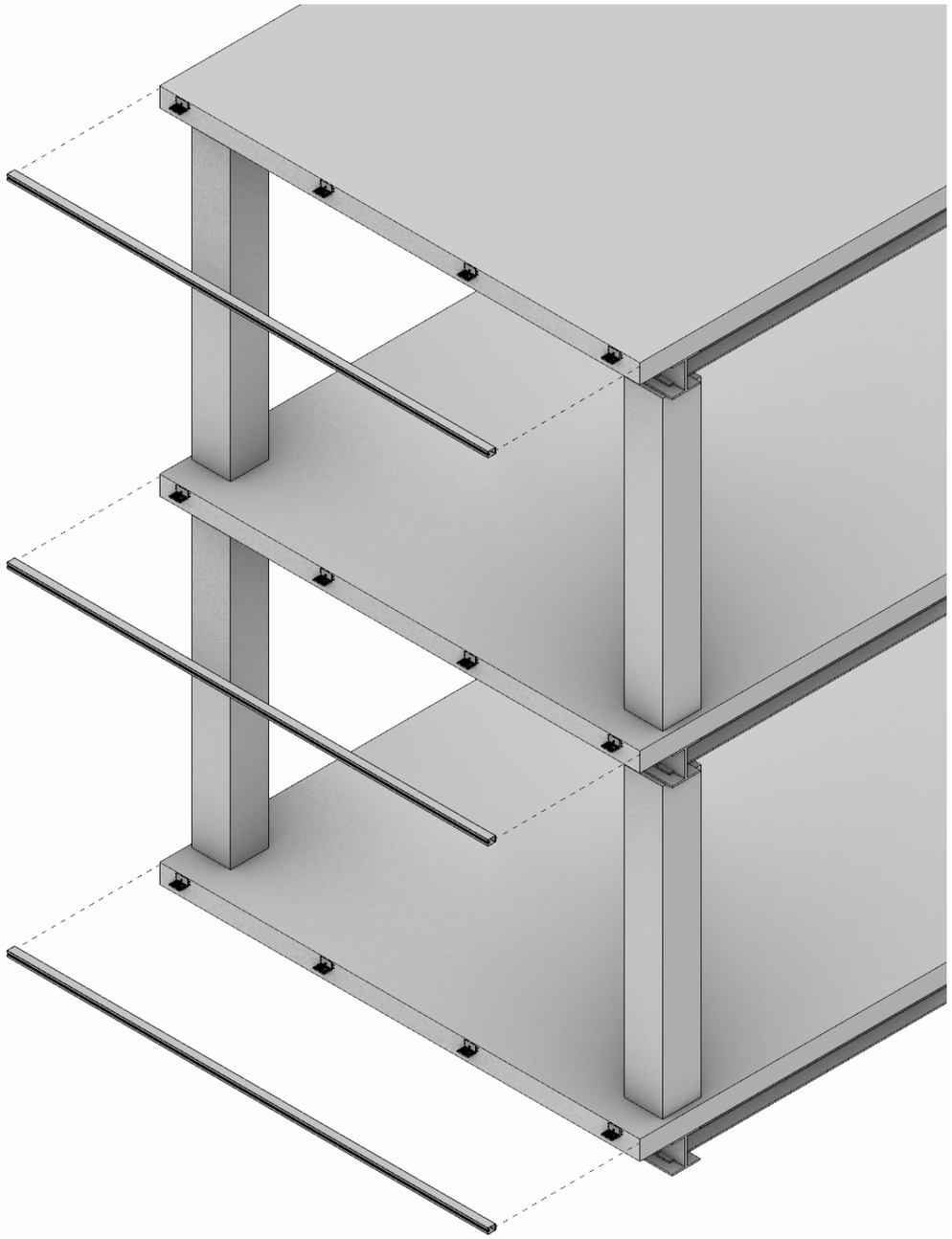
Assembly Order

1. Fixing of anchors in concrete slab

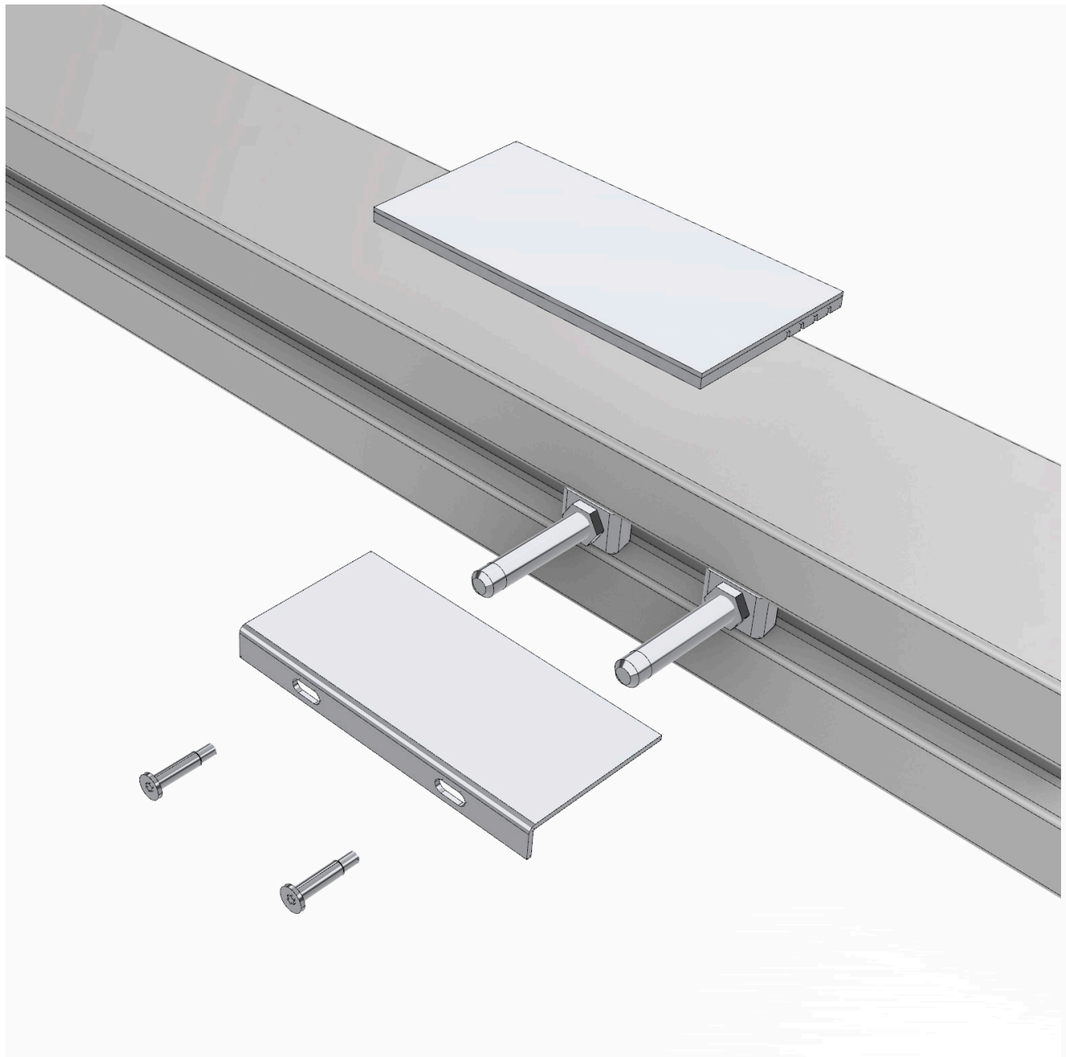


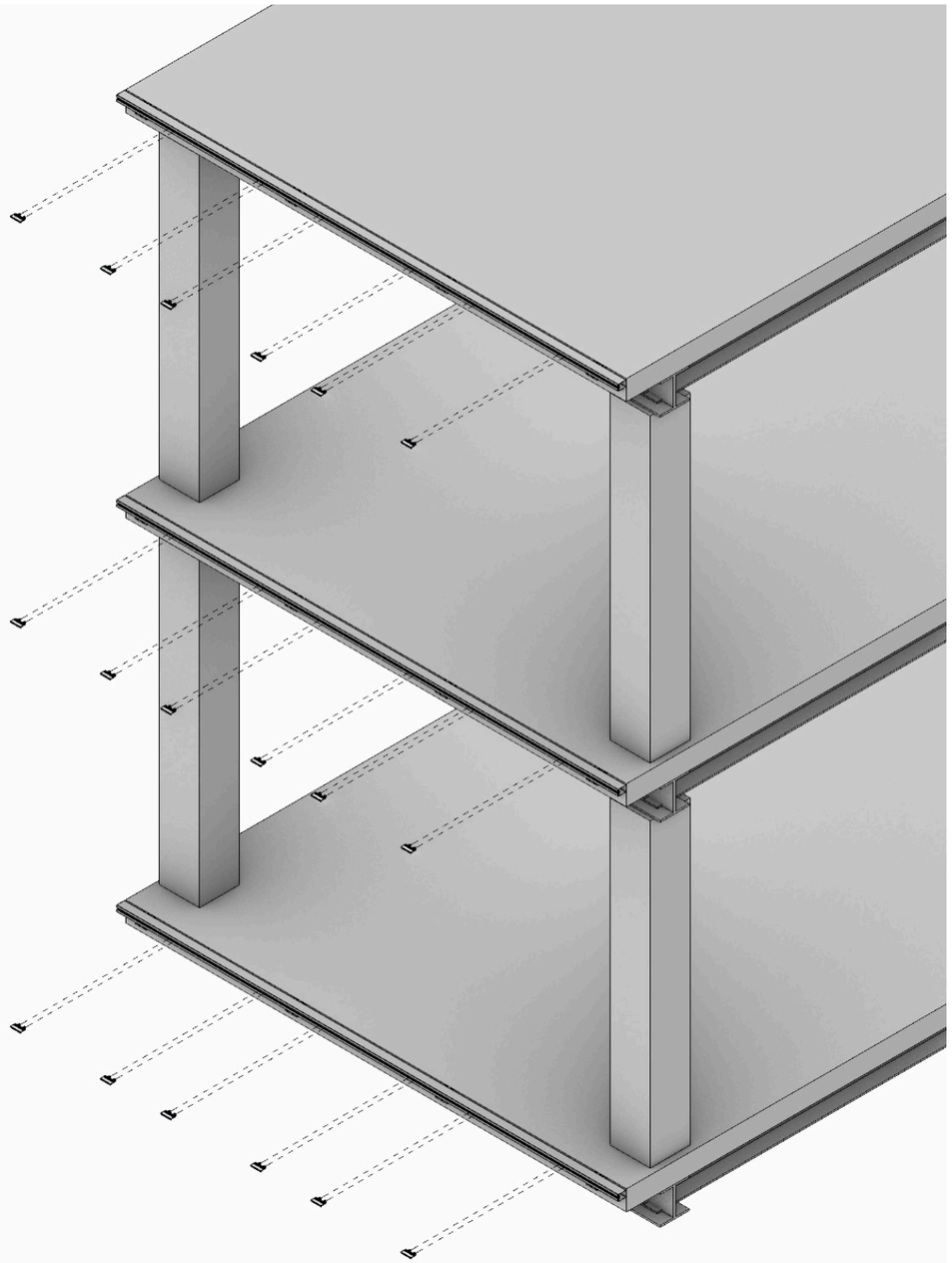


2. Fixing of steel beams to anchors

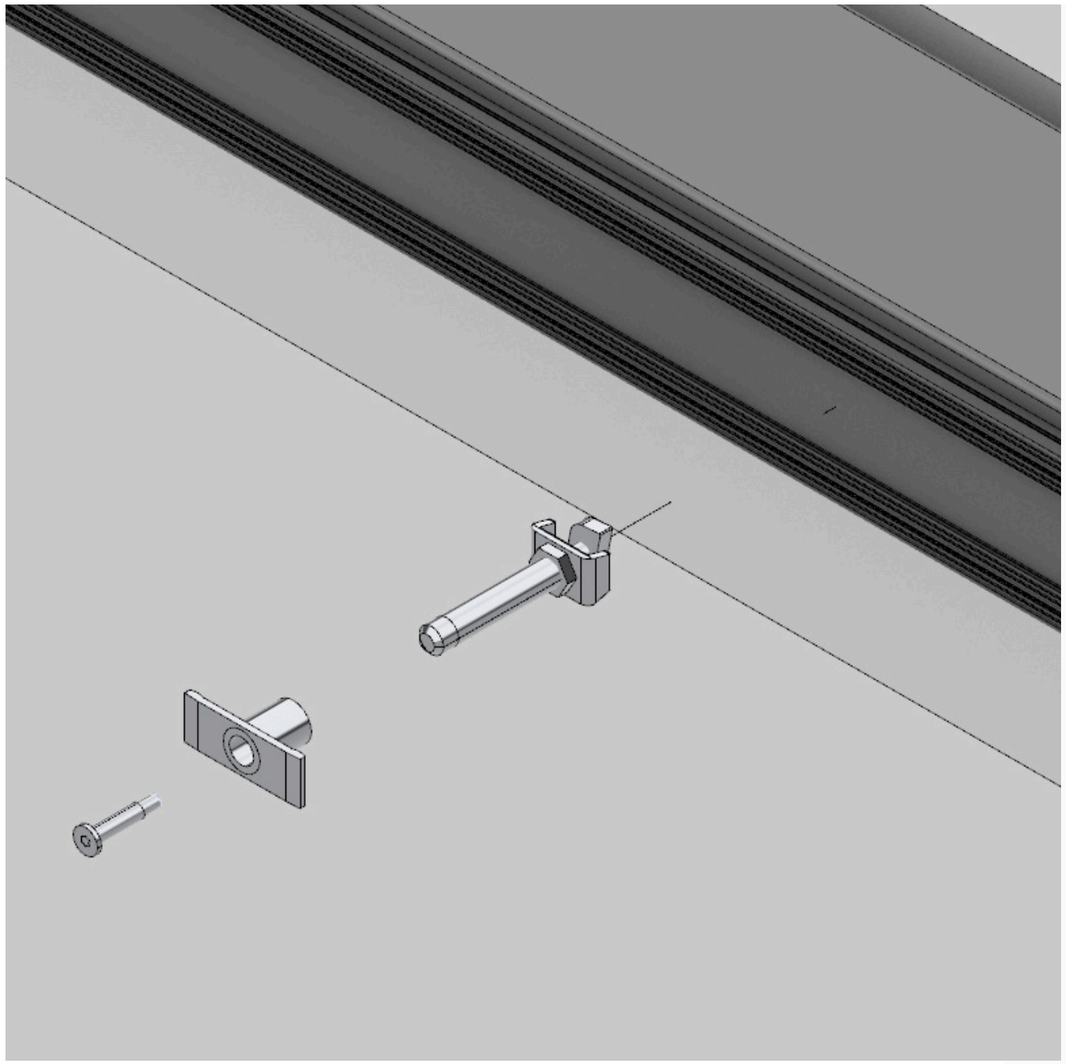


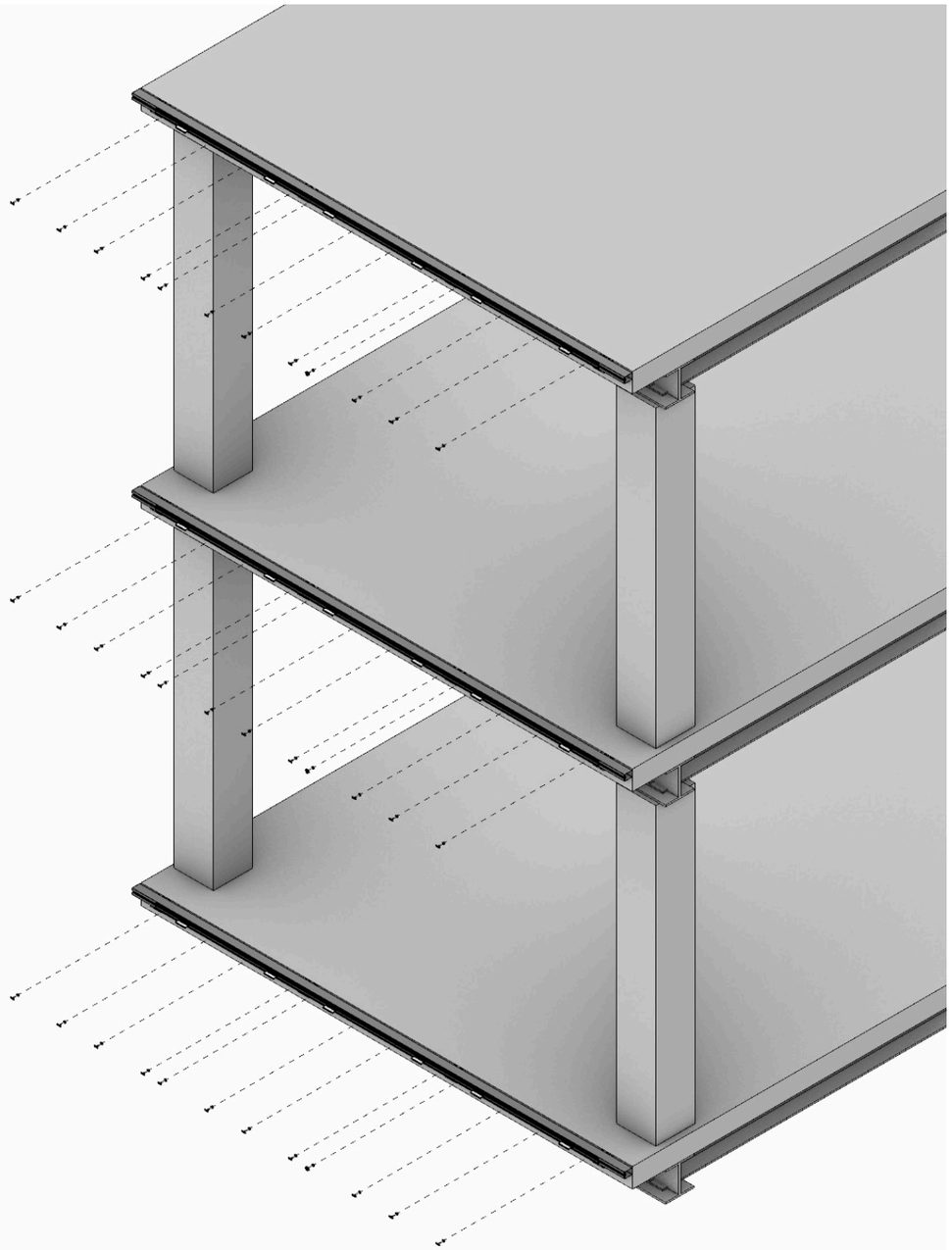
3. Fixing of support blocks



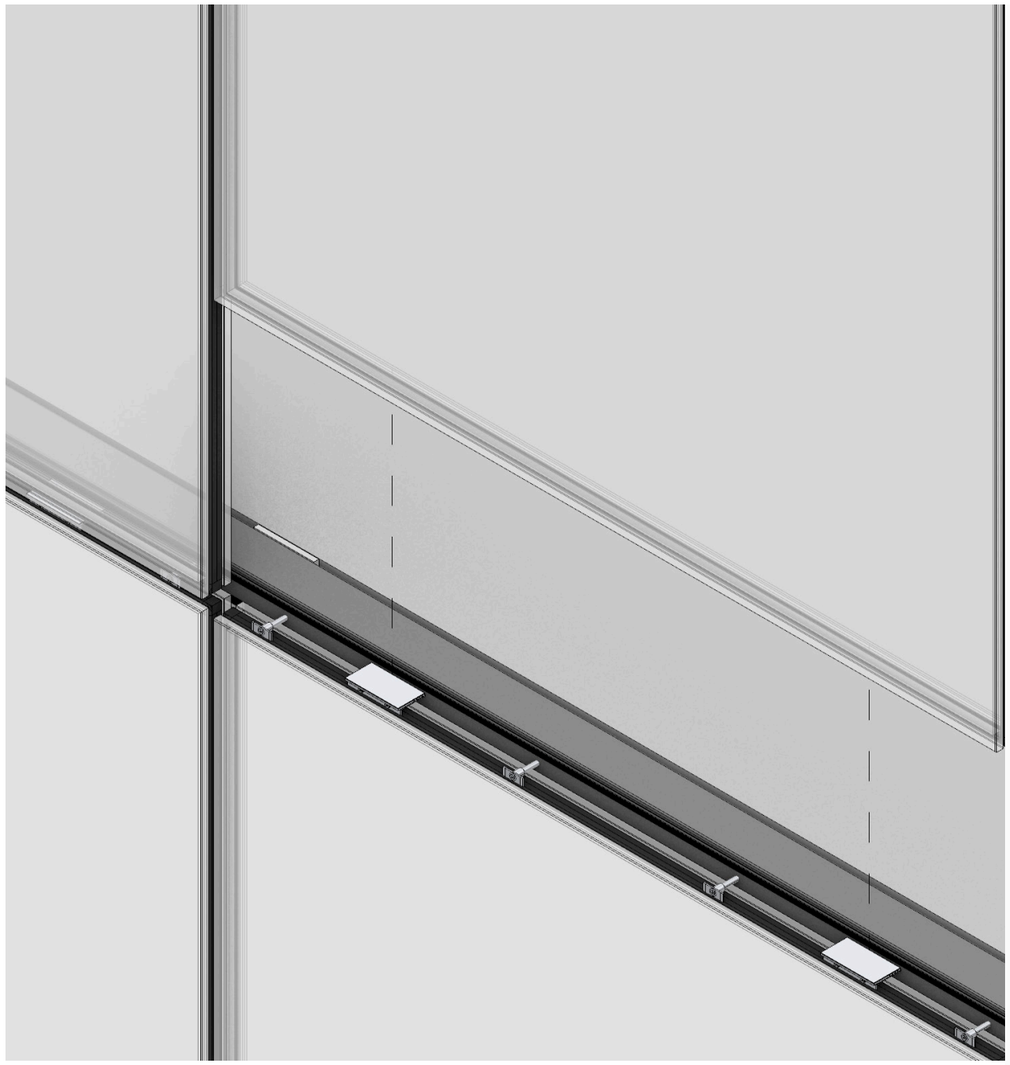


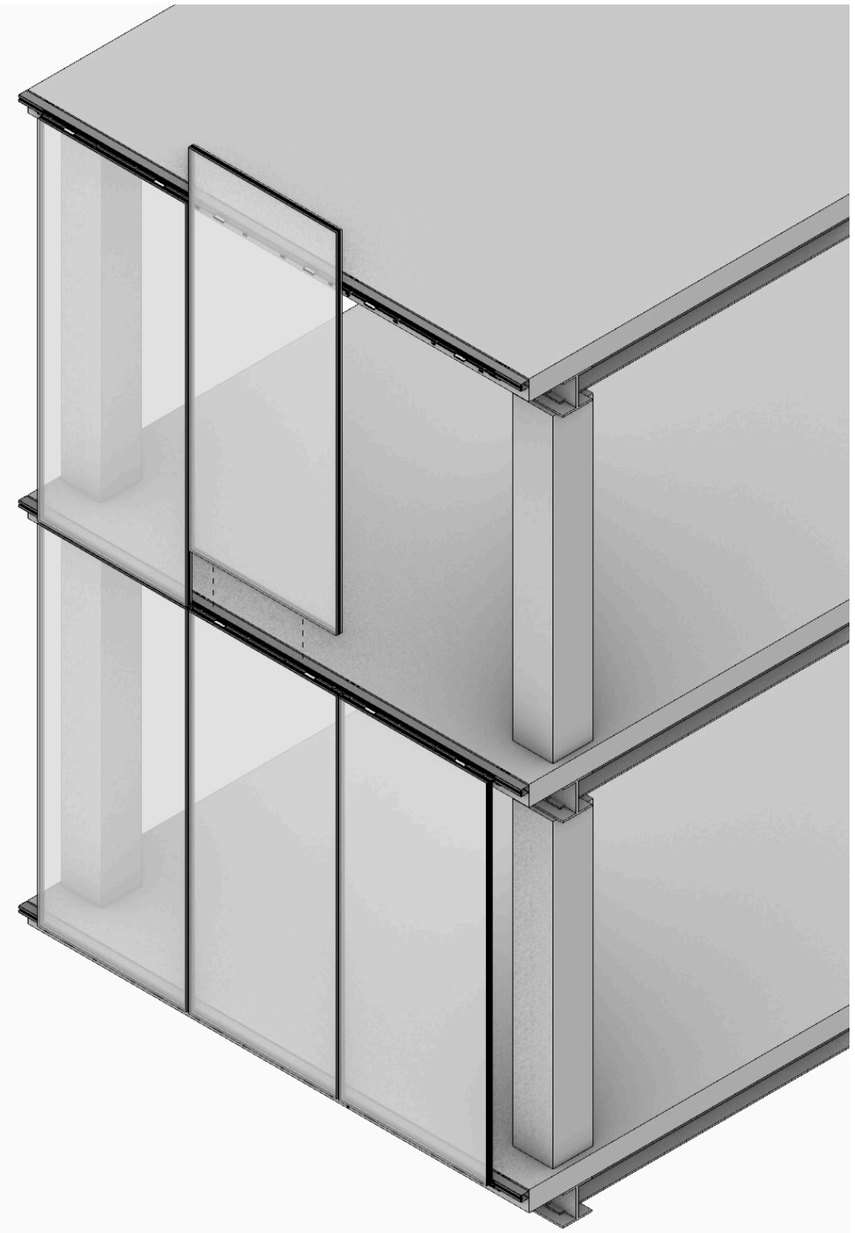
4. Fixing of Toggle Fixing Clips





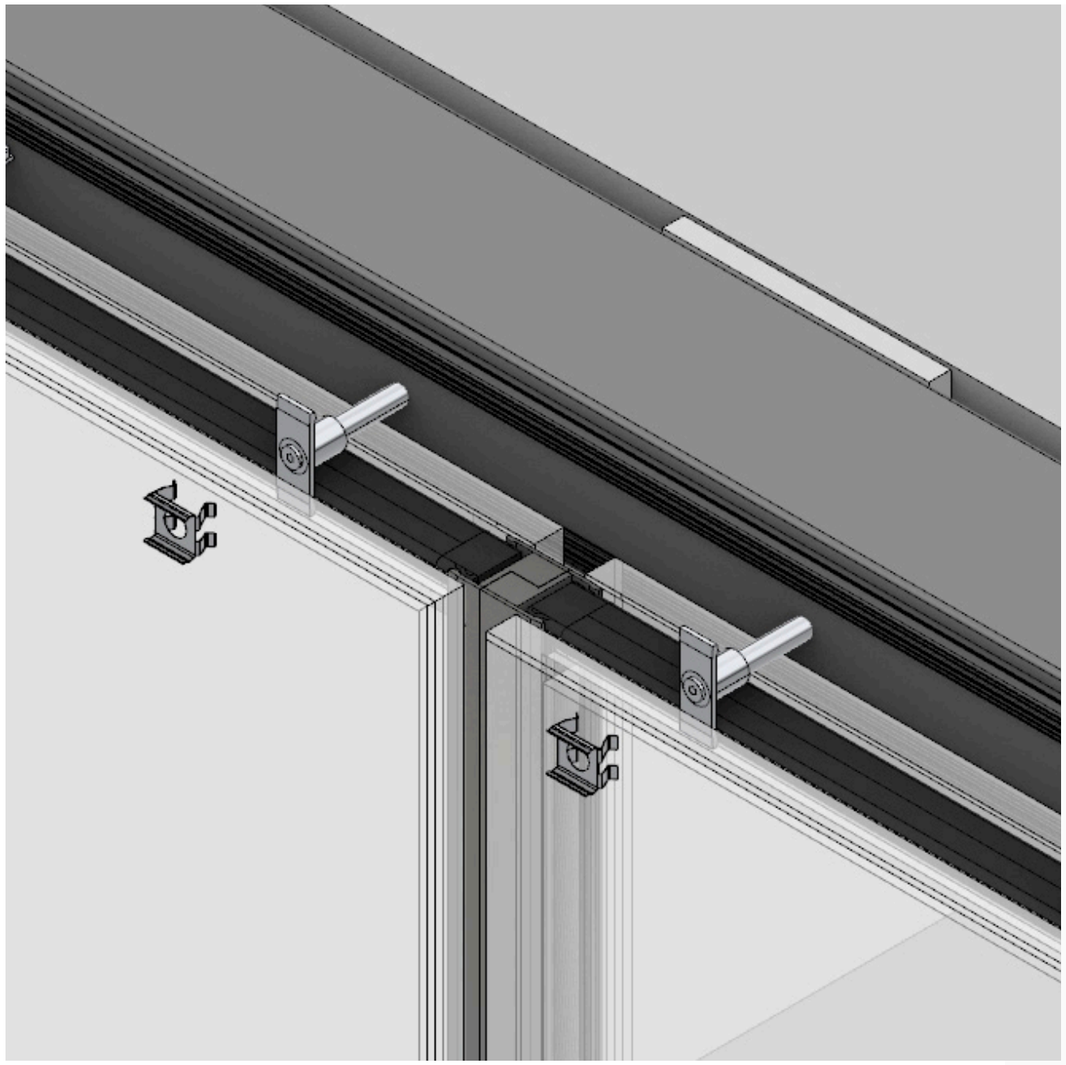
5. Placement of IGU on Support Blocks

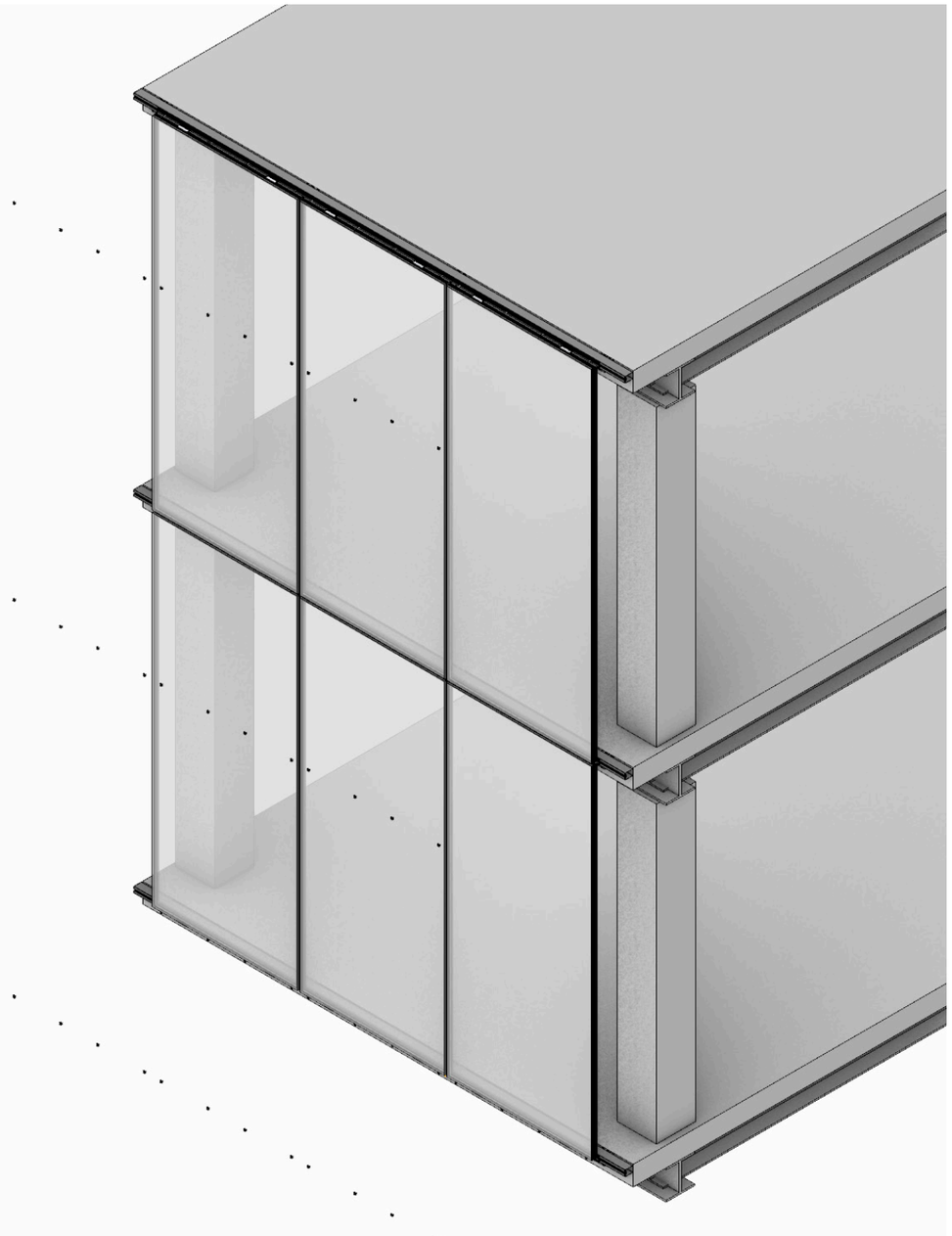




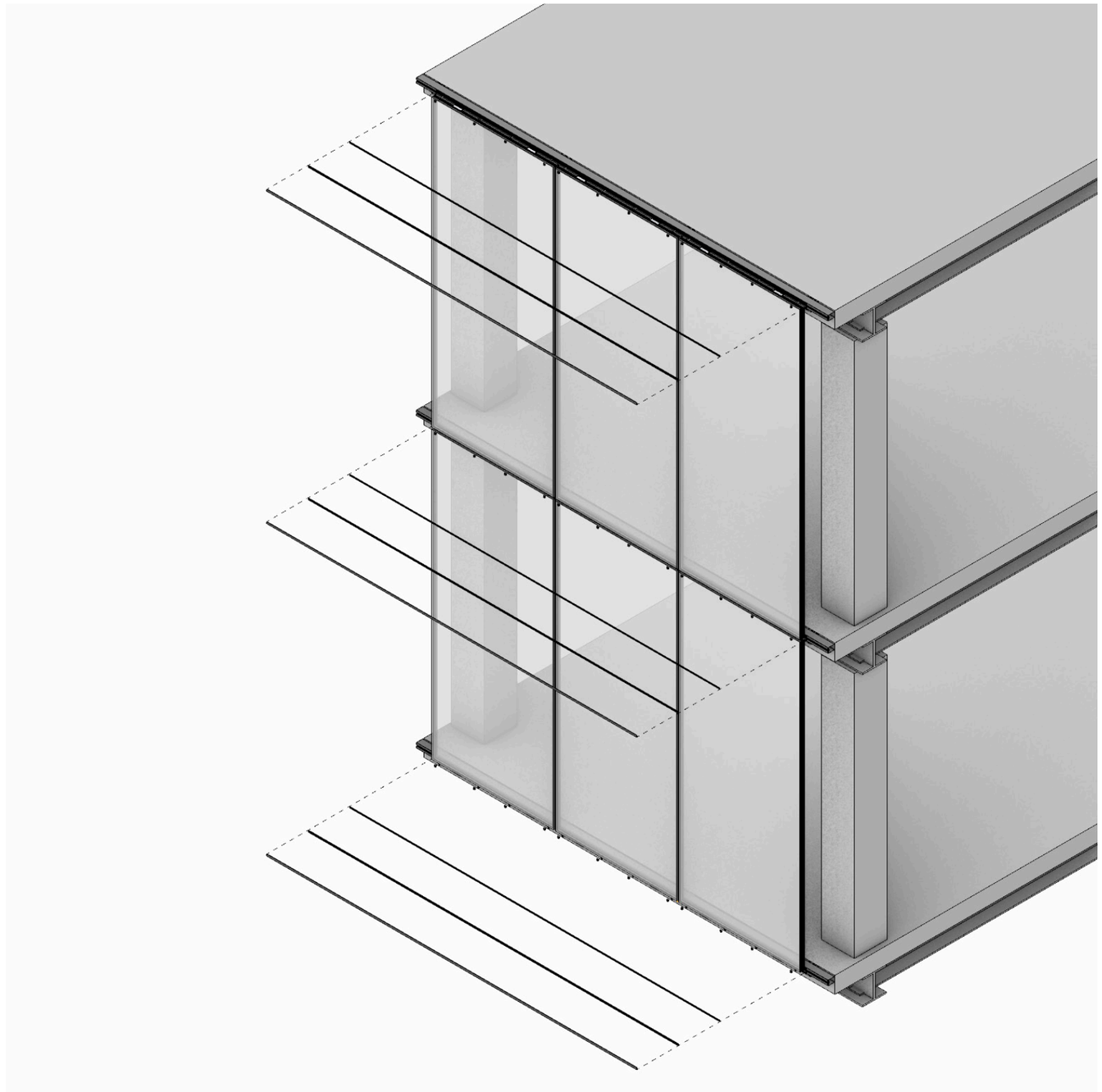
6. Turn of Toggle Fixing Clips

7. Fixing of Spring Clips for Gasket Holding

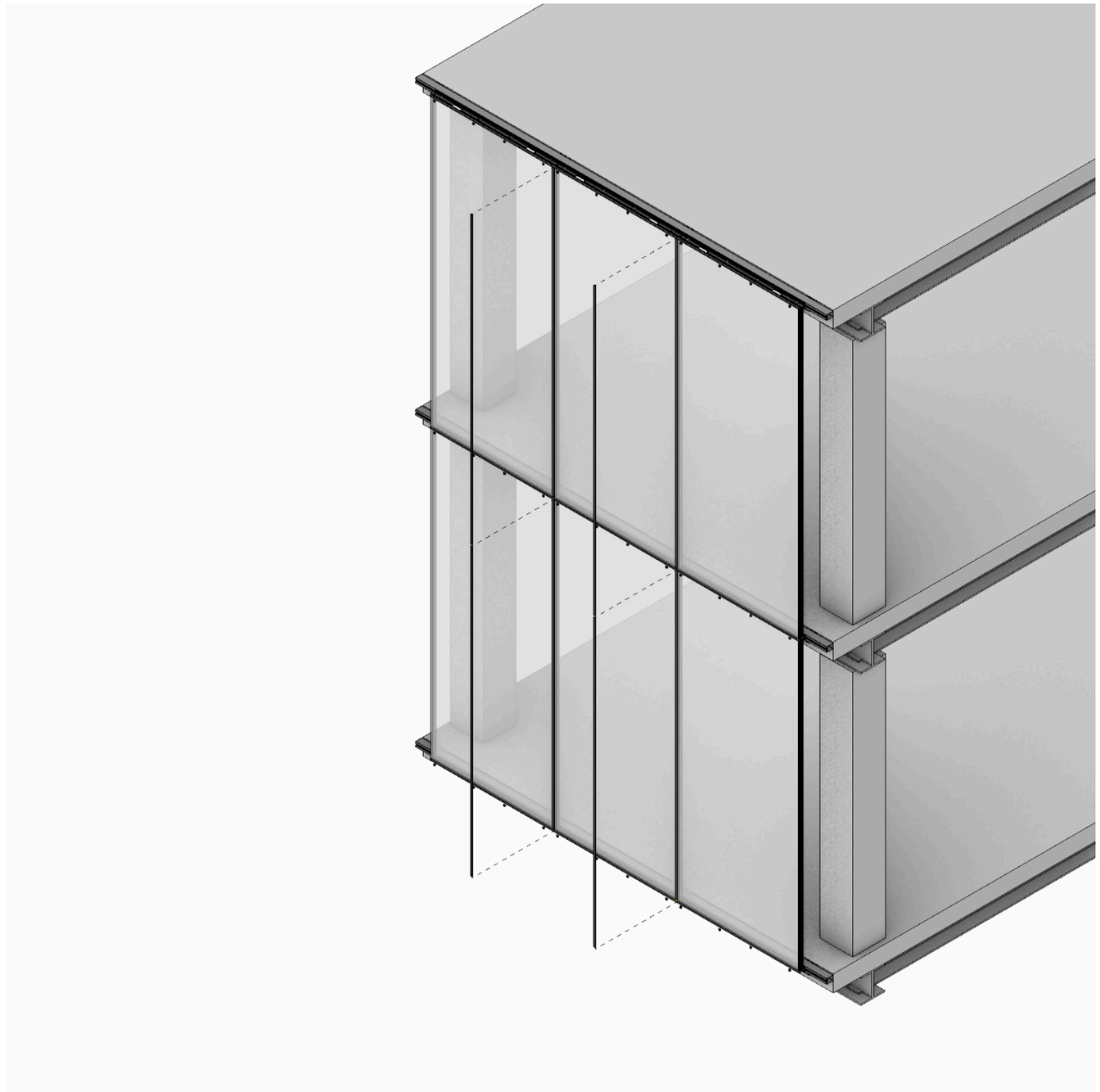


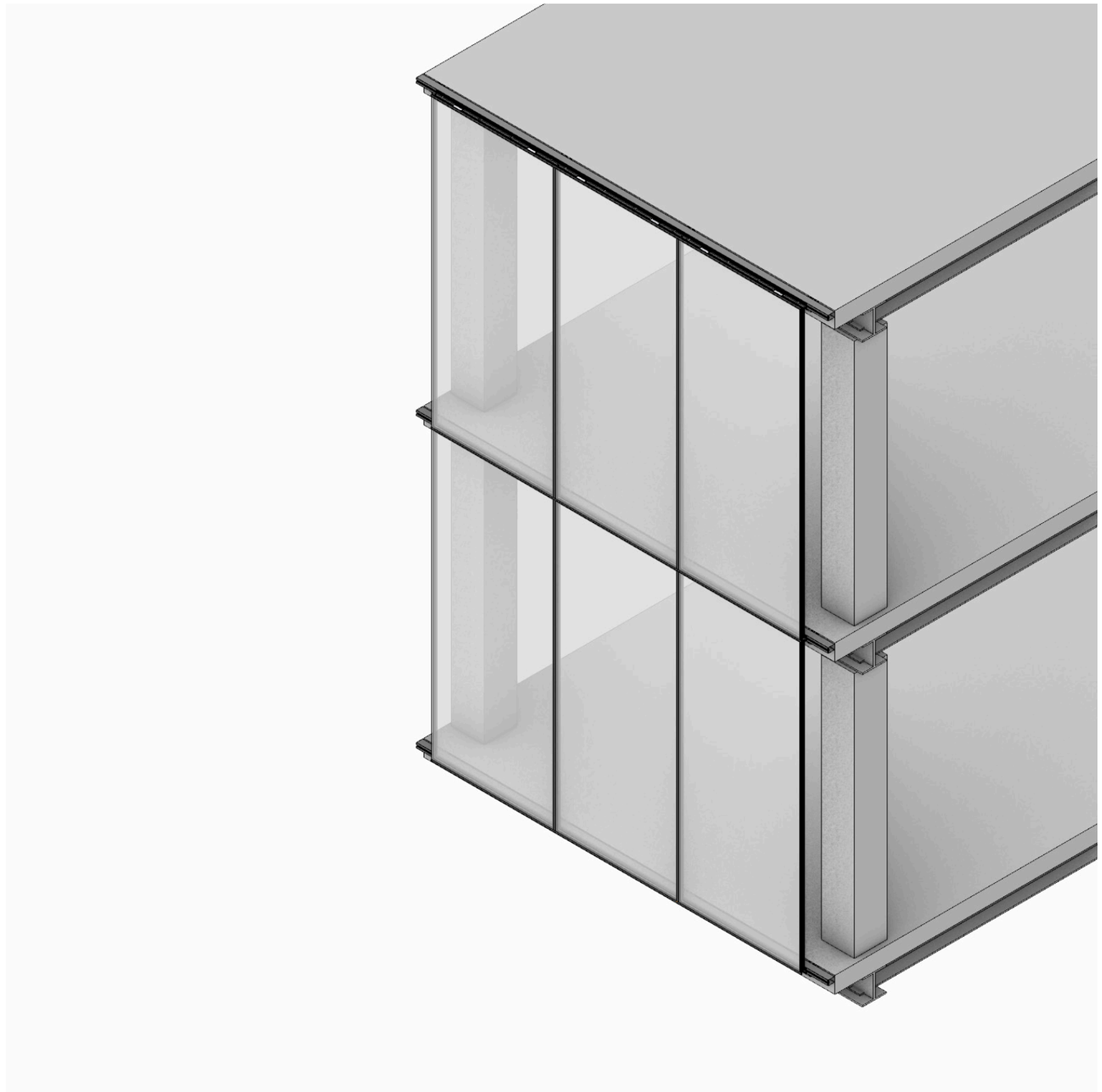


8. Placement of horizontal gaskets



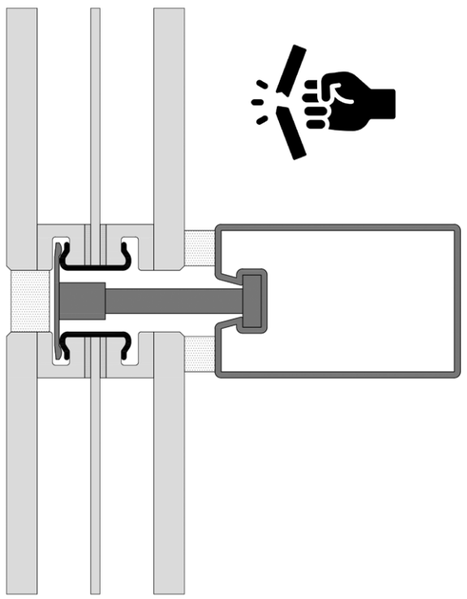
9. Placement of Vertical Gaskets





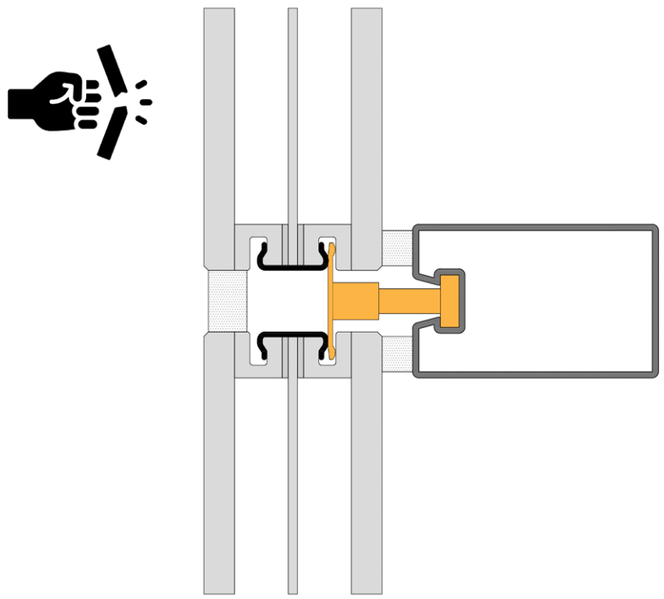
Safety Measures

inner pane breakage



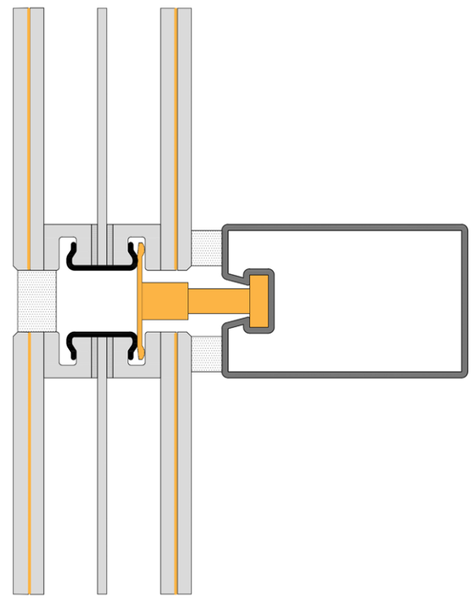
fixings

outer pane breakage



add safety inner fixings

additional measures

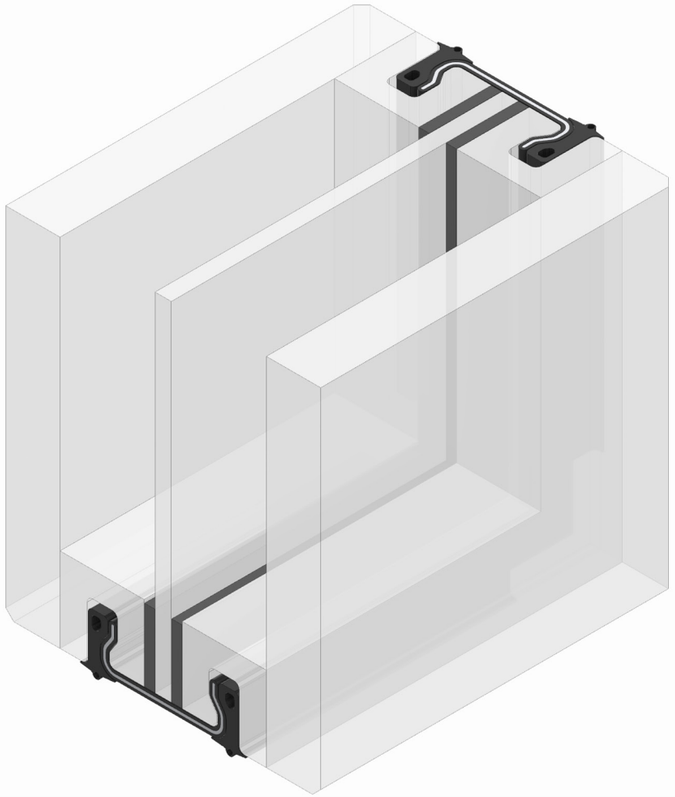


lamination

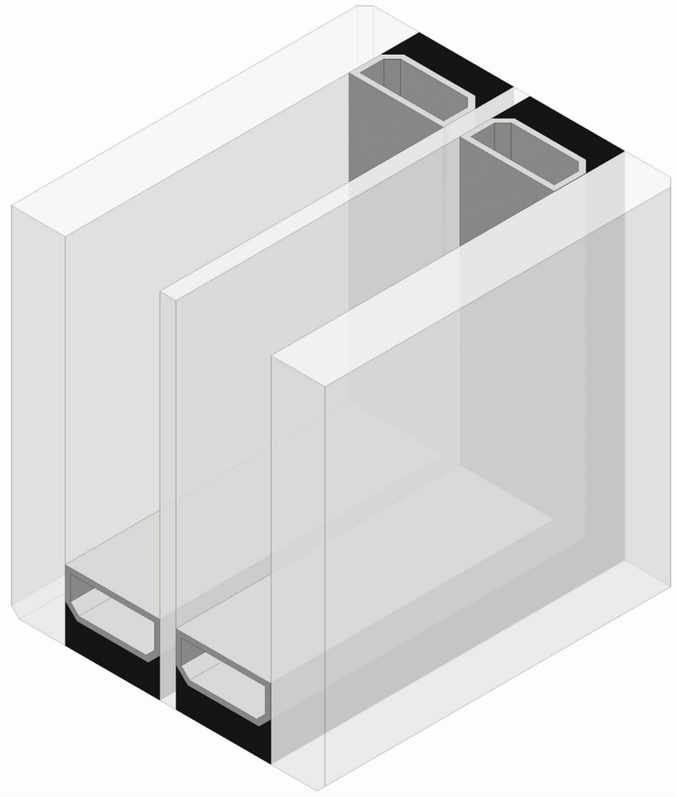
Conclusions

Answer to Main Research Question:

What are the potentials and limitations of implementing a **circular** design of **maximised transparency** in an insulated glass unit (IGU) that can be applied in fully glazed facades?

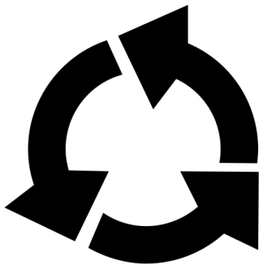


New Circular IGU



Standard IGU

Circularity



Potential

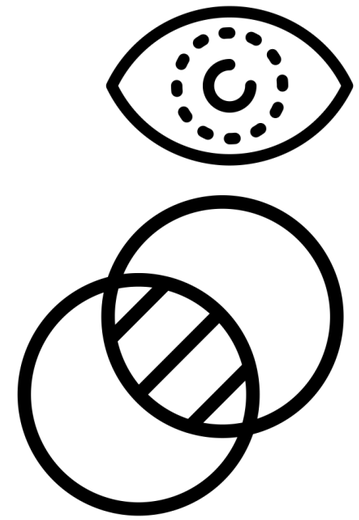
-> **Fully reversible** design
  -> Mechanical clamping connection
  -> Fusion of cast glass to float glass surface

Limitations

-> Use of **coating** for desired u-value
  -> Reduced quality of specific recycled glass pane

-> If **lamination** is necessary for structural reasons
  -> Either downcycle of laminated pane
  -> Or use of cast glass with thicker cross-section
  (provided that the external pane is heat treaded for safety)

Transparency



Potential

Internal Connection
-> **Reduced visible effect** compared to a standard IGU

Limitations

-> Desiccant
-> Metal foil for moisture barrier
-> Spring clip metal

Recommendations for further research

Testing

Glass extrusion process

Glass fusion process

Structural stability of IGU

Air and moisture impermeability of edge seal

Sufficiency of desiccant

Sound insulation

Thank you!

Time for questions