P5 Presentation

The transparent facade of the future

Design strategies for maximizing transparency with self-supporting glass facade systems

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RESEARCH DEFINITION

STAGE 1 → Analysis of Glass Technology

STAGE 2 → Preliminary Concepts

STAGE 3 → Design Research
3 Design Strategies

STAGE 4 → Final Design Development

CONCLUSION

PRESENTATION
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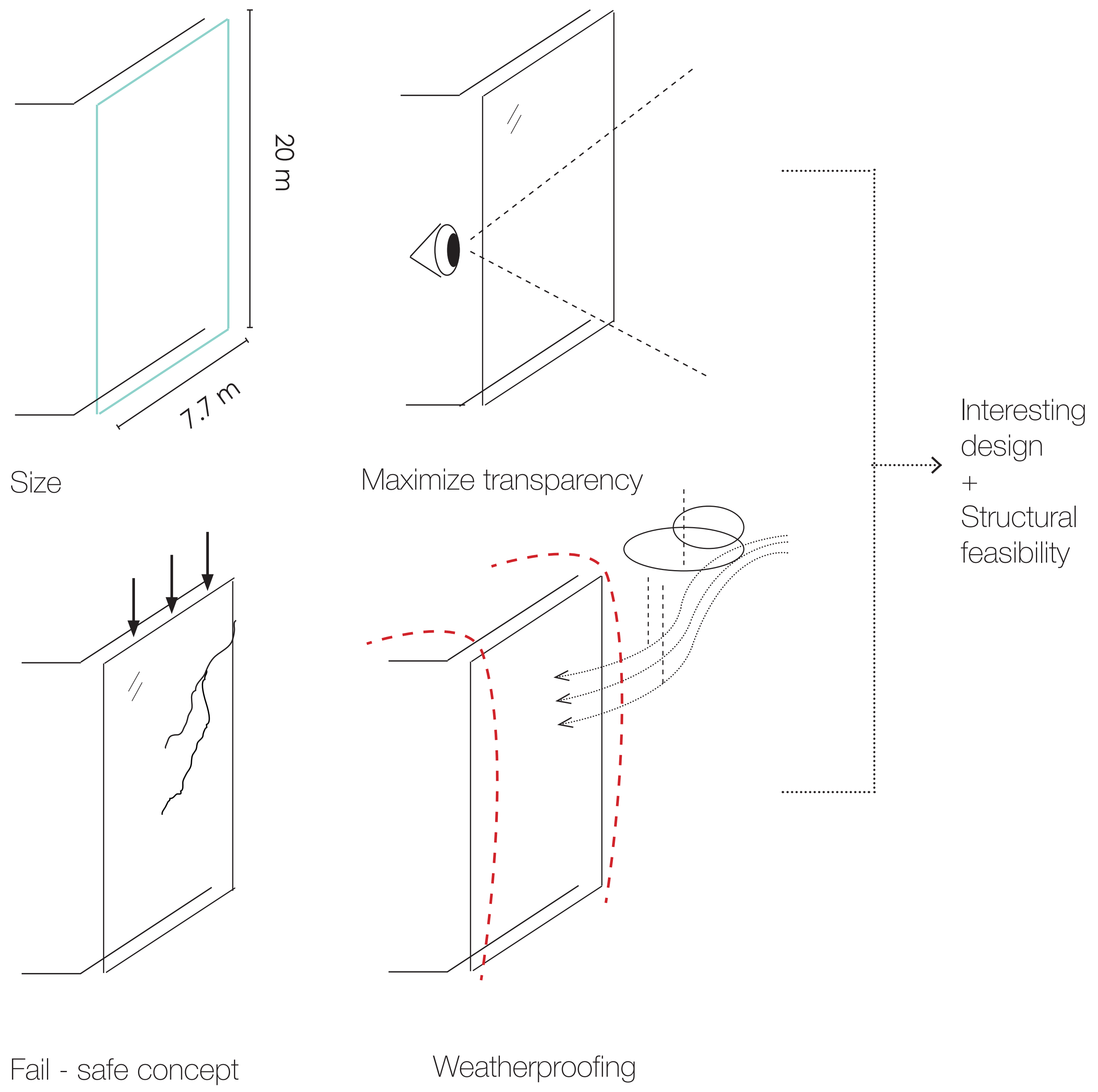
/// RESEARCH DEFINITION ///

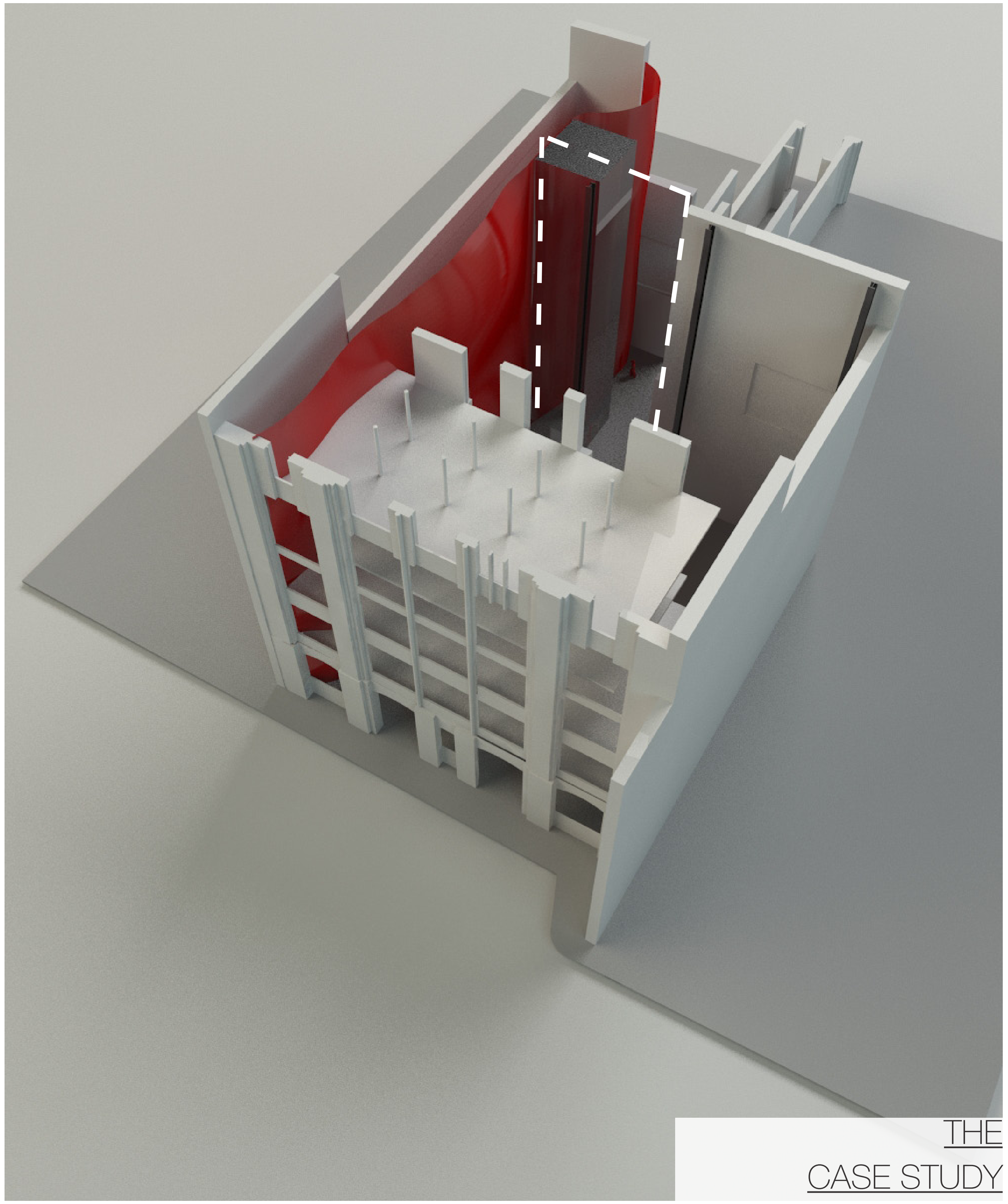
Zamora Offices - Alberto Campo Baeza

Rainbow Panorama - Olafur Eliasson

PROBLEM
DEFINITION

OMA ABT TU Delft SCHELDEBOUW





THE
CASE STUDY

“What are the design strategies that one can employ in order to maximize transparency in glass facades and which strategy is the most appropriate to follow for the structural design for a transparent facade of the future that will be applied in ‘La Fayette Modern’ ?”

1 | What is the optimal geometry of glass components to be used for the construction of the facade?

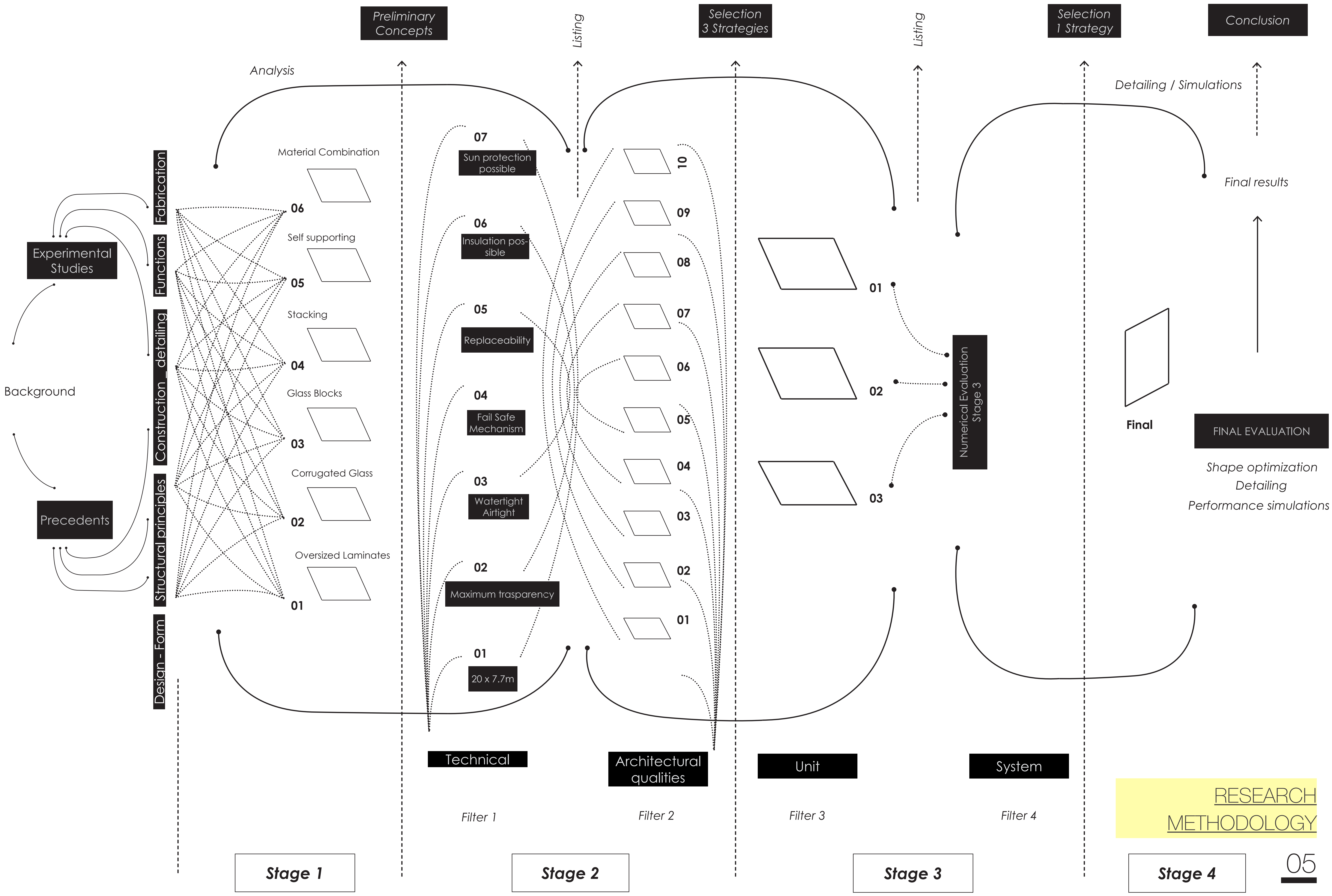
2 | What are the criteria to evaluate an optimal structural design strategy for the glass facade?

3 | Which parameters can influence the perfomance of a glass component?

4 | How can manufacturing availabiltiy and processes influence the structural design with glass?

5 | What are the ways, in which we can enhance the safety of the glass facade?

6 | How should a structural joint between glass components be designed in order to increase transparency?



RESEARCH METHODOLOGY

/// STAGE 1_ ANALYSIS OF GLASS TECHNOLOGY ///

Form - typologies

01 Linear 1D

Column | Rods & Bars | Mullion | Beam

Are components whose dimensions are small in 2 directions and large in a 3 rd direction - lengthwise.

02 Surfaces 2D

Plates | Slabs

Flat sheet geometry where the dimensions are large in the two directions and small in the third (thinkness).

03 Shells & Solids 3D

Shell | Folded Plate | Cells - Unit | Massive block

Loading conditions

Columns & Bars

Generally subjected to **axial loads.**
_In frames and girders ties and struts are respectively subjected to **tension** and **compression**.
_In columns we can have depending on the joining method (articulated or fixed) respectively pure **vertical compressive axial load** or axial load **combined with bending stresses**.

Beams & Fins

Generally correspond to the geometry of the linear elements but they are also subjected to bending and shear forces.
_**transverse** bending
_**longitudinal** bending
_**shear stresses**
_**axial stresses**
_Eccentrical load can cause **torsion**

Plates

Are subjected to **axial forces** exclusively that act **in the plane** of the element itself. They can be prone to local buckling.
_**Tension** trasferred by point fixings in friction.
_**Compression** transferred by point fixings in contact.
In both cases laminated glass for residual stability reasons is employed.

Slabs

Subjected to forces acting perpendicular to their plane. Distinguished from the plates because of the different direction of the loading. They can be prone to local buckling.

Shells

Shells are formations subjected to **in - plane stresses** and we distinguish them in two categories the curved elements and the curved surfaces consisted of flat elements (faceted surfaces)

Solids

Because of their geometry and width-height ratio they possess a greater stability and resistance to bending stresses and torsion than flat sheets or linear elements.

Composition

One - piece cross-section

Strips of float glass have maximum thick up to 25mm. The maximum slenderness ratio of 1/50 results in a maximum height of 1m for a compression member. Therefore glass tubes or solid cast glass struts are **more suitable as compression elements**.

Plane Beams - Fins

Bending stresses around the major axis which places the **stress concentration around the edges**.
Increasing depth can help reducing tensile bending forces. Lamination of 3 pieces toughened glass.
Carrying dead and wind loads. Outer edge subjected to compression

2 directional spanning
1 directional spanning
4 point support

Single - ply slabs

Consist of a single pane of float glass, toughened or strengthened. The most common form in slabs.Carries the external wind loads and transfers them to the continuous supports at the edges (frame). Extremely slender.
Individual supports lead to thicker glass than linear supports.

Curved glass

Cylindrical, conical, spherical, or any other curved forms, single pane or laminated toughened glass units. Reducing glass thicknesses because of the load bearing capacity of the shell.

Composition of solids

Bundle of columns

Composite cross-section

Compared to one - piece elements the combination of multiple cross sections joined together can create interesting and stronger compression elements.
_ **Glueing glass to glass**
_ **Glueing glass strips to metal connecting sections**
_ **Joining strips via individual fixings**

Rings | Massive stack | I - Profile | Bundle of columns

Composite cross-section

Composing an extremely efficient cross section by composing individual monolithic elements.
Creating shapes that can optimally handle the bending stresses. (ex. I -shape).
_higher torsional rigidity
_higher bending strength
_more stable
Contact or friction fixing points via elastic intermediate pad.

Multi - ply slabs

Consist of **multiple layers of single slabs** loosely stacked and bonded with adhesive.
Shear stiff interlayer good for **bending stiffness**
Non beneficial in safety if one of the plies brakes.In that case a more viscoelastic layer is preferred.
Residual stability after the failure of a single plane.

Multi - ply with edge seals

Creates a **short of hollow box** that is sensitive to deformations of the structure that cause twist.
The air cavity acts structurally
Benefit or disadvantage related to temperature and hence pressure conditions.

Faceted shells

Faceted surfaces are consisted of elements with radius of curvature very large compared to their size. They are usually undergoing very high compressive stresses, which means that the stability has to be ensured.

Combination with materials

Limited use of glass in ties and structs because of the limited sizes of the product and sudden failure behaviour. Combining glass with other materials can allow overcoming these hindrance.
_plastic
_metal
_timber
Product of this method is the concentric prestressed monolithic glass tube

Material combination

Lending glass a **ductile behaviour** by combining it with a ductile material . Therefore now it can exhibit apart from high compressive strength an tensile strength in order to carry the safely the loads for a certain amount of time after it fails.

PVB or Sentry Glas interlayer
Glass glued on transparent polycarbonate core

Slabs with ribs & stiffeners

Combination of slabs with ribs can allow for **larger spans** and more efficient structure. **Reducing stresses and deformations.**
_Uninterrupted spans
_Additive assembly
_Multi-leaf insulating sections

Trussed slabs

The glass plane here carries the compressive loads and the truss in one or two axes the tensile loads.
Truss connected via props or webs.

Membranes

Very interesting from engineering and architectural point of view.
Elements are subjected exclusively to high tensile axial forces uni - directional or bi - directional
Transferring the forces to neighbouring elements is up to now feasible only by clamping or individual fixings. Causes local stress concentration.
Residual load bearing capacity is not yet adequate in tensile stresses.

Form - typologies

01 Flat Glass

02 Curved

Single curved

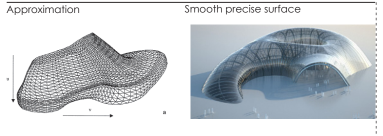
Double curved

A surface is doubly ruled if through every one of its points there are two distinct lines that lie on the surface. The hyperbolic paraboloid and the hyperboloid of one sheet are doubly ruled surfaces. The plane is the only surface which contains three distinct lines through each of its points.

Single panel | Corrugated

Synclastic surfaces | Anticlastic anticlastic | Freely developable surface

Approximation | Smooth precise surface



03 Solid

A solid or stereometric shape can be achieved by a mold that forms the glass into shape or by means of stacking flat surfaces until they achieve a 3D object.

Forming processes

Primary process - flat glass

Step 1 _ Production of flat glass

Floating / pouring still liquid glass on a bed of molten tin. This allowed the production of a glass panel with two perfectly flush surfaces. One is resulting from the perfectly flat surface of the molten tin and the other, upper one, from the gravity that flattens the surface of the molten glass. By cooling the slowly moving ribbon of the molten glass it can solidify and basically allow for a continuous process with the ribbon cut in different panels. Effects of the process

1550 °C | 1050 °C | 600 °C | 100 °C

Melting tank — Melting, Refining, Homogenising
Float Bath — Floating on bath of liquid tin
Annealing Lehr — Cooling to 100 °C over a length of up to 150 m glass ribbon
Cutting to size, Further Processing, Transport & Storage

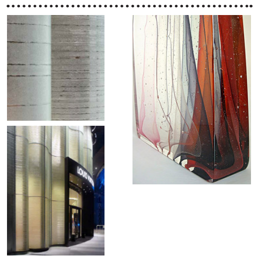
Cast glass

Glass casting is the process in which glass objects are cast by directing molten glass into a mould where it solidifies. Modern cast forming methods are. Sand casting and Kiln casting

Sand casting

Kiln casting

Pate de verre means glass paste. Crushed glass mixed with binders. The paste is applied in the inner surface of a negative mould as a coating. After the coating is fired at the appropriate temperature the glass is fused and creates a hollow unit that can have thick or thin walls.



Curved forming

Step 2 _ Production of curved glass

Hot - Bending

Curved annealed glass is manufactured by slowly heating flat glass up to the softening temperature. When the flat panel starts slumping by gravity, it is taking its curved shape on the customized mold. Once the geometry is achieved a slow cooling process known as "annealing". Curved glass can be also produced tempered and heat strengthened.

Cold - Bending

During the cold-bending process, several sheets of tempered glass are combined to make a laminated safety glass sandwich and then shaped as a glass/film laminate in an autoclave to become a single unit. Two processes:

_**Cold-bending with shape-enhancing lamination**
By using shear-compliant film (PVB film) sheets of glass are mechanically anchored to a shape-fixing substructure, in order to lend permanence to their shape.

_**Cold-bending with shape-fixing lamination**
By using shear-resistant film (SG film by DuPont) shapes are maintained solely on the strength of the film's shear resistance.
Once laminated in the autoclave, the composite glass sheet permanently retains its geometric curvature without being dependent on a shape-fixing substructure.

Lamination frame | Glass and interlayers | Lamination | Release form

Hybrid forming

The skin could be created using single-curvature hot-bent glass according to a limited number of familiess but is preferred to use "ad hoc" panels produced using variable mould machines. The glasses are, then, successively cold-bent, before lamination or on-site, in order to adapt its curvature to the all different non - circular supporting lines.

Flat glass | Hot bending | Cold bending

Type of connection

01 Non - positive

In non - positive connections the joint is held together by applying a force that presses the individual elements together.

02 Positive

Positive connections are connecting individual components together based solely on interocking of geometries

03 Material Bonding

Forces can be transmitted through the adhesion connective forces developed in a molecular or atomic level.

Form of force transfer

Friction connection

In this type of connections the forces occuring in the glass element are transferred via friction to the joint. Here meaning the mechanical interlocking between the microscopic surface imperfections of the two material faces in contact. The forces therefore are transferred via axial/shear force from the glass to the joint.

Contact connection

In contact connections the compressive force acting perpendicular to the contact faces provides the force-tranfer mechanism.

Welding

Not used in building construction yet due to the insurmountable problems occuring from the stresses developed as a result of unevenly distributed temperatures.

Metal soldering

Not used in building construction yet due to the insurmountable problems occuring from the stresses developed as a result of unevenly distributed temperatures.

Adhesive joint

Widely used in contsruction with glass. Employ large contact faces for stress distribution via elastic adhesives. Forces are dependent on temperature and duration of the load. Relatively low stresses developed. Forces are transferred perpendicular or parallel to the joint surfaces.

Clamp Fixings

Linear clamp fixing

01. Without safety

02. With safety

Linear supports offer resistance against wind pressure loads in facades.

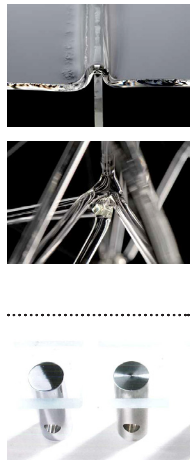
Point clamp fixing

Resistance of facades against wind suction can be achieved by ways of individual clamping.

Combination clamp fixing

1 Lead light
2 Putty fillet
3 Rebate with glazing bead
4 Patent glazing with capping strip
5 Gasket glazing

Bonded Fixings



Glues

Glueing is the most common way of adhesive bonding. Adhesive can be applied:

_Whole surface
_ Linearly
_Discrete points

Silicones

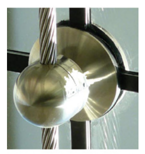
Is a type of facade construction in which the glass is permanently connected to an adapter frame via a loadbearing waterproof silicone joint

01. Black

Black silicon is made from polymer base plus chalk, silisic acid and soot fillers.

02. Transparent

Transparent silicones are possible, but require more expensive polymers such as resins. This is why they are not established in facades yet.



Drilled Fixings

Types of movability

01. Rigid fixing

02. Hinged fixing

Form of disc

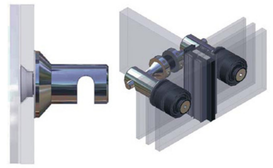
The disc point fixings are made of stainless steel and are in contact with two sides of the glass pane. Their diameter is according to the drilled hole and it should be at least 50mm.

Form of hole

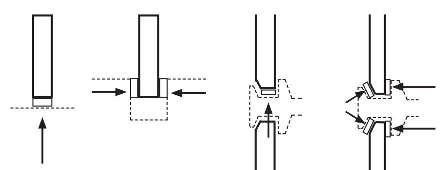
Cylindrical

Cylindrical - conical

Cylindrical - conical with undercut

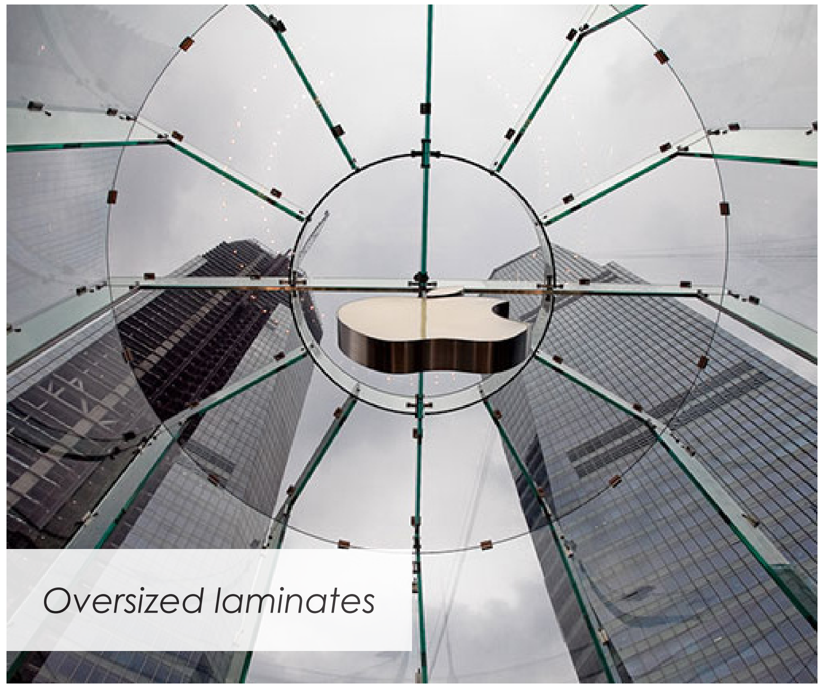


Cylindrical - conical with undercut



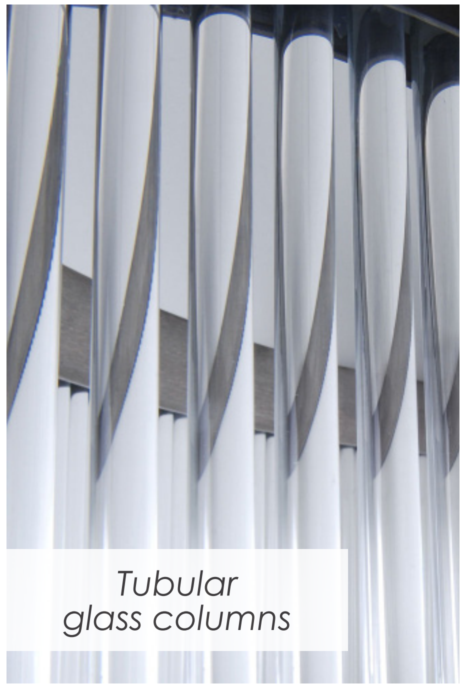
Force transfer on supports

PRELIMINARY STUDIES



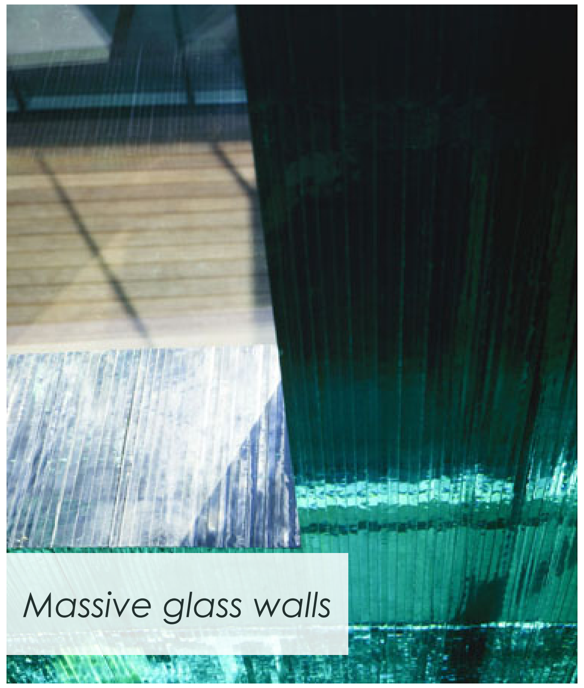
Oversized laminates

Curved glass

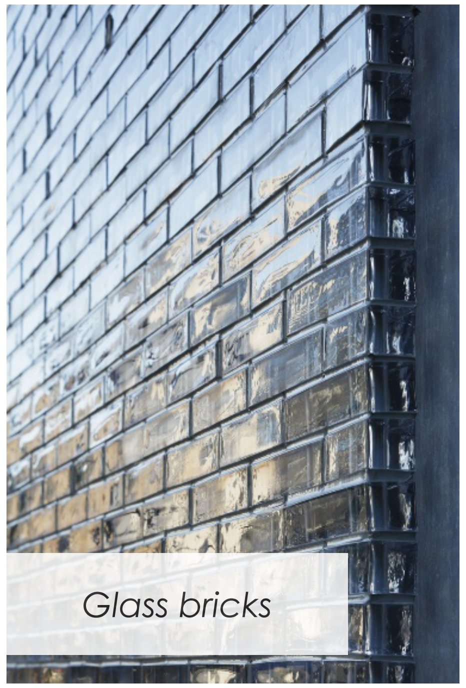


Tubular glass columns

I glass profiles



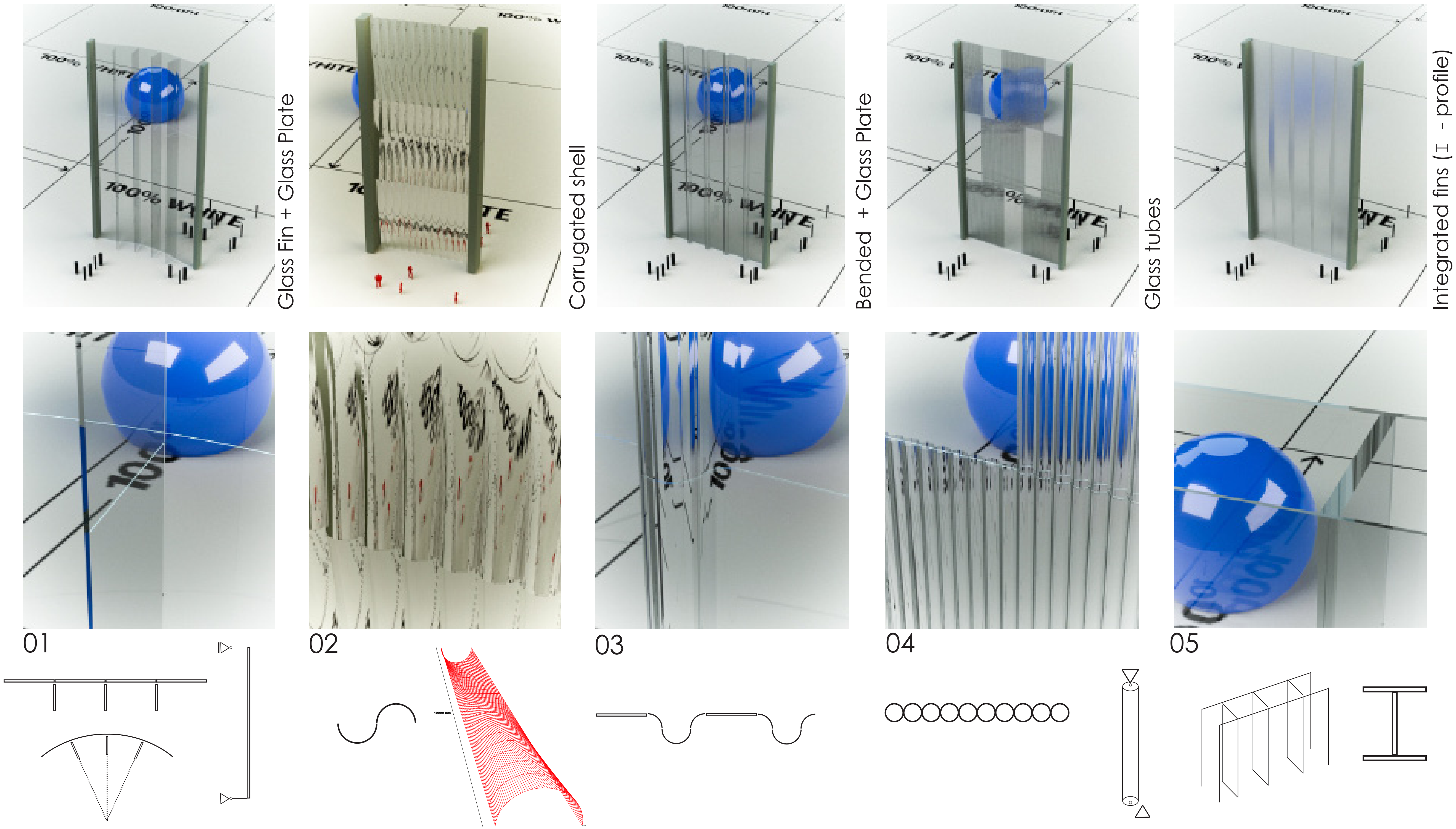
Massive glass walls



Glass bricks

Transparency | Form | Structure | Construction | Fabrication | Connections

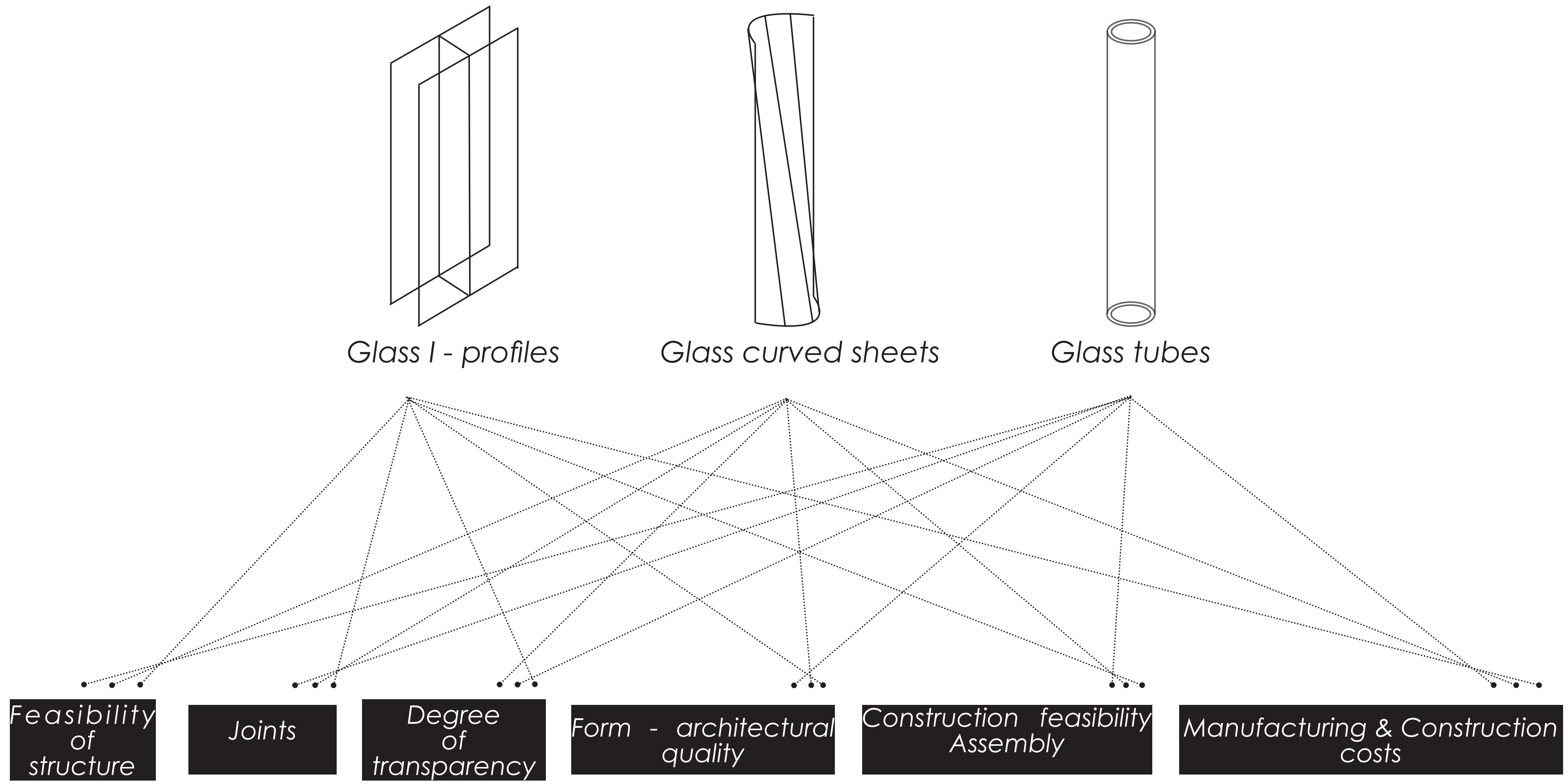
/// STAGE 2_PRELIMINARY CONCEPTS GENERATION ///



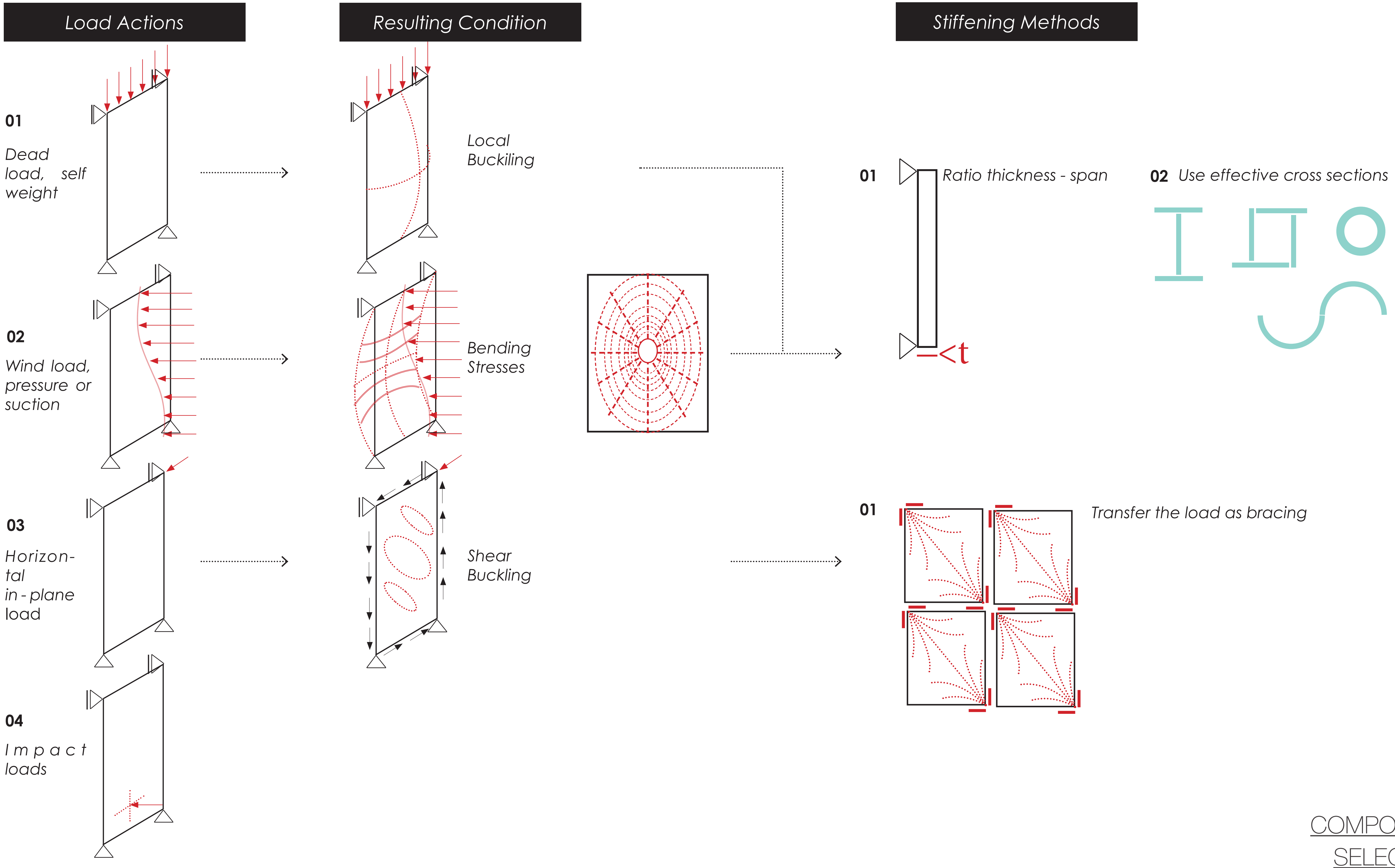
FIRST CONCEPTS

NEW Design methodology based on

Glass Component type



/// STAGE 3_DESIGN RESEARCH - 3 STRATEGIES ///


Load Actions
Resulting Condition
Stiffening Methods
01
Dead load, self weight
Local Buckiling
02
Wind load, pressure or suction
Bending Stresses
03
Horizon-tal in - plane load
Shear Buckling
04
I m p a c t loads
01
Ratio thickness - span
—<t
02 Use effective cross sections
01
Transfer the load as bracing

01 **Self supporting skin /**
No secondary support

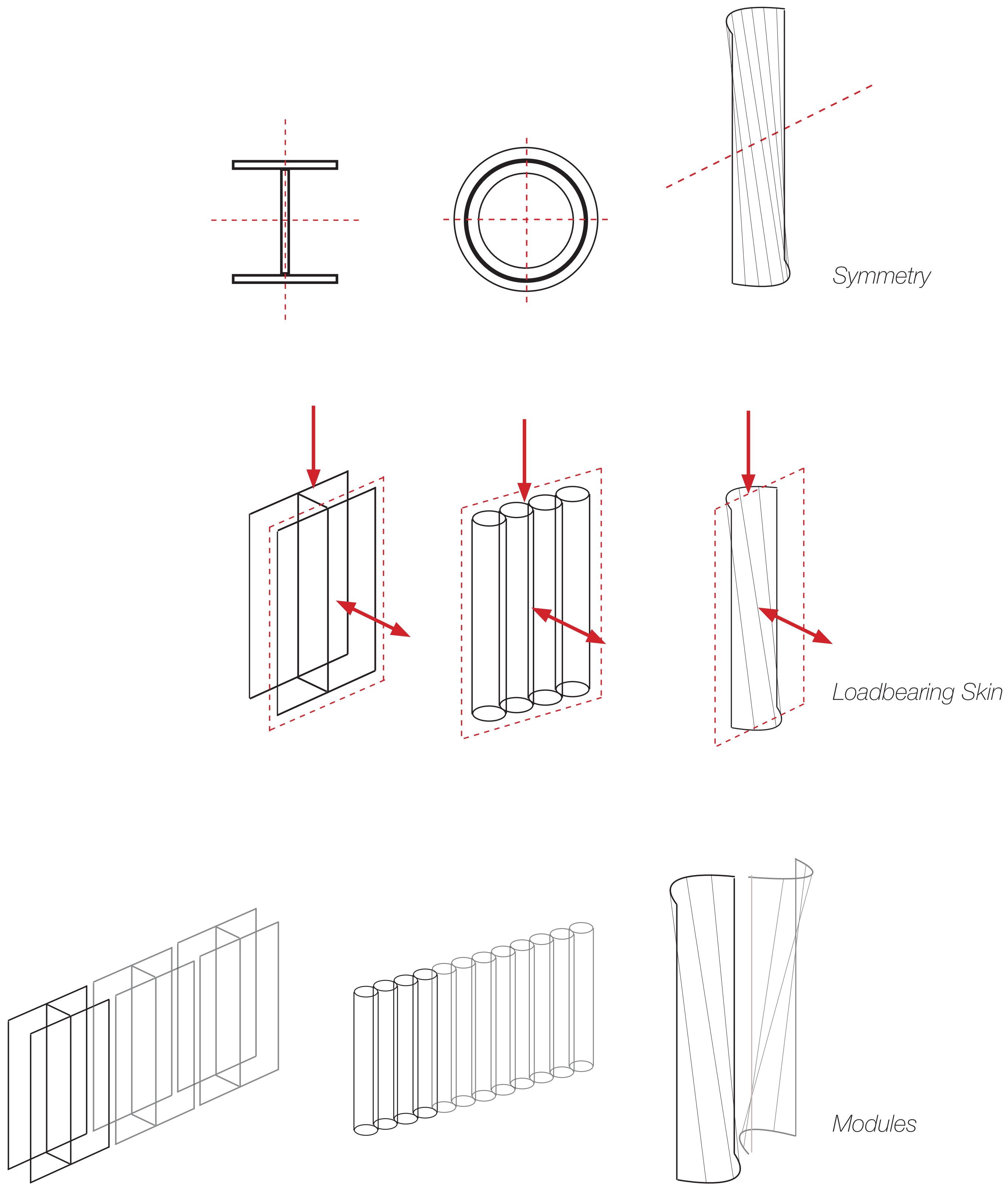
02 **Symmetry /**
at least along one axis

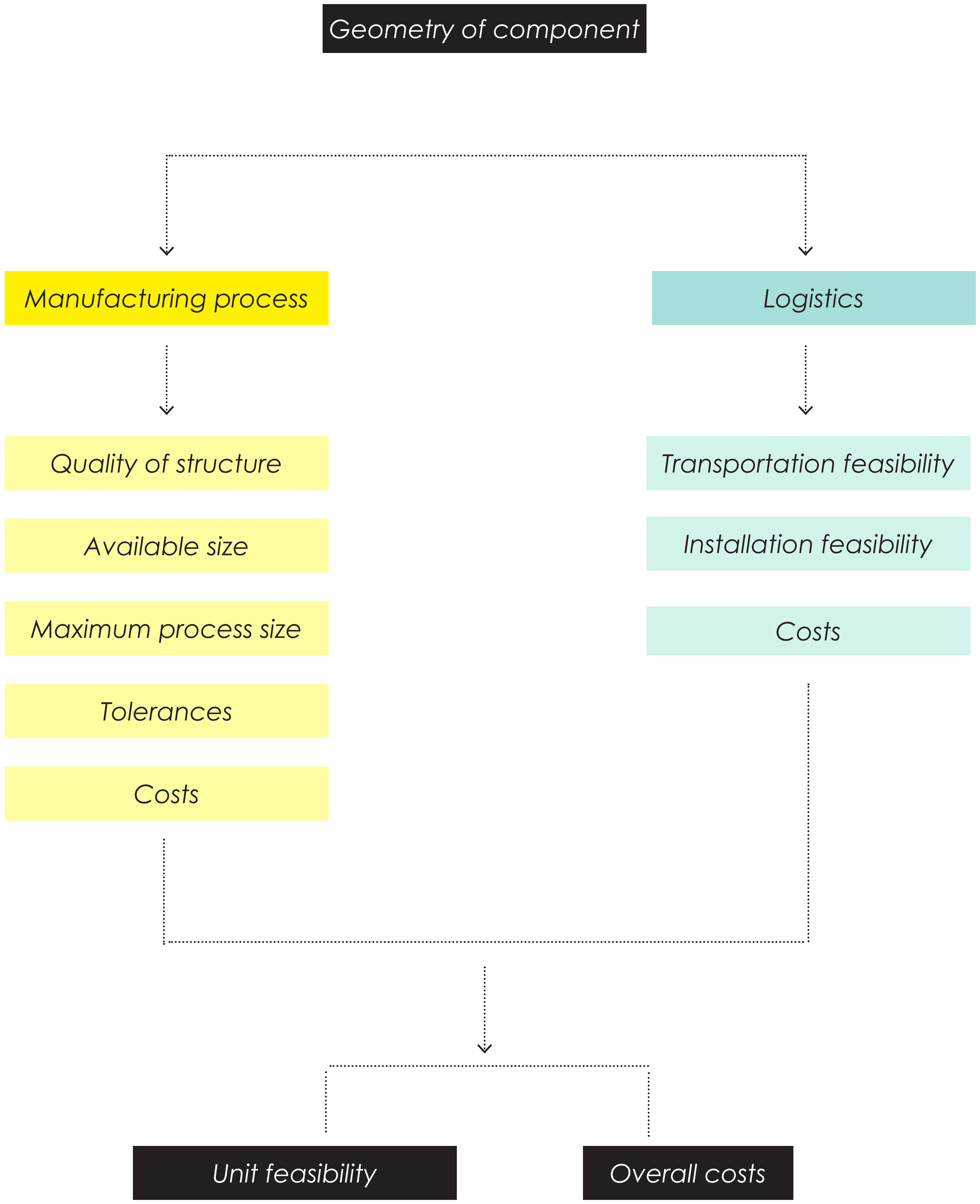
03 **Homogeneous appearance /**
Same from exterior and interior

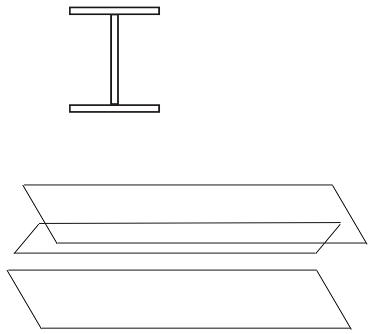
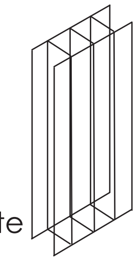
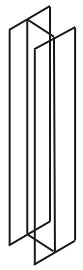
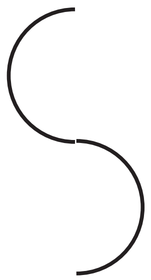
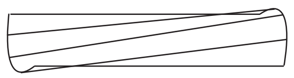
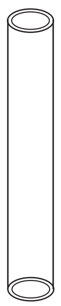
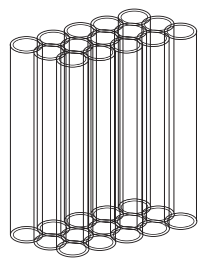
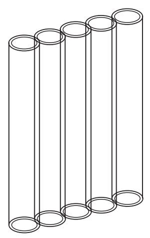
04 **Transparent or frameless joints /**

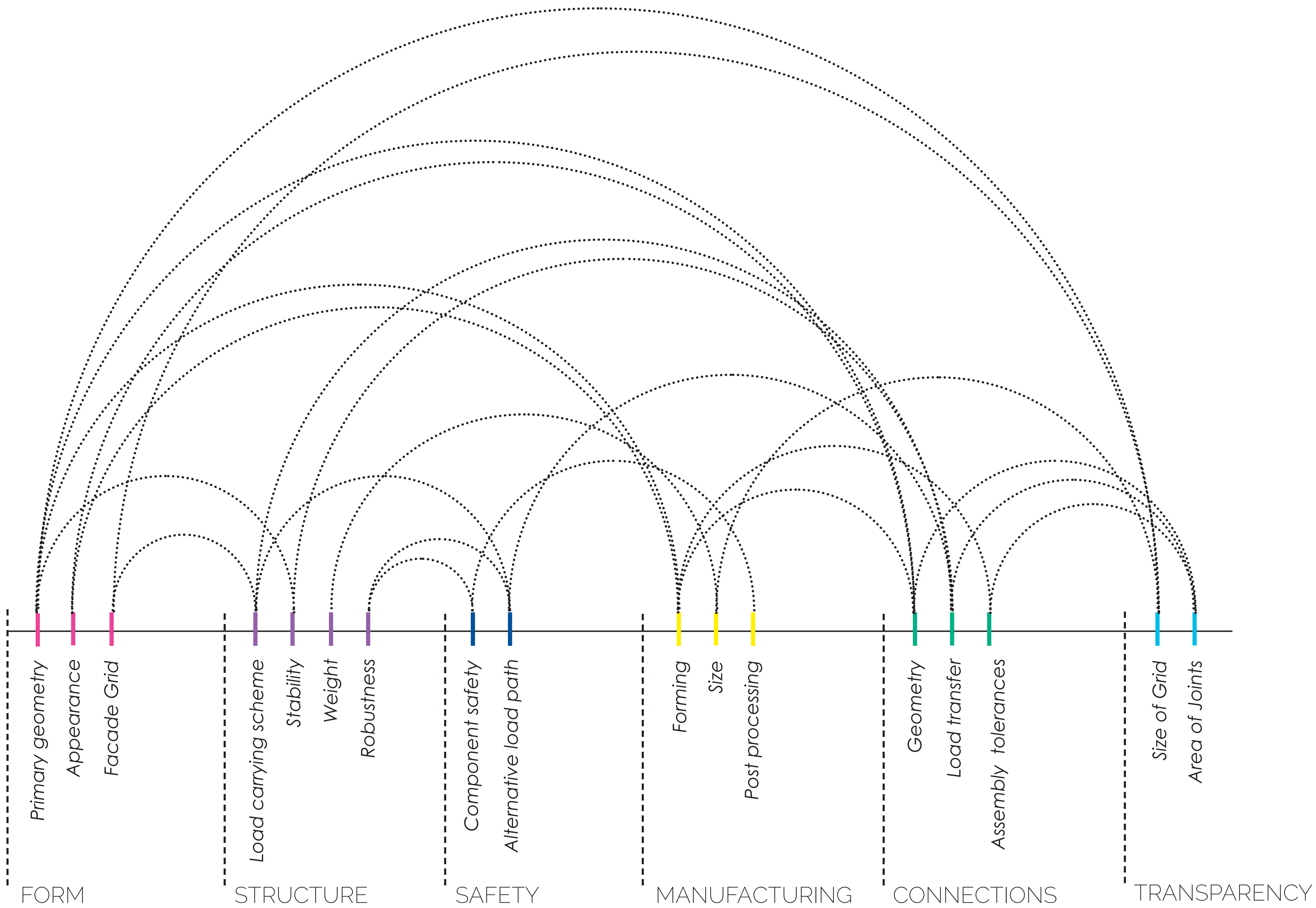
05 **Design versatility /**
Many form potential

06 **Modules /**
Possibility of assembly in units

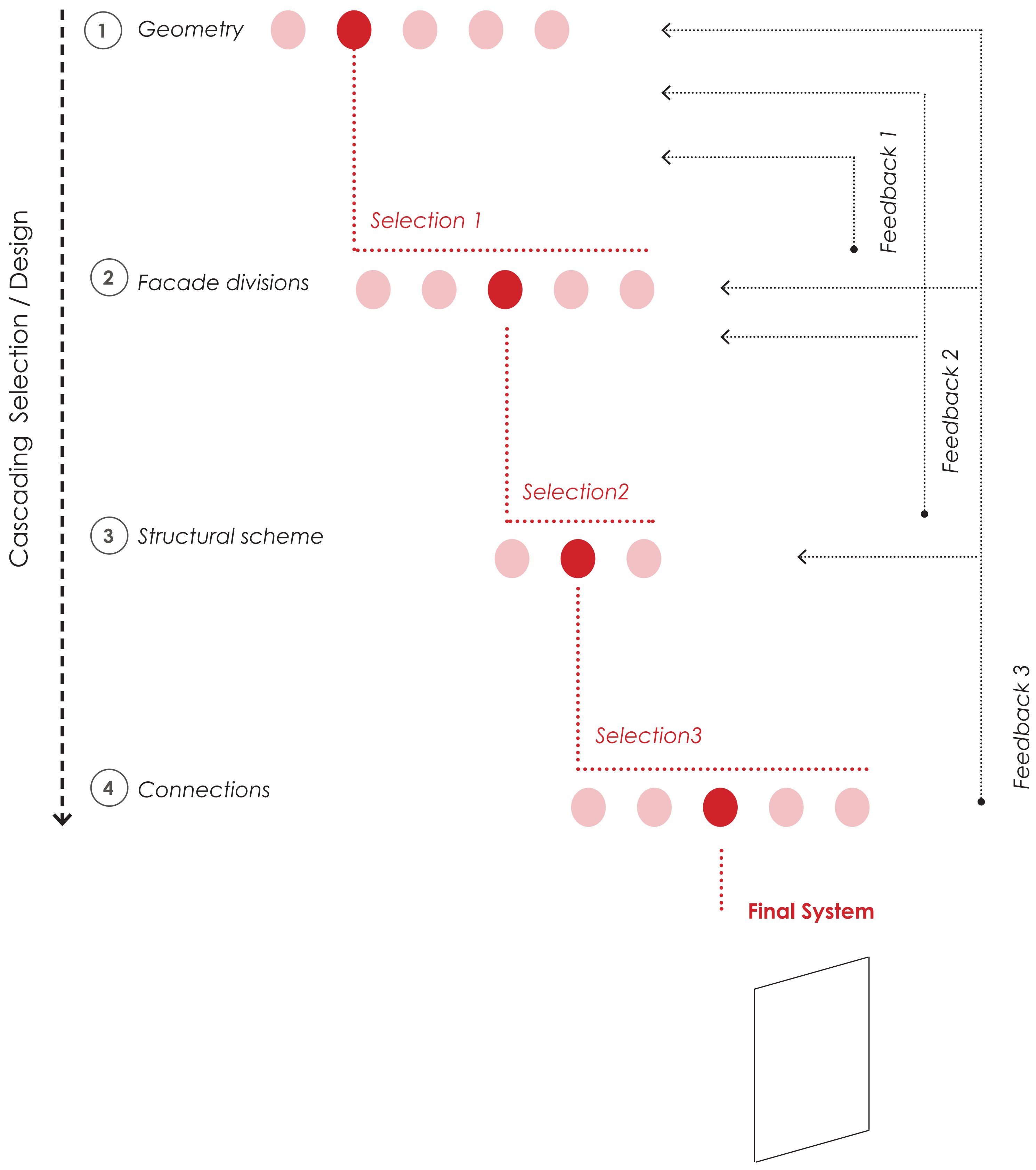



Geometry of component
Manufacturing process
Logistics
Quality of structure
Available size
Maximum process size
Tolerances
Costs
Transportation feasibility
Installation feasibility
Costs
Unit feasibility
Overall costs

Geometry		Manufacturing								Logistics		Safety	
Primary shape	Unit scheme	Process	Max. Raw size	Min. Radius /Diameter	Max. Processing size	Max. lamination size	Max. Realized size	Tolerances	Costs	Feasibility	Costs	Lamina-tion	Tempering
 Flat sheet	 Ribbed plate  I-profile	Float glass	approx. 25000 mm		8000mm in Europe 15000mm in China	15000mm in glass industry 23500mm in aircraft autoclave	14000m	++ for oversized (+-1mm/m)	++ (for oversized)	++ (for oversized)	++ (depend-ing on producer)	++	++
 Bended surface	 Double curved	Cold Bending	size of flat panel depend-ing on radius	-	+	every size produced		+	+	+	- (for pre-bent)	++	++
	Single curved	Hot Bending	6000mm length	++	6000mm length	every size produced	5600m length	- (+-2mm) (depends on the complexity and size)	- - custom mould + adjustable mould	+	- -	+	++
 Hollow tubes	 Bundle	Centrifug-ing process	standard 1500mm SCHOT -10000 mm	420mm	+	1500mm	not specified	- - (-+5 mm)	- -	+	+	+	+ (size limita-tion)
	 Single row	Daner process	- -			- -			+	+	+		

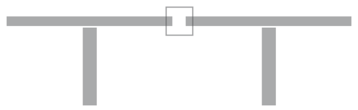


SYSTEM PARAMETERS

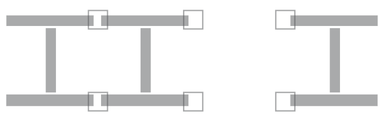


SELECTION
METHOD

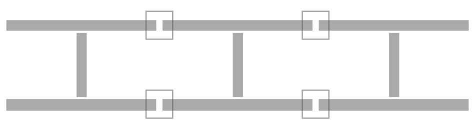
01 Thick plate



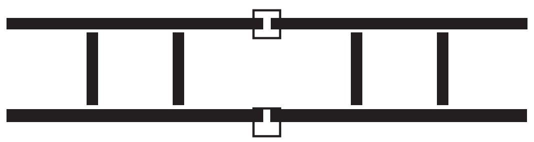
02 T- shape



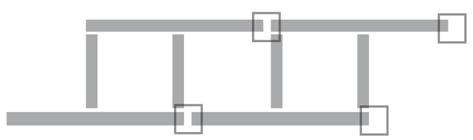
03 I - profile



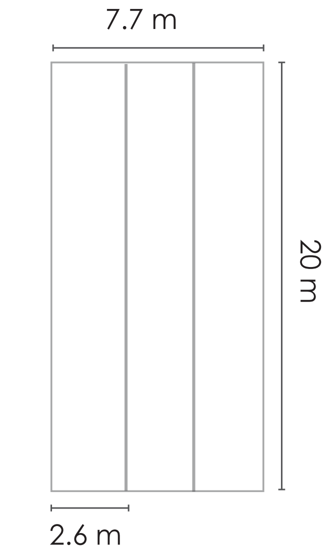
04 Wide I - profile



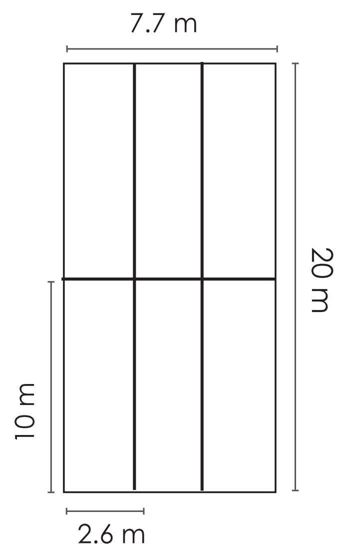
05 Ribbed plate



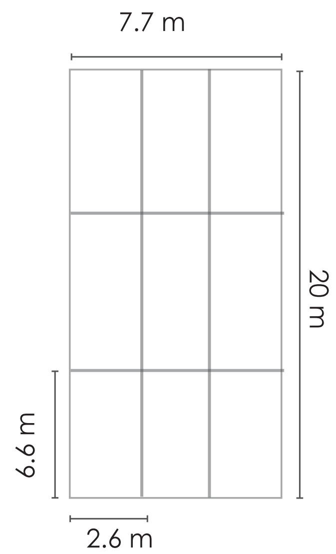
06 Ribbed plate 2 open edges



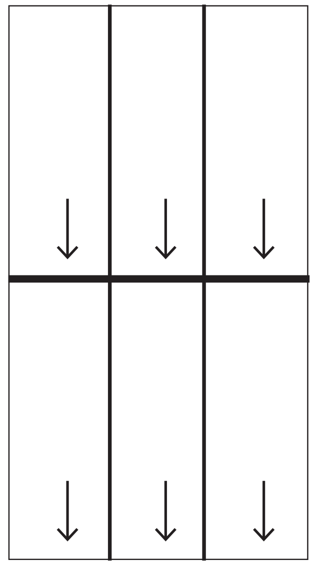
01 Extreme



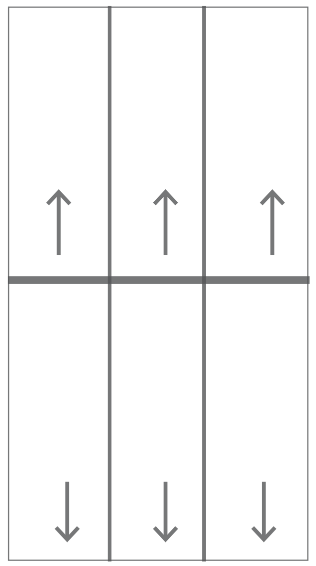
02 Oversized -transportable



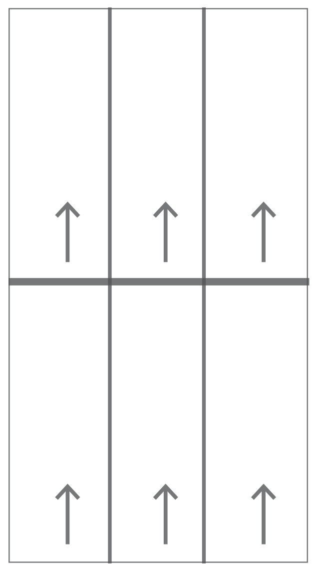
03 Smaller - economic



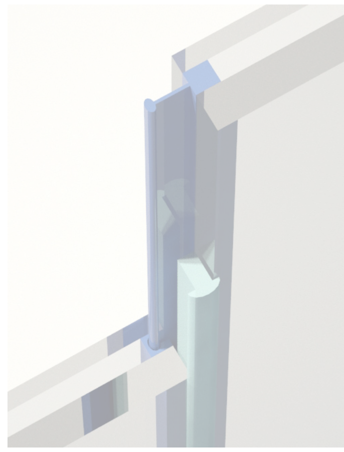
01 Stacking



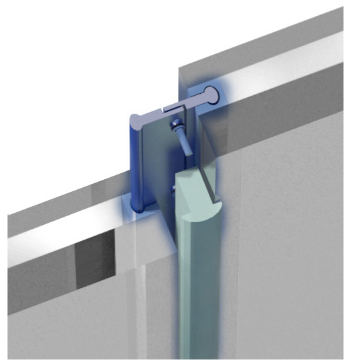
02 Half hanging Half standing



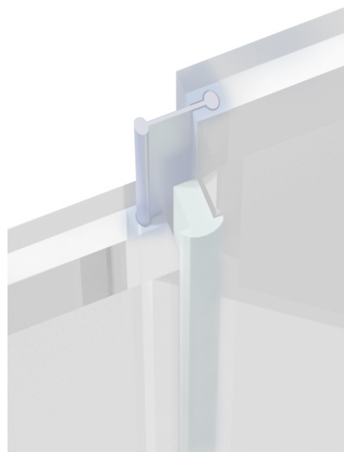
03 Hanging



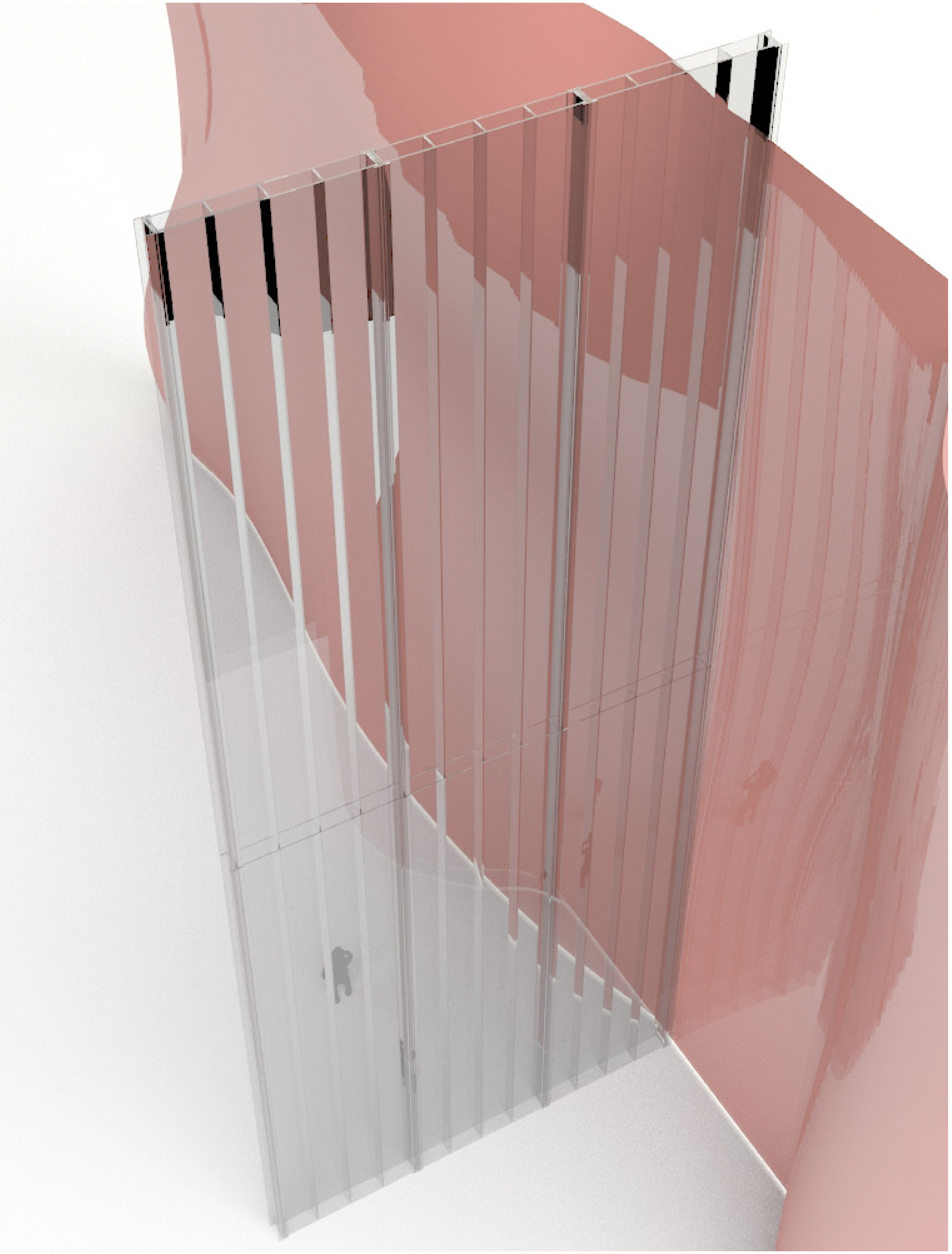
01 Sliding assymetrical profiles

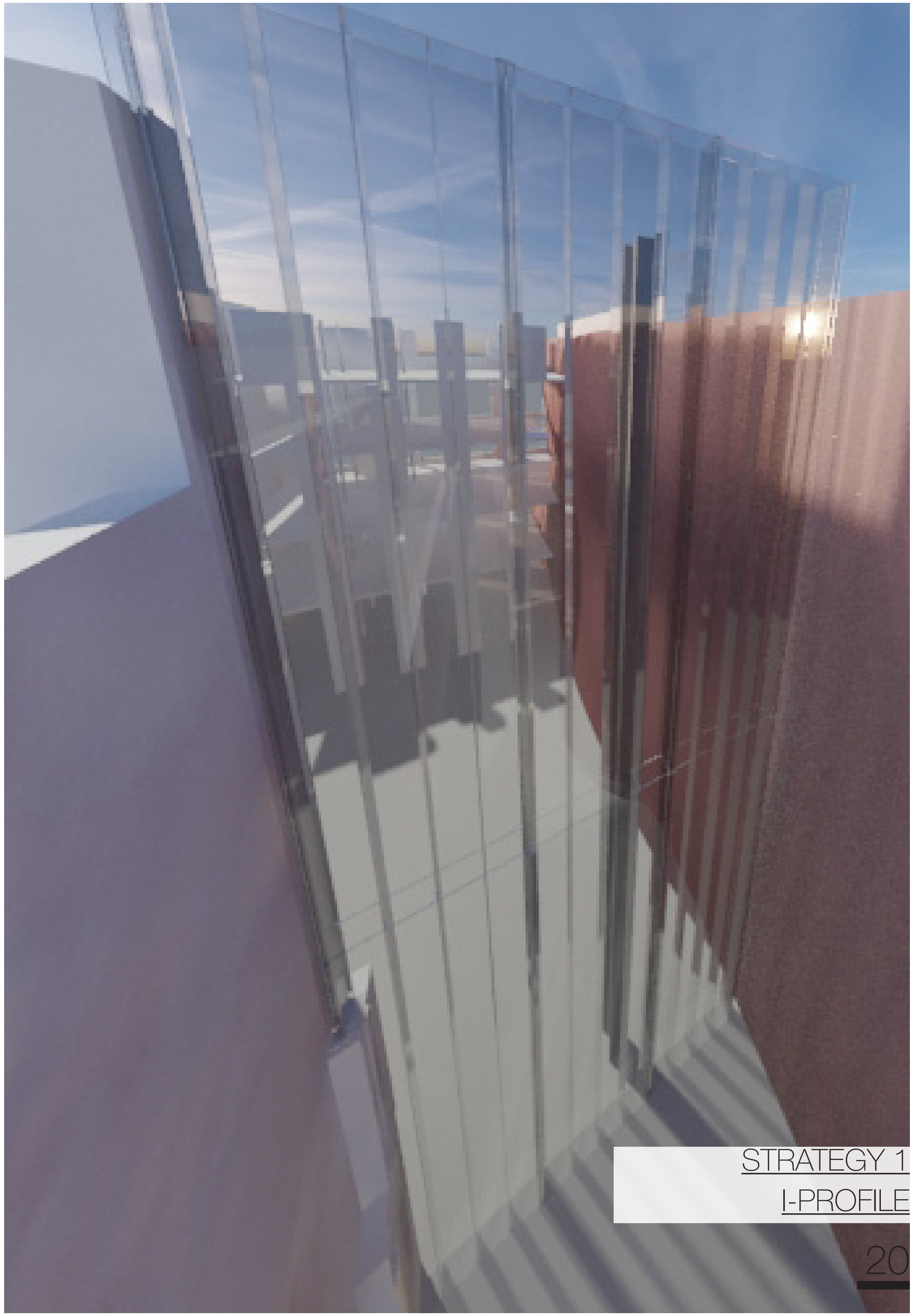


02 Intermediate adjustable member

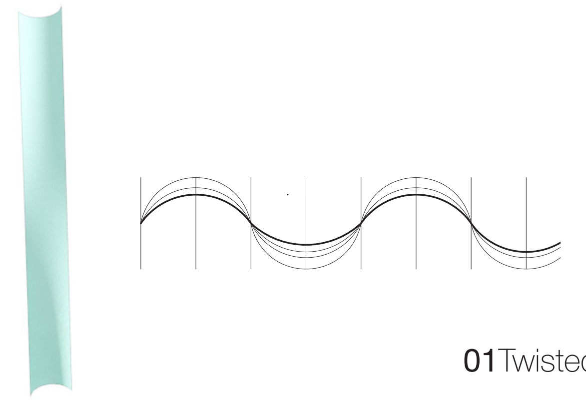


03 Intermediate sliding section

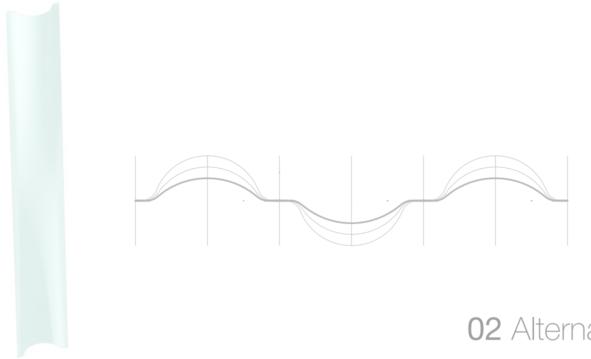




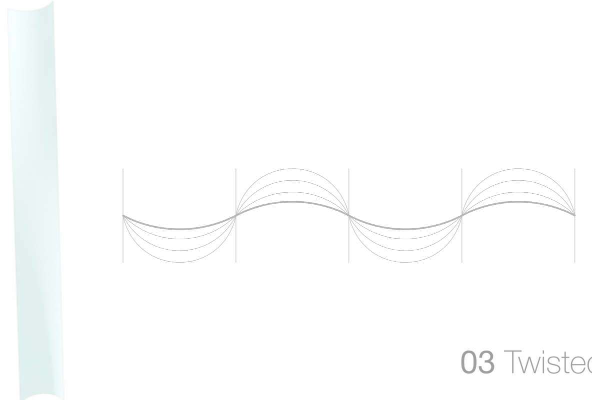
STRATEGY 1
I-PROFILE



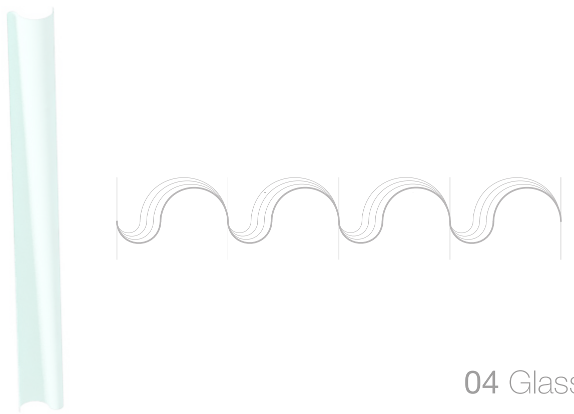
01Twisted curve 1



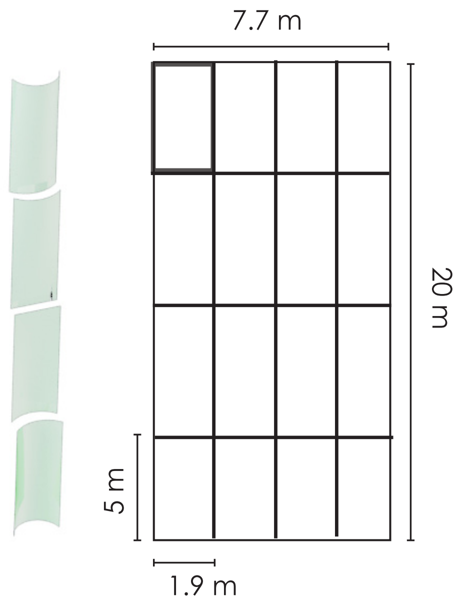
02 Alternative 2



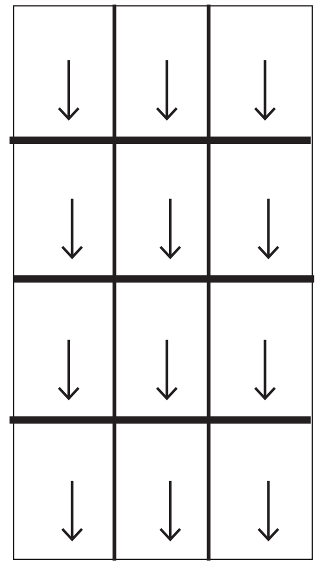
03 Twisted curve 2



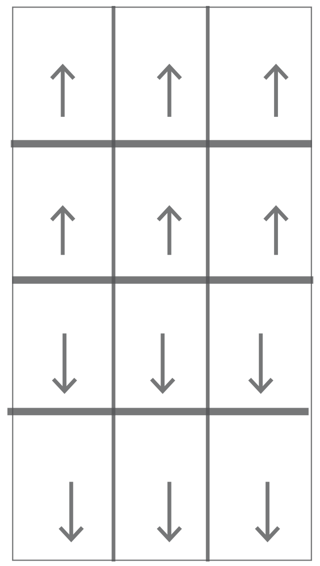
04 Glass curtain



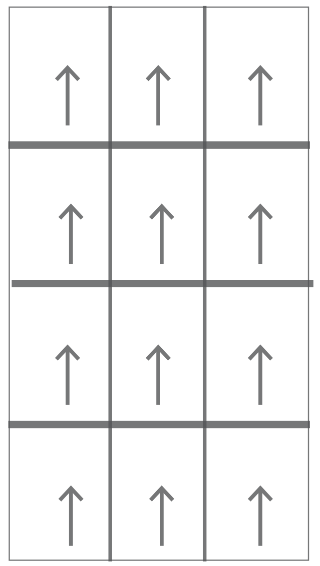
01 Even Grid 4 x 4



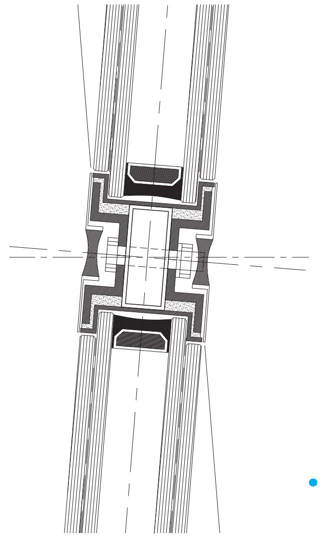
01 Standing

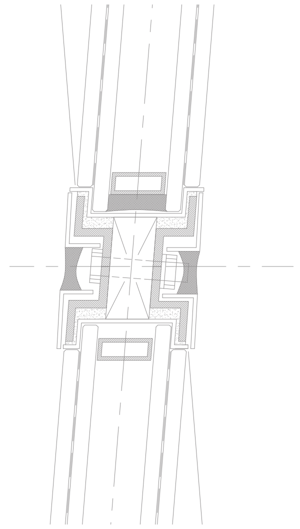


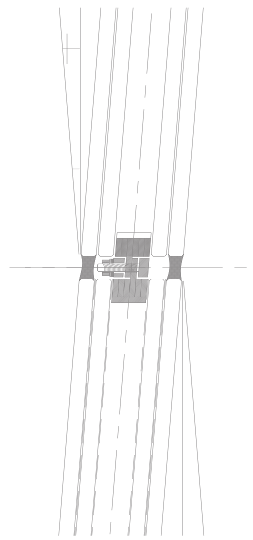
02 Half hanging - Half standing



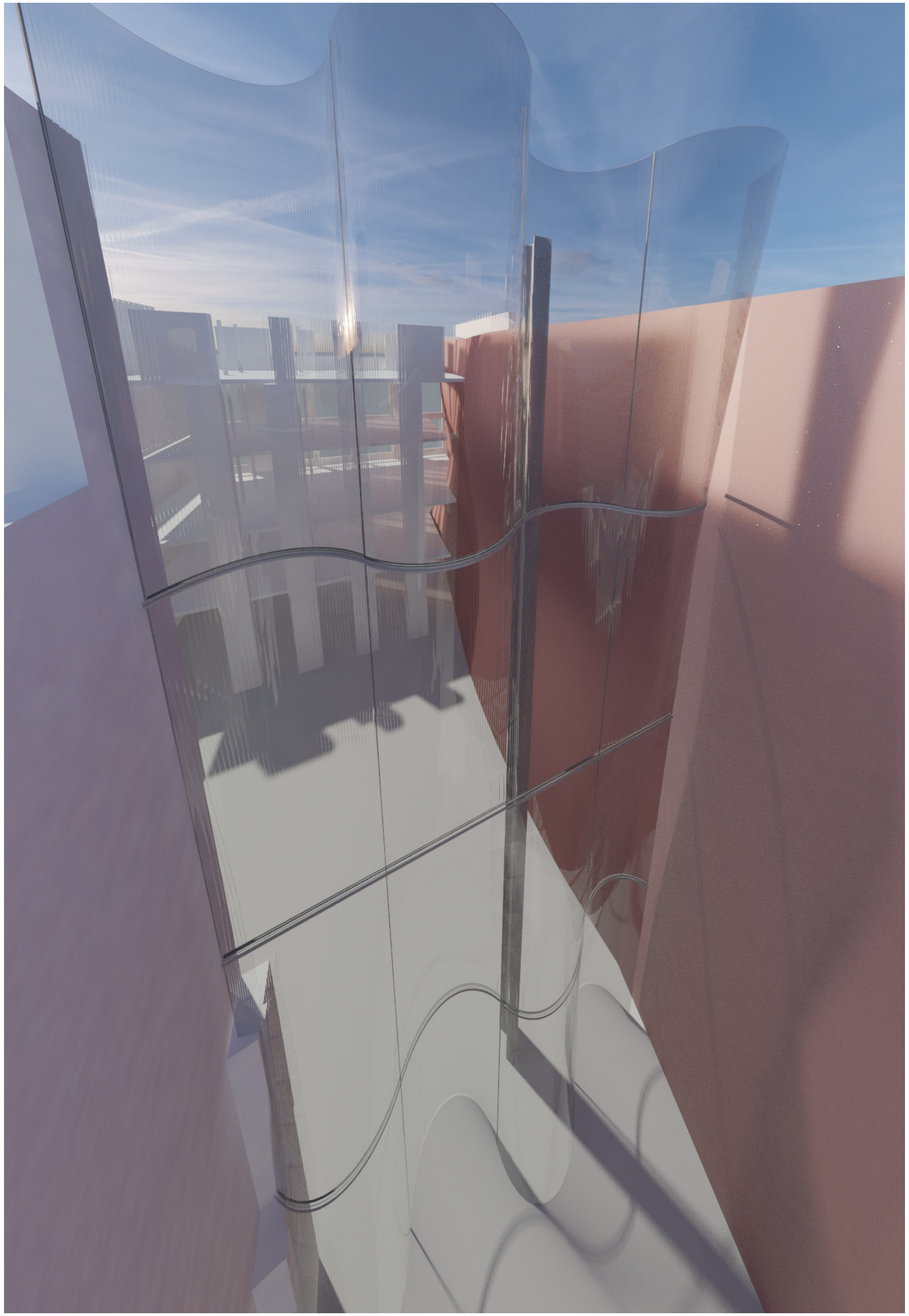
03 All hanging

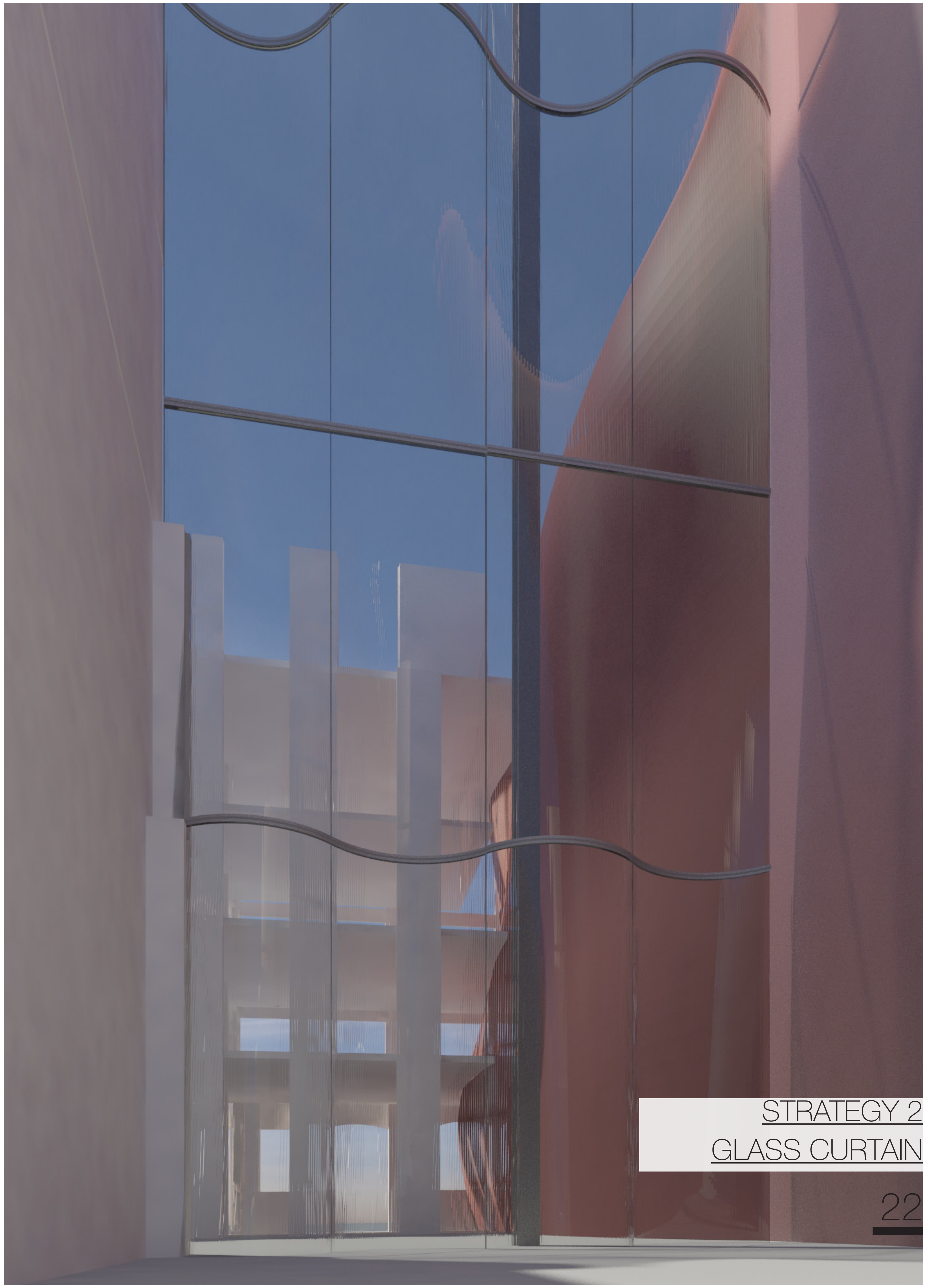






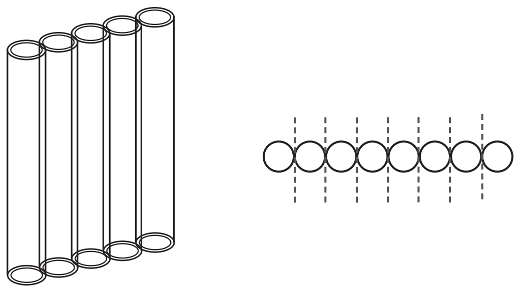
STRATEGY 2
GLASS CURTAIN



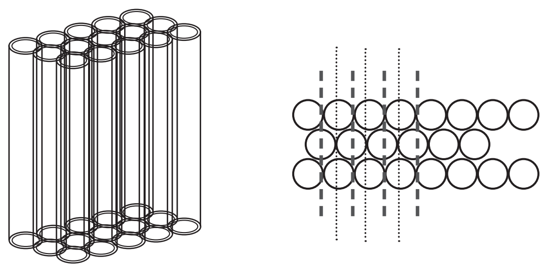


STRATEGY 2

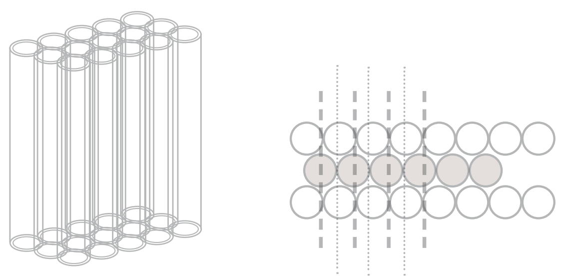
GLASS CURTAIN



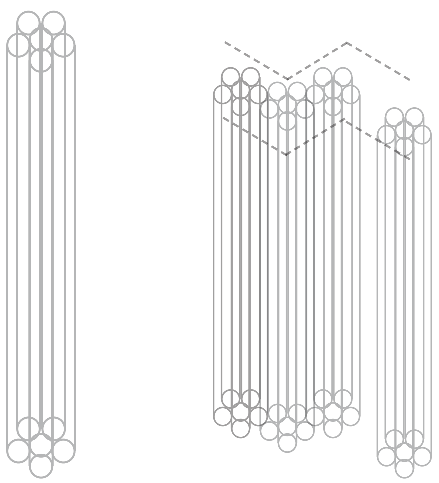
01 Single row hollow tubes



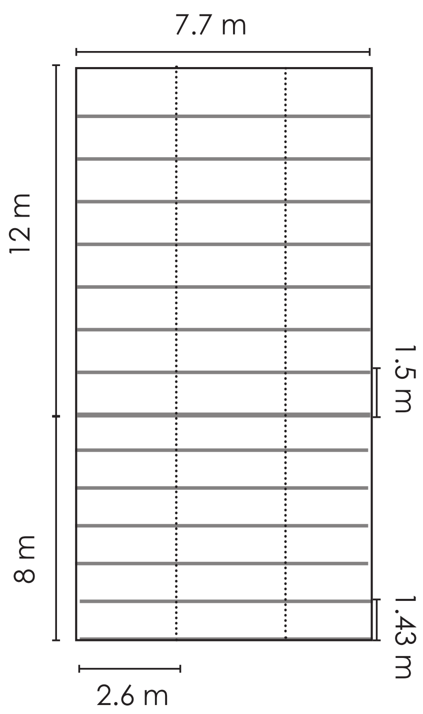
02 Multiple rows hollow tubes



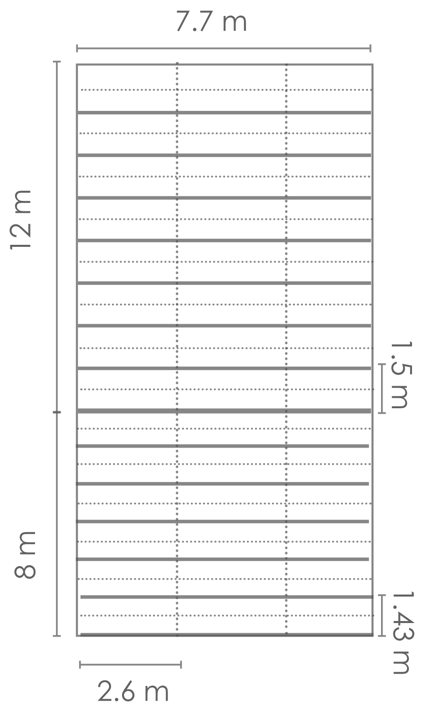
03 Hollow out massive core



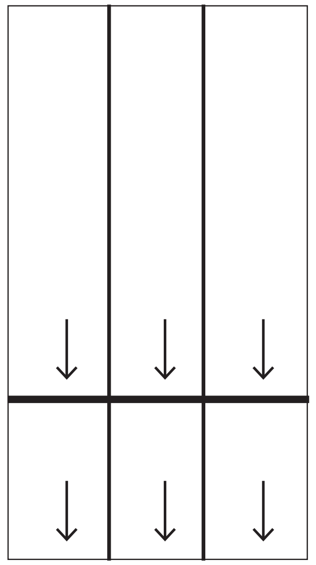
04 Massive bundles



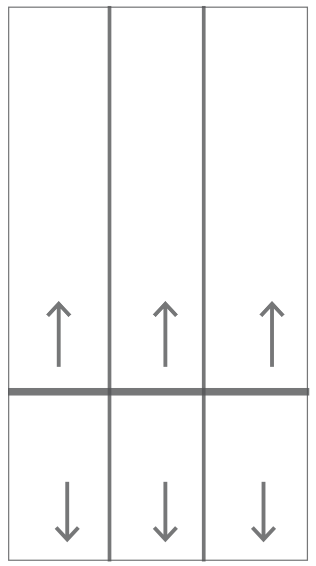
01 Normal grid



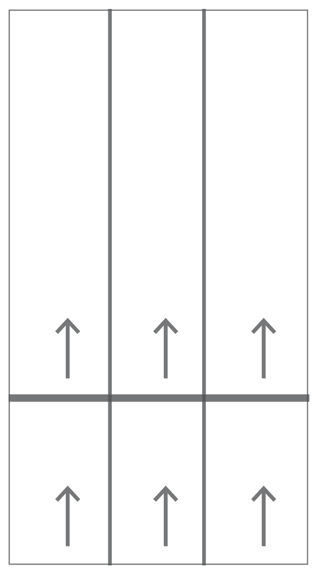
02 Overlapping grid



01 Standing



02 Half hanging - Half standing

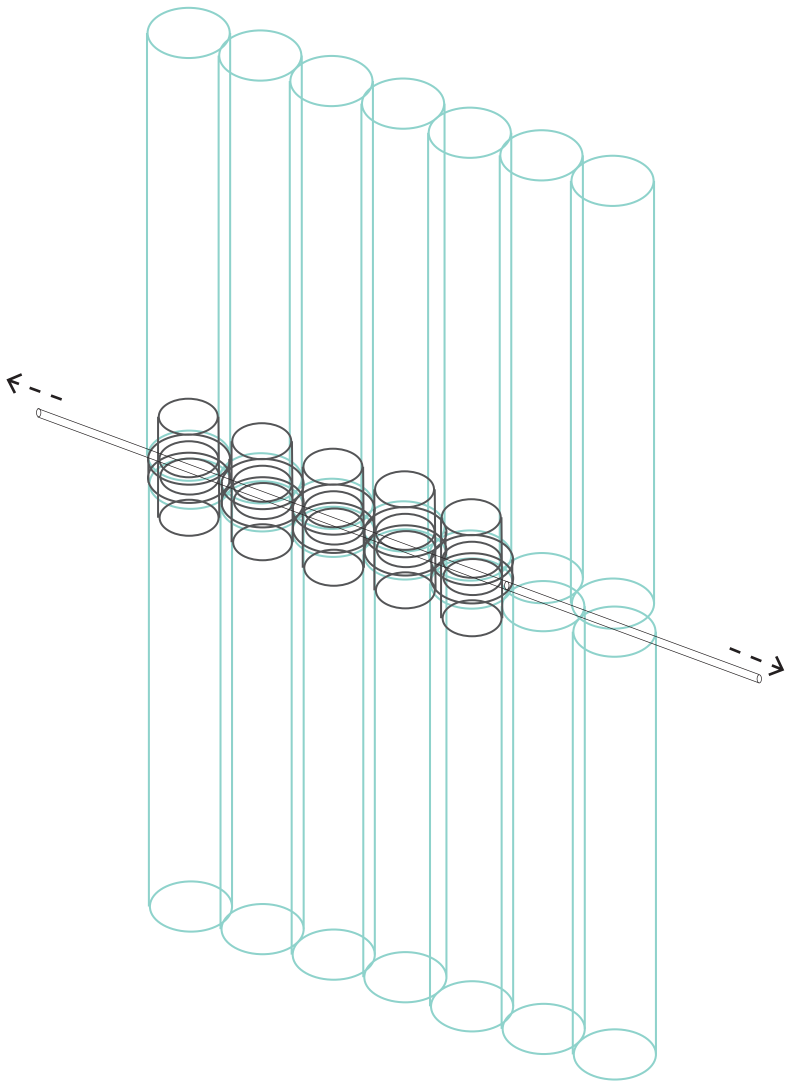


03 All hanging

01 Intermediate transparent sleeve

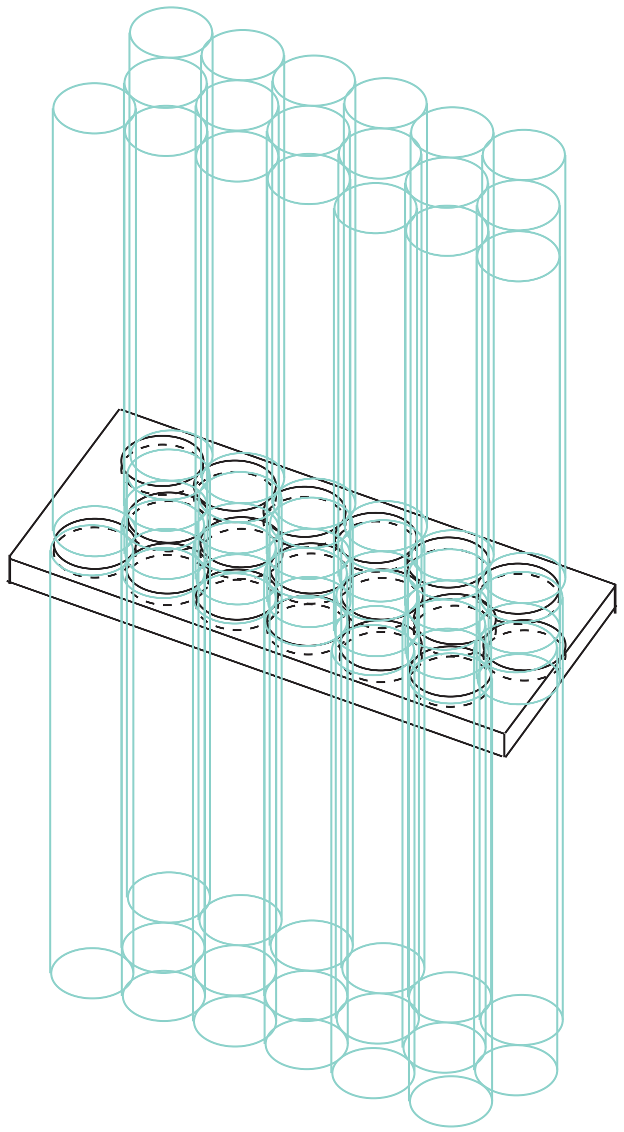
STRATEGY 3
TUBE WALL

CONCEPT 1
Single row units

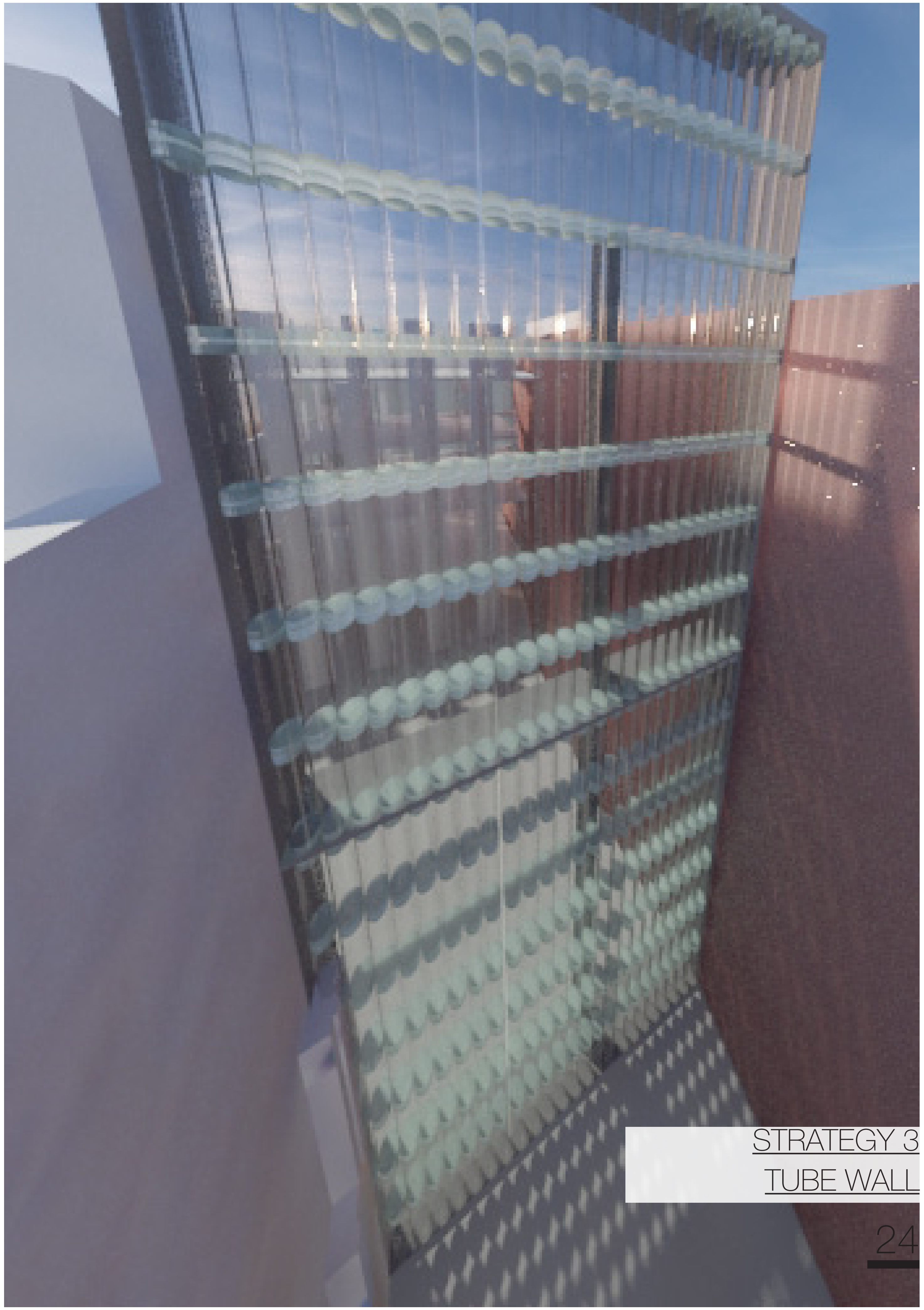


01 Single row hollow tubes with intermediate transparent sleeve joint. Stabilized by post tensioned rods.

CONCEPT 2
Multiple row units



02 Multiple row of tubes. Intermediate support. Tubes fixed in a special dish profile with resin added at the bottom.



STRATEGY 3
TUBE WALL

	Units			System				Overall Feasibility
	Size	Costs	Form potential	Structure Feasibility	Form / Appearance	Joints	Transpar-ency	
Strategy 1 / I-profile	+ +	+	-	++	-	+	++	++
Strategy 2 / Curved	+	+	++	+	++	-	+	+
Strategy 3 / Tubes	- -	- -	+	-	++	- -	-	+

	Units			System				Overall Feasibility
	Size	Costs	Form potential	Structure Feasibility	Form / Appearance	Joints	Transpar-ency	
Strategy 1 / I-profile	+ +	+	-	++	-	+	++	++
Strategy 2 / Curved	+	+	++	+	++	-	+	+
Strategy 3 / Tubes	- -	- -	+	-	++	- -	-	+

1 | Transparency

2 | Structural performance

3 | Size

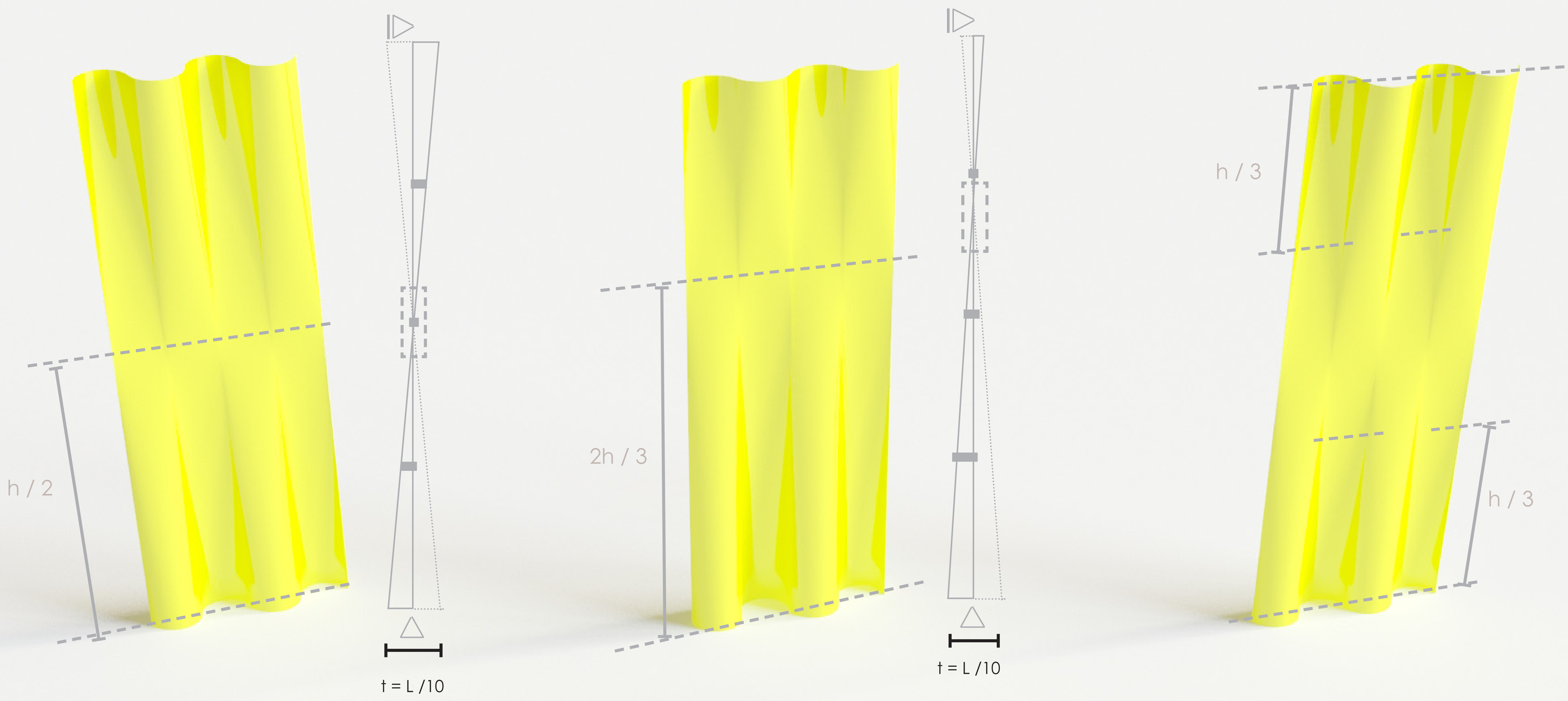
4 | Design Versatility

5 | Processing

6 | Information availability

7 | Architects' preference

/// STAGE 4_FINAL DESIGN DEVELOPMENT ///



01

_Common symmetry axis

_Middle weak point

02

_Common symmetry axis

_ Elevating the twist axis higher (2h/3)

_ Avoid weak central connection

03

_ Not common symmetry axis

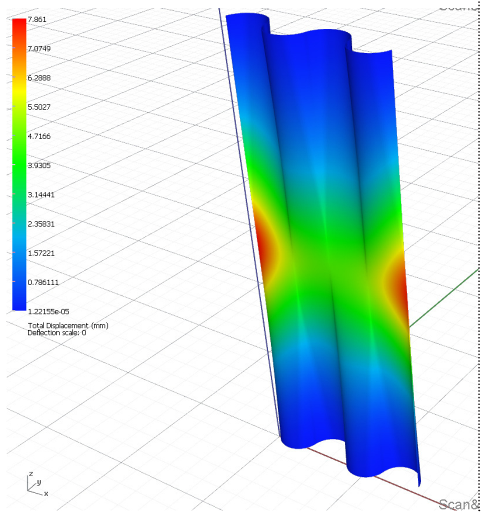
_ Alternating for each panel

_ Avoid weak central connection

_ Complicated surface

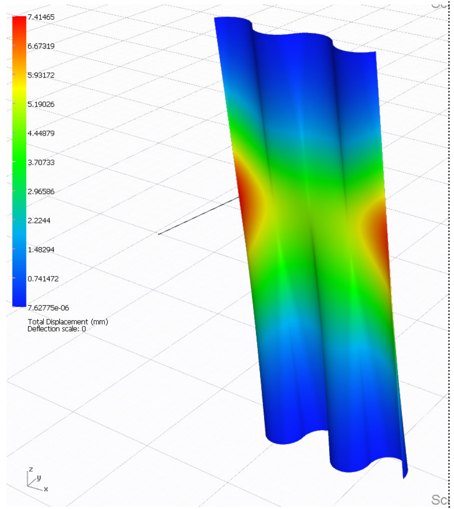
_ Uneven load distribution

01



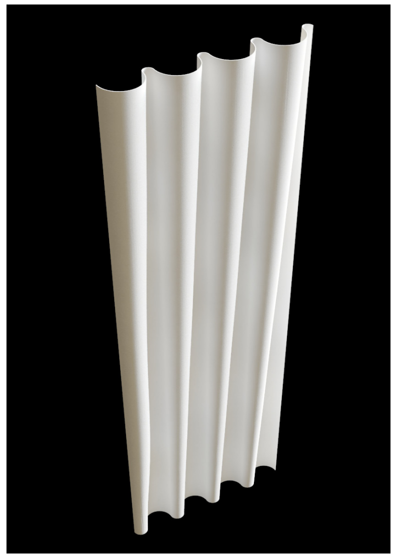
Maximum displacement
7.86mm

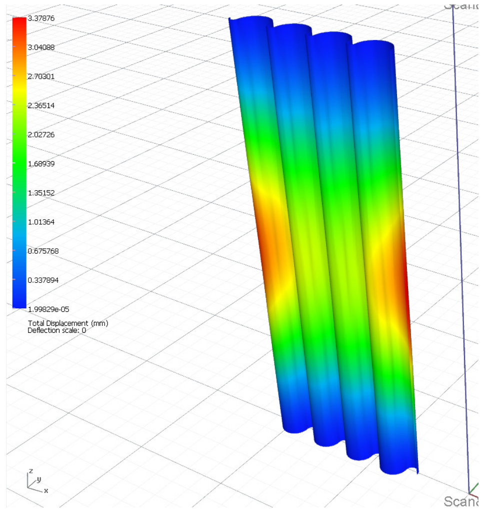
02



Maximum displacement
7.41mm

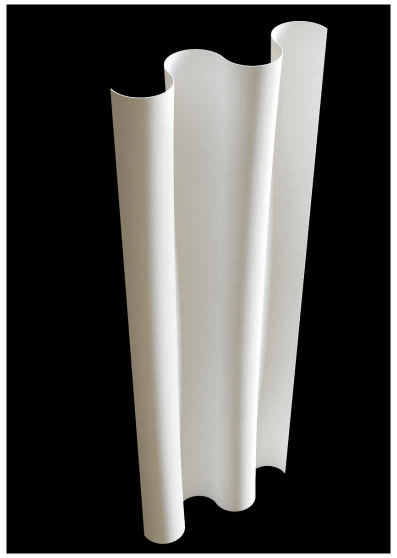
03

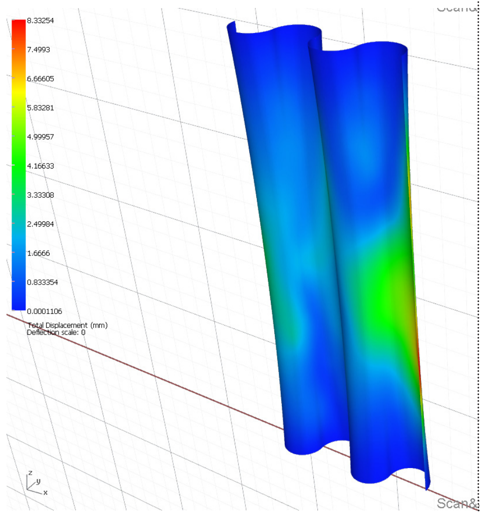




Maximum displacement
3.33mm

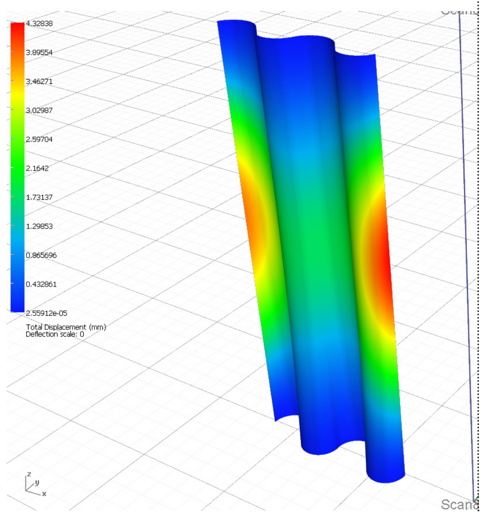
04





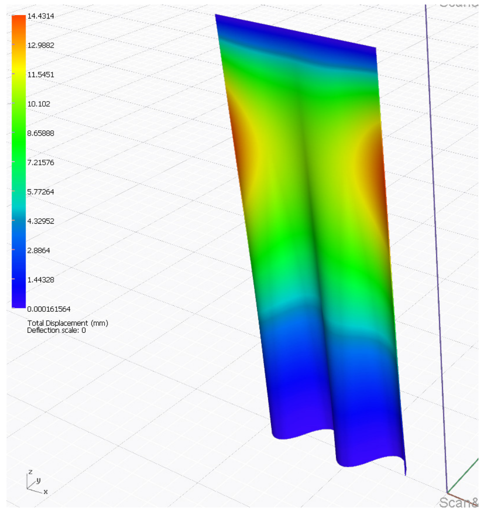
Maximum displacement
8.33mm

05



Maximum displacement
4.32mm

06



Maximum displacement
14.12mm

01 Geometry & Material

The calculation can be done only for monolithic solid element. Not an option to model seperate materials. The surface has to be only out of one material.

02 Boundary conditions

Non accurately modeled. They are presented as fixed, instead of hinge at the bottom and roller at the top.

03 Safety factor

The partial factor of safety to enhance reliability of the structure is not applied.

04 Maximum stresses

Not an option to evaluate the stresses in plane of the facade. We can only check for displacements and global stresses.

01 Design Value

The most interesting of the designs. Resembles a glass curtain hanging from the ceiling.

02 Structural shape

Stiff double-curved sinus shaped shell reducing towards the top to a flat edge. The pyramidoid scheme provides greater stability by lowering the center of gravity.

03 Transparency

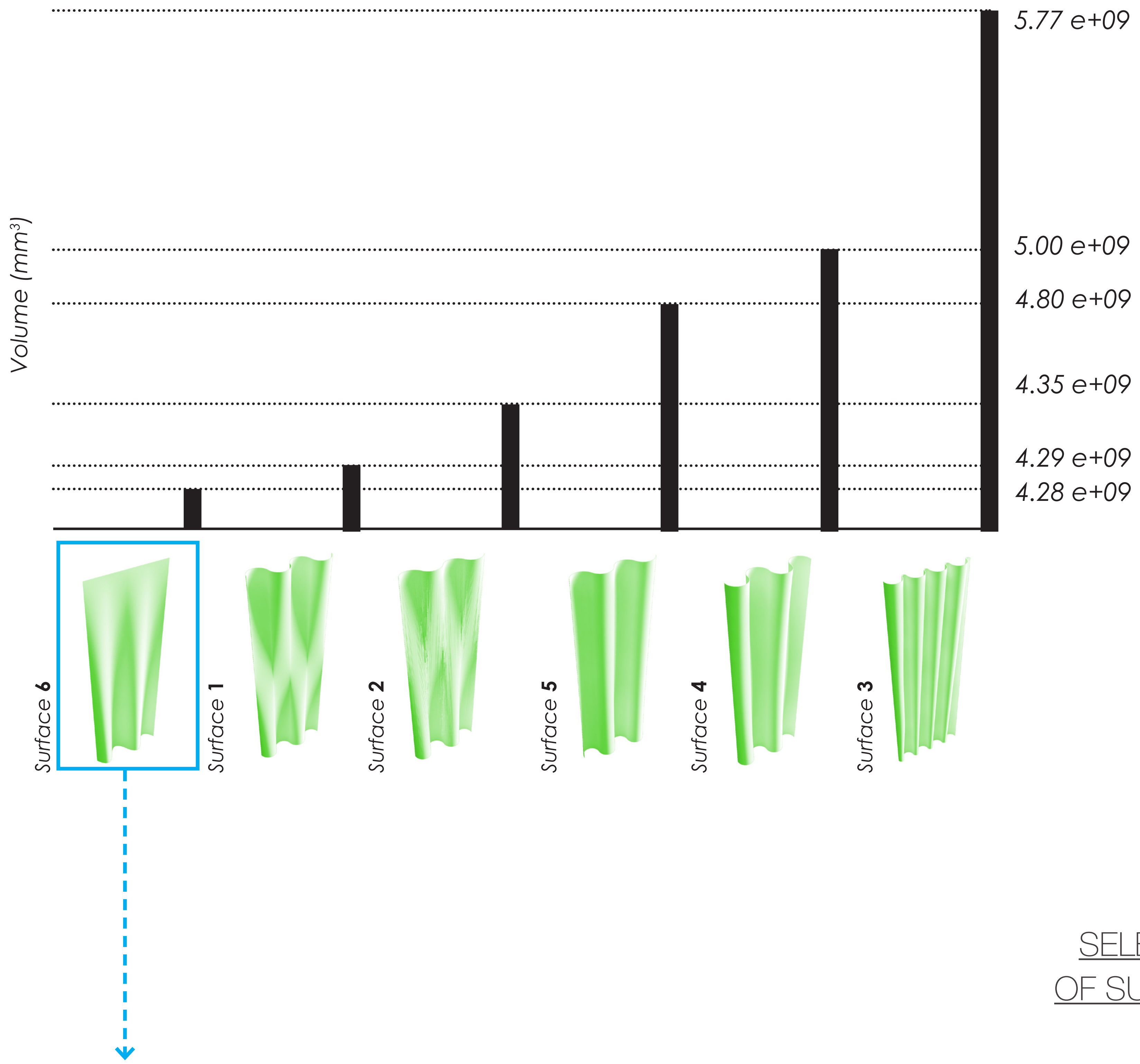
The deflections are transferred at the top part of the element. No need for additional supports behind the surface like in the twisted panel.

04 Manufacturing

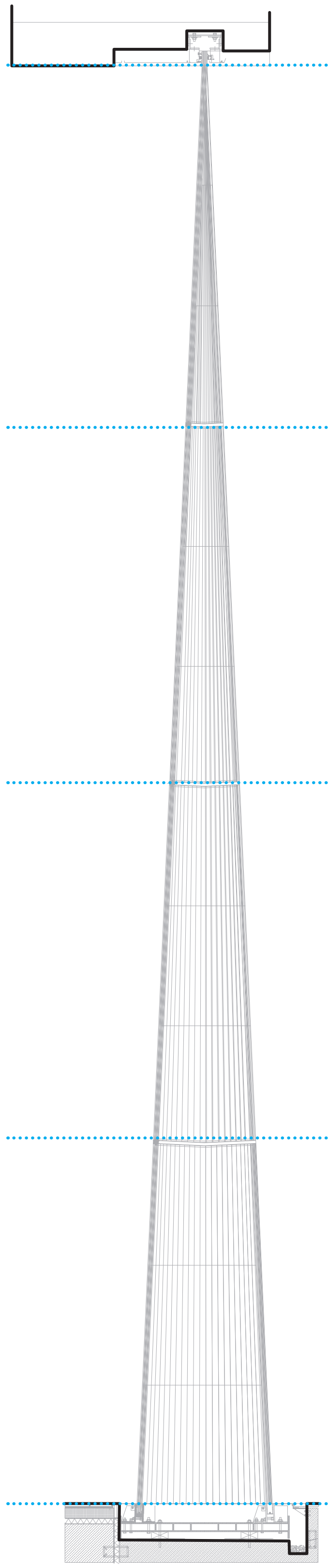
Because the curvature is reduced towards the top edge, the overall complexity and intensity of radii is less than in the other facade shapes.

05 Cost

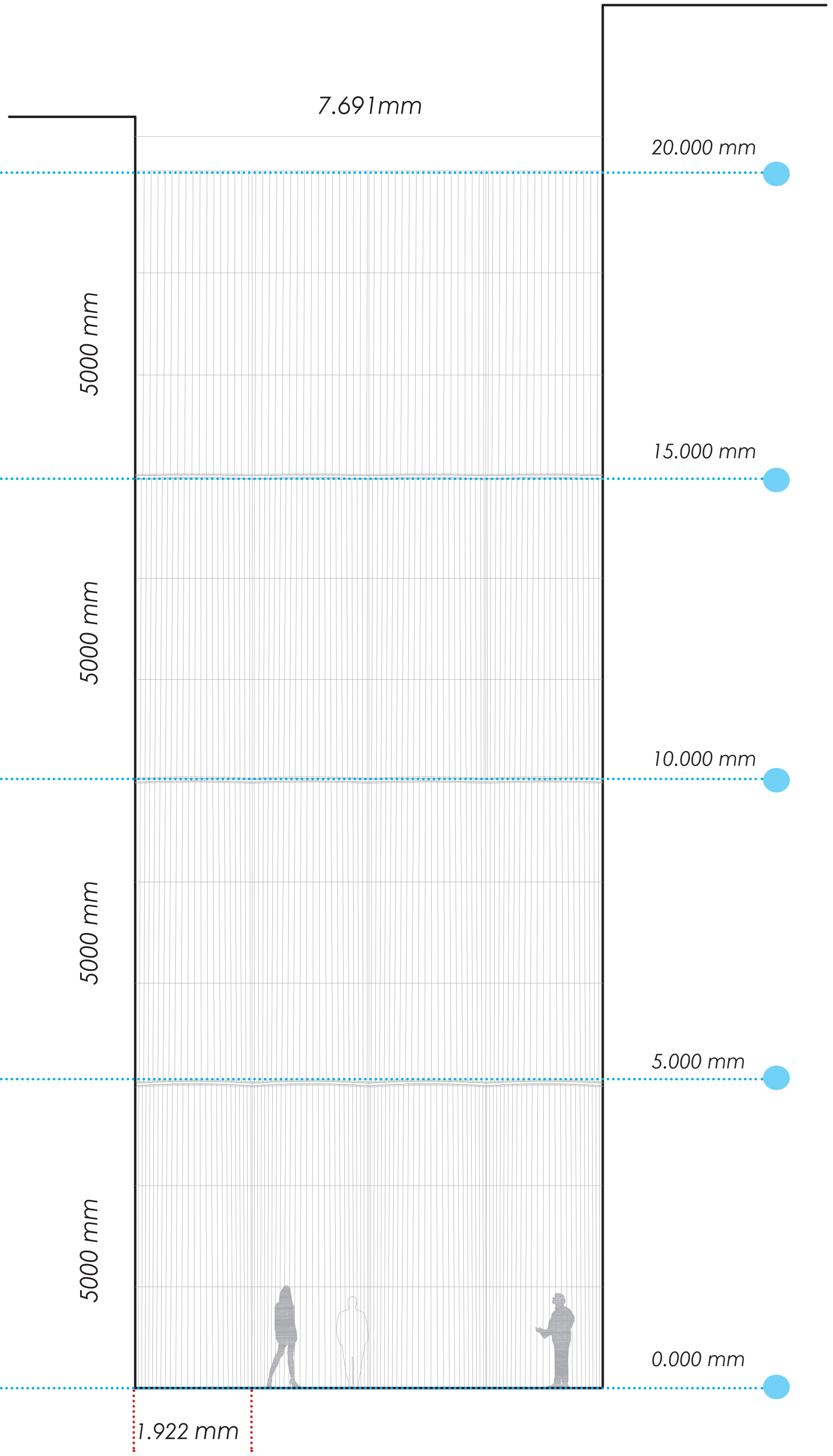
The most effective shape as the use of material is less. Calculated volume **4.28e+09 mm3**.



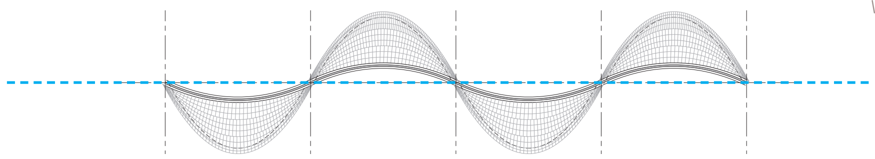
SELECTION
OF SURFACE



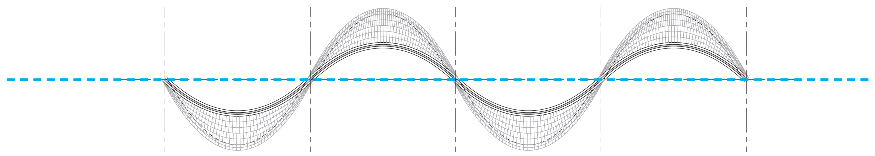
Vertical Section / Scale **1-20**



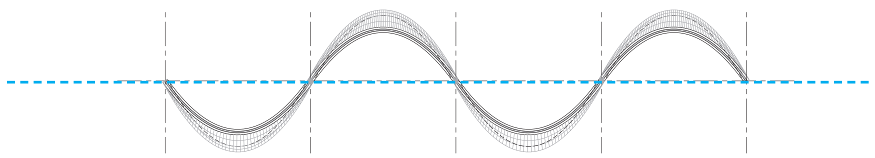
Elevation / Scale **1-20**



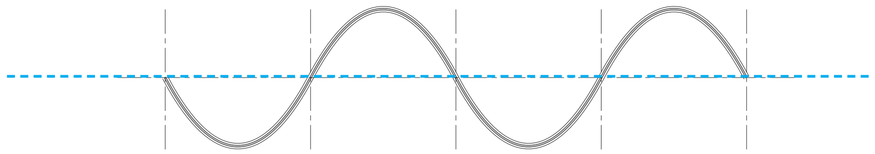
Horizontal section **04**



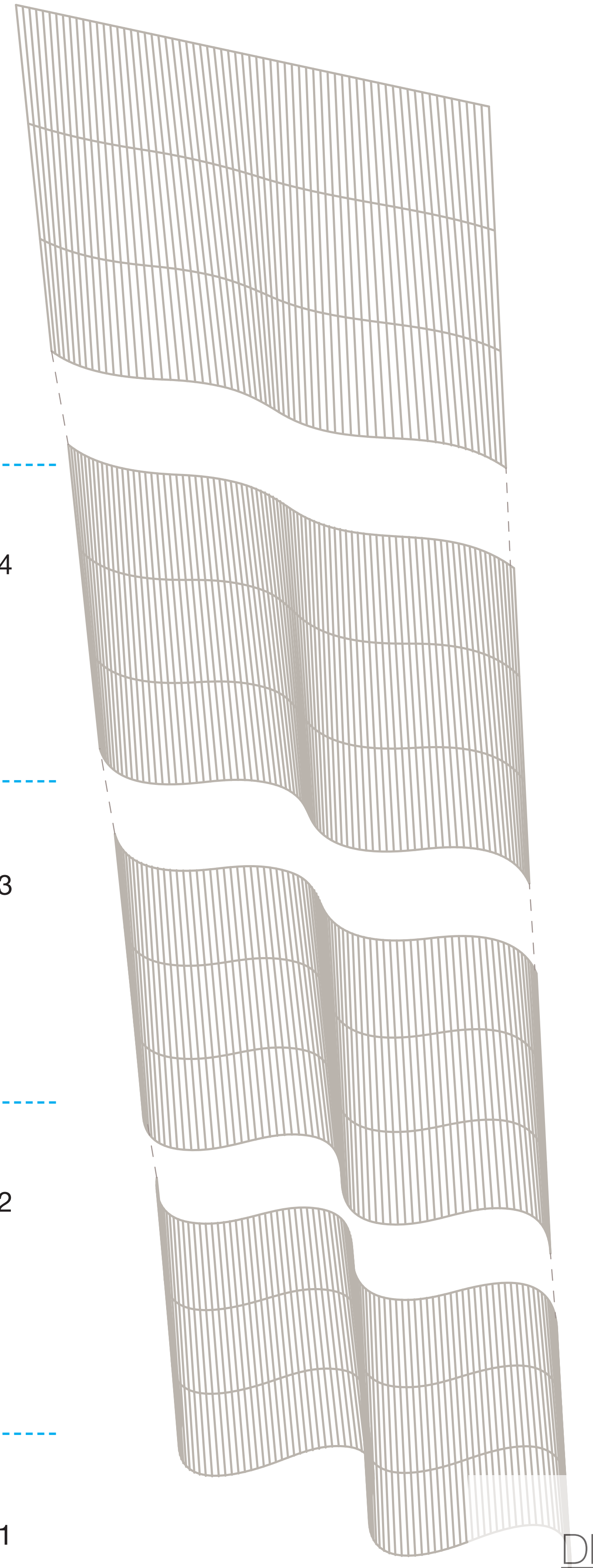
Horizontal section **03**



Horizontal section **02**

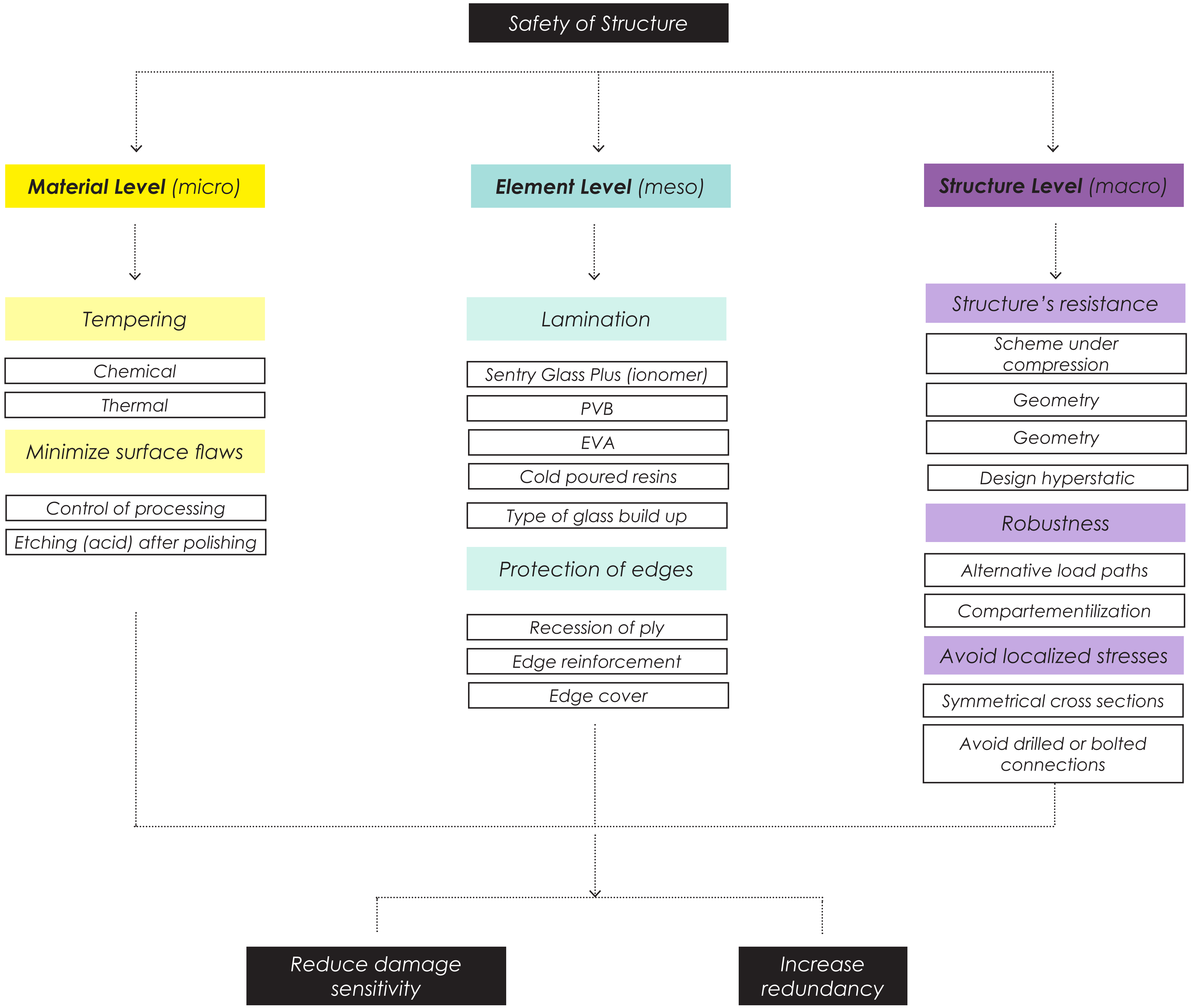


Horizontal section **01**



FINAL DESIGN

RENDERED VIEWS



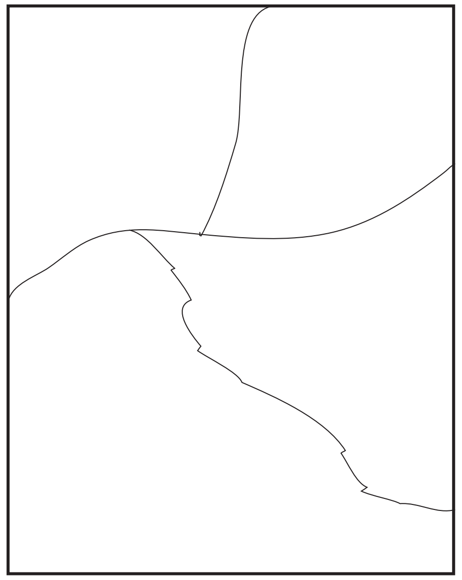
MEASURES FOR SAFE STRUCTURE

NO PRE-STRESS

PRE-STRESS

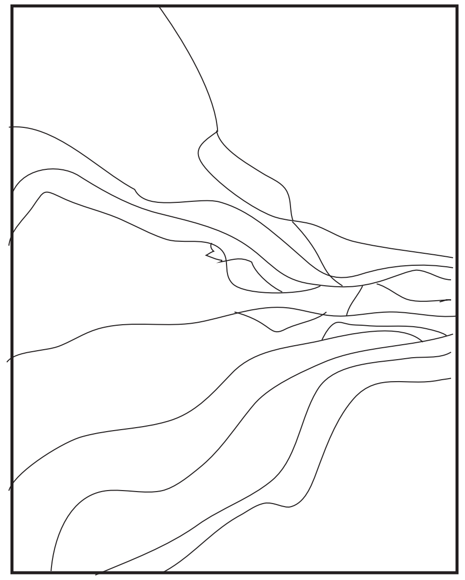
Maximum Tensile strength

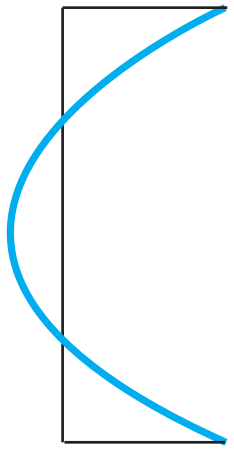
Annealed glass



45 N / mm2

Heat strengthened glass

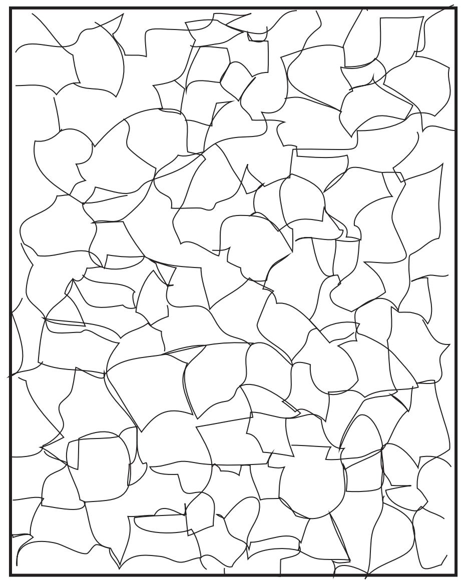


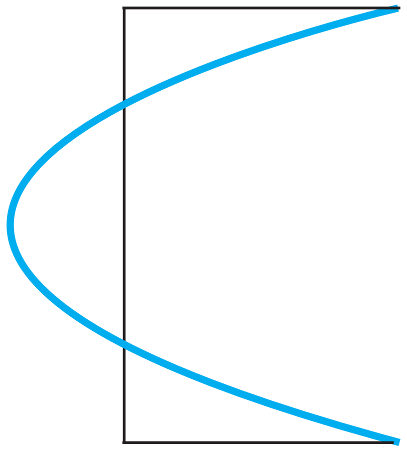


70 N / mm2

_Lower damage sensitivity
_Long term stress resistance
_Thermal stress resistant
_Impact resistant
_Scratch resistant

Fully tempered glass

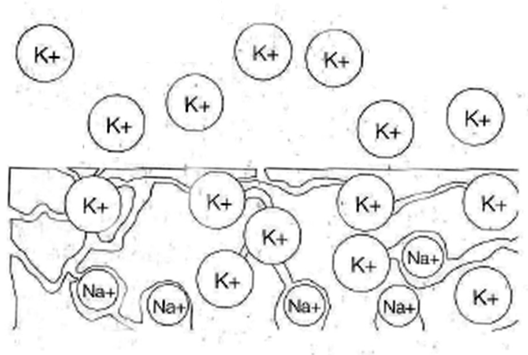


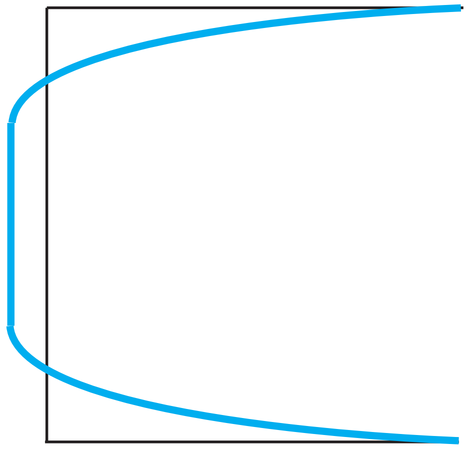


120 N / mm2

_Soft body impact resistant
_Thermal stress resistant
_Long term load resistant
_Prone to hardbody impact
_Prone to deep scratches
_Chipping
_Nickel sulfide inclusions

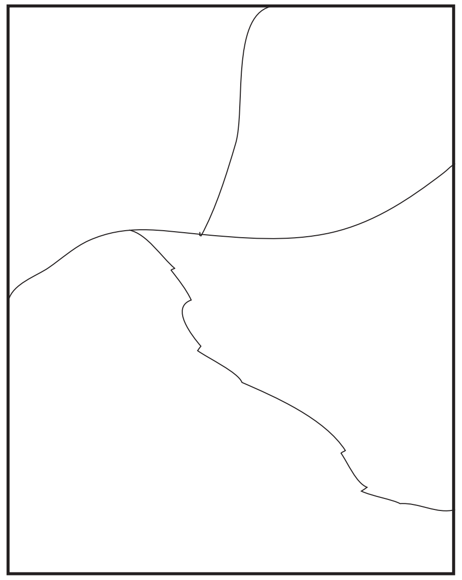
Chemically strengthened





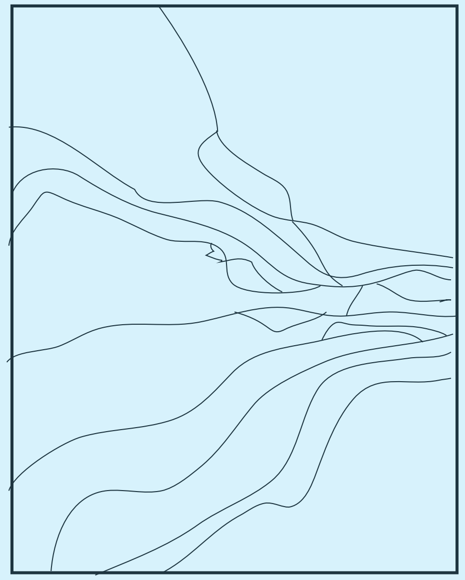
_Cutting or drilling remains possible
_Thin layer of compression
_Prone to self-fatigue
_For complicated geometries
_Expensive process
_Rare in structural application

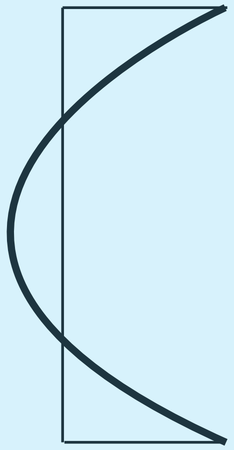
Annealed glass



45 N / mm2

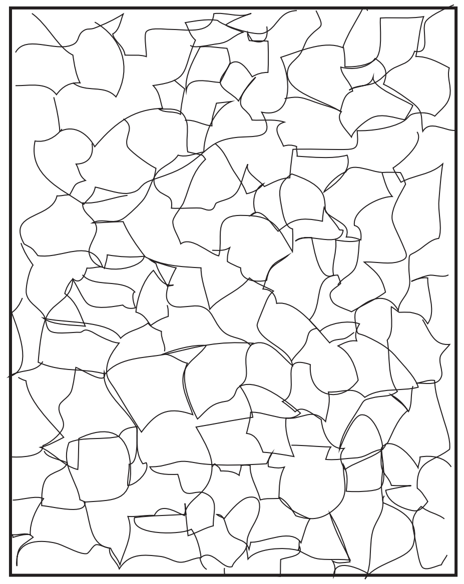
Heat strengthened glass

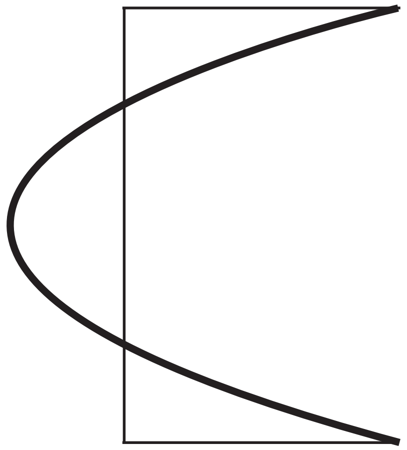




70 N / mm2

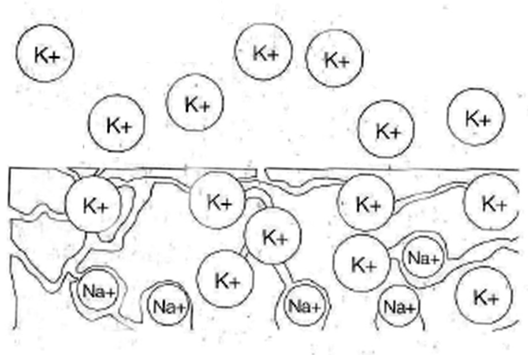
Fully tempered glass

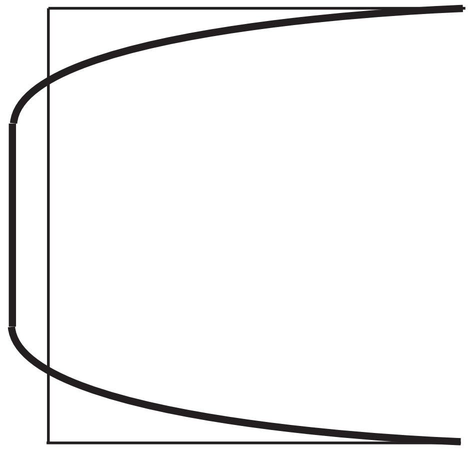




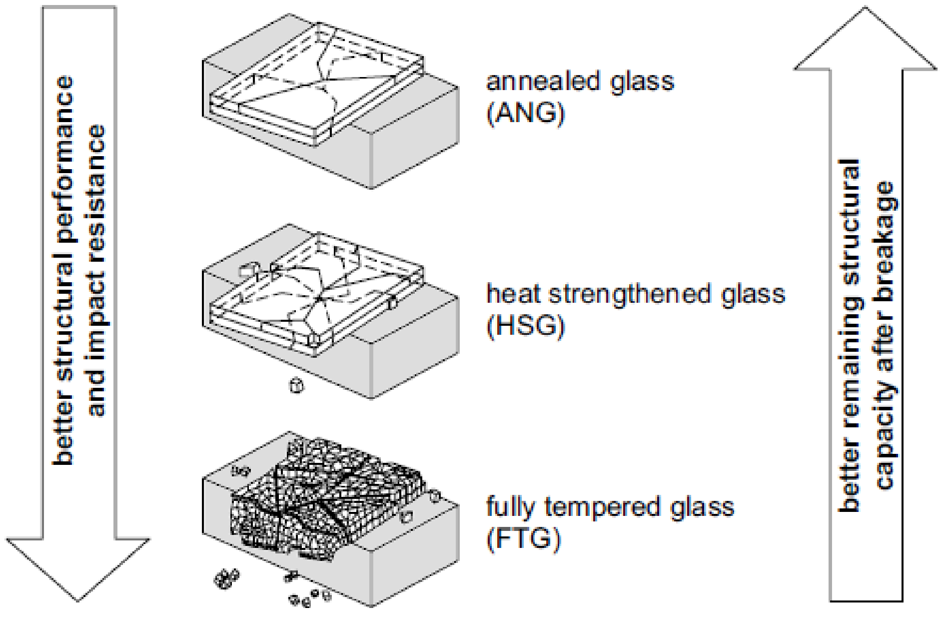
120 N / mm2

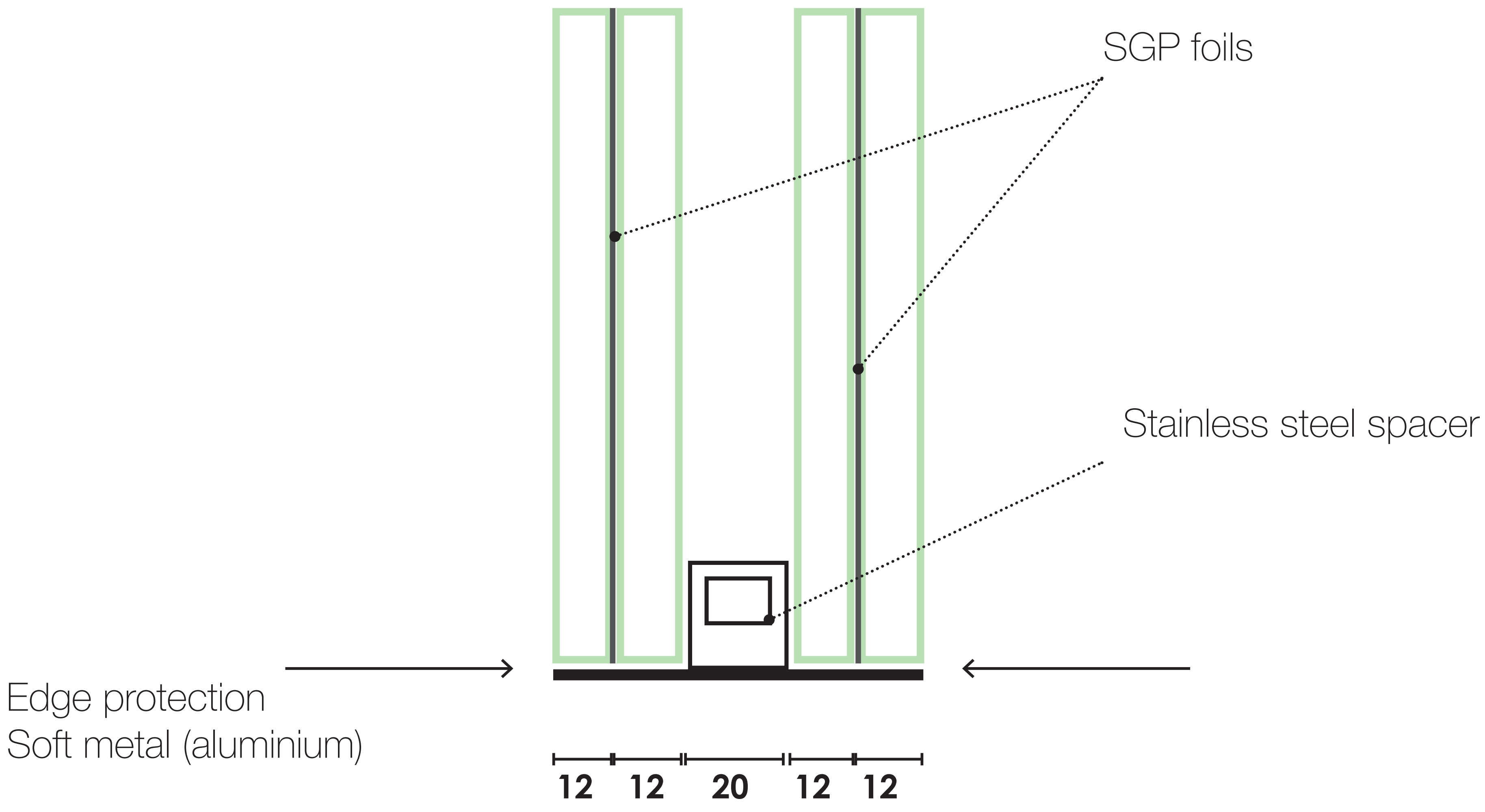
Chemically strengthened



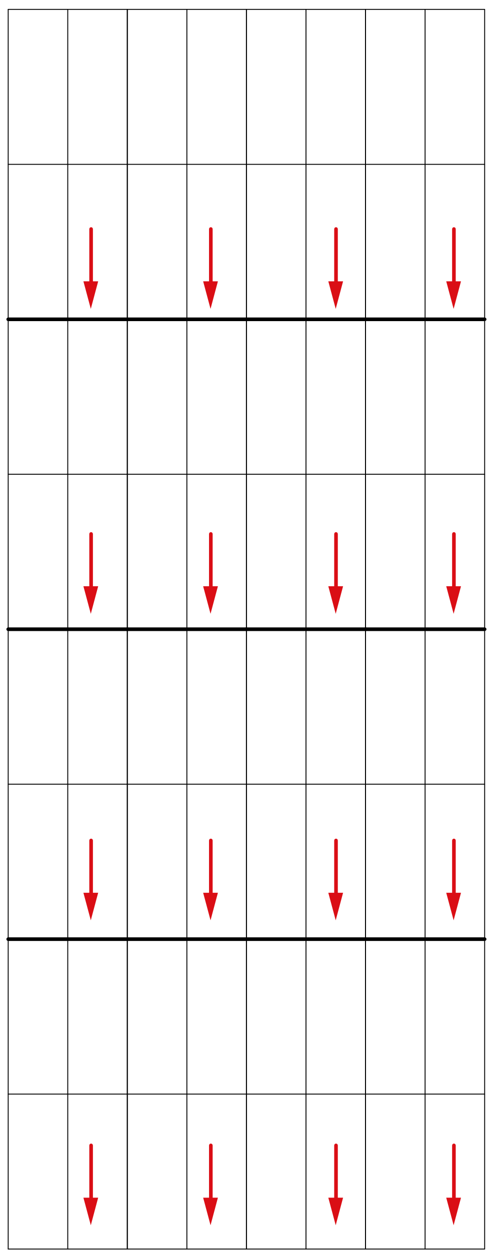


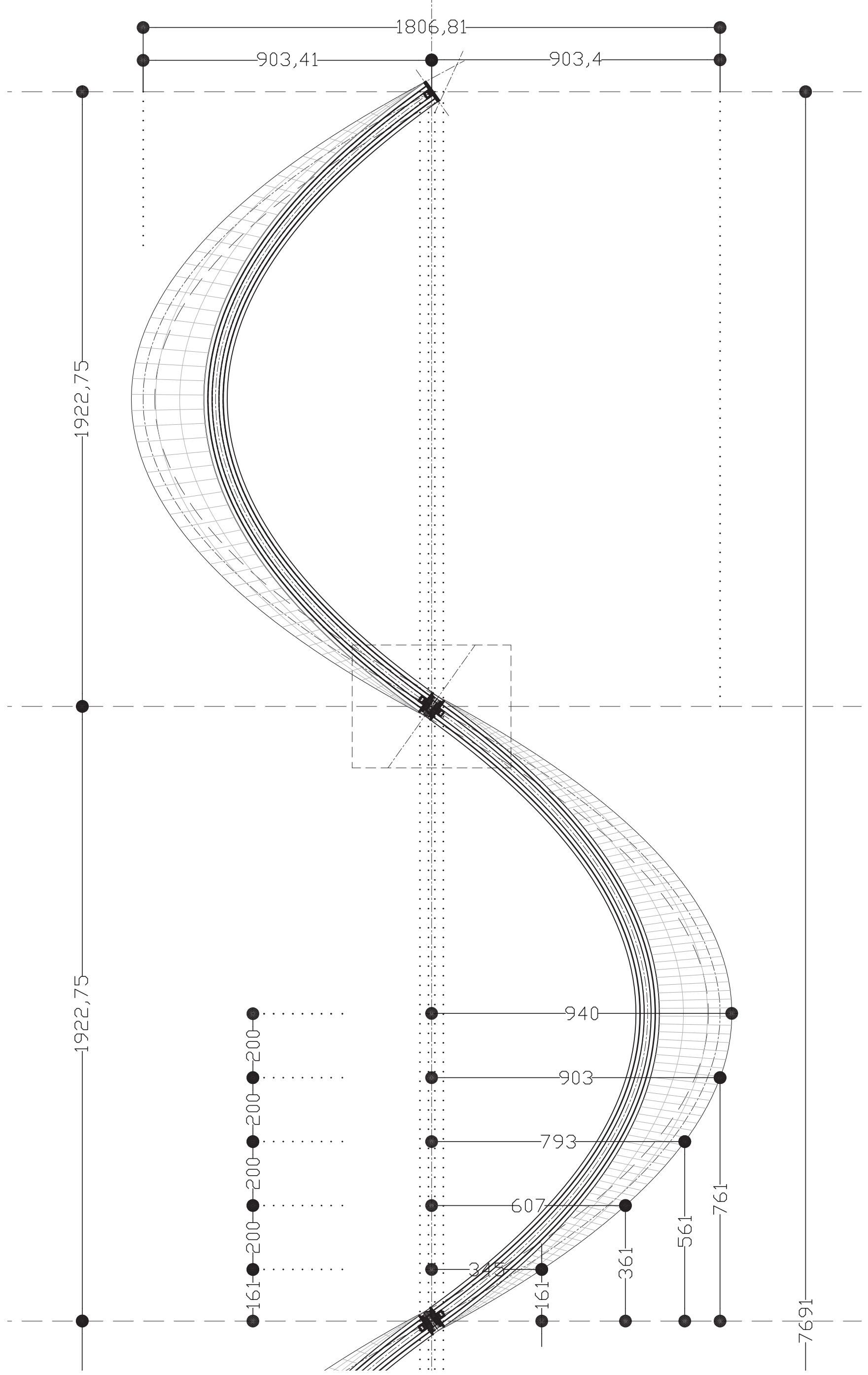
Polyvinyl Butyral **PVB**	SentryGlas Plus **SGP** (DuPont ™)
Tensile strength <= 20 Mpa	Tensile strength 300 MPa
High elasticity	100 times more rigid structure
Affected by temperature	Less affected by temperature
Load duration dependent	Load duration dependent
Prone to creep	5 times higher tear strength
Average tear strength	Difficult in lamination
	Thinner laminates

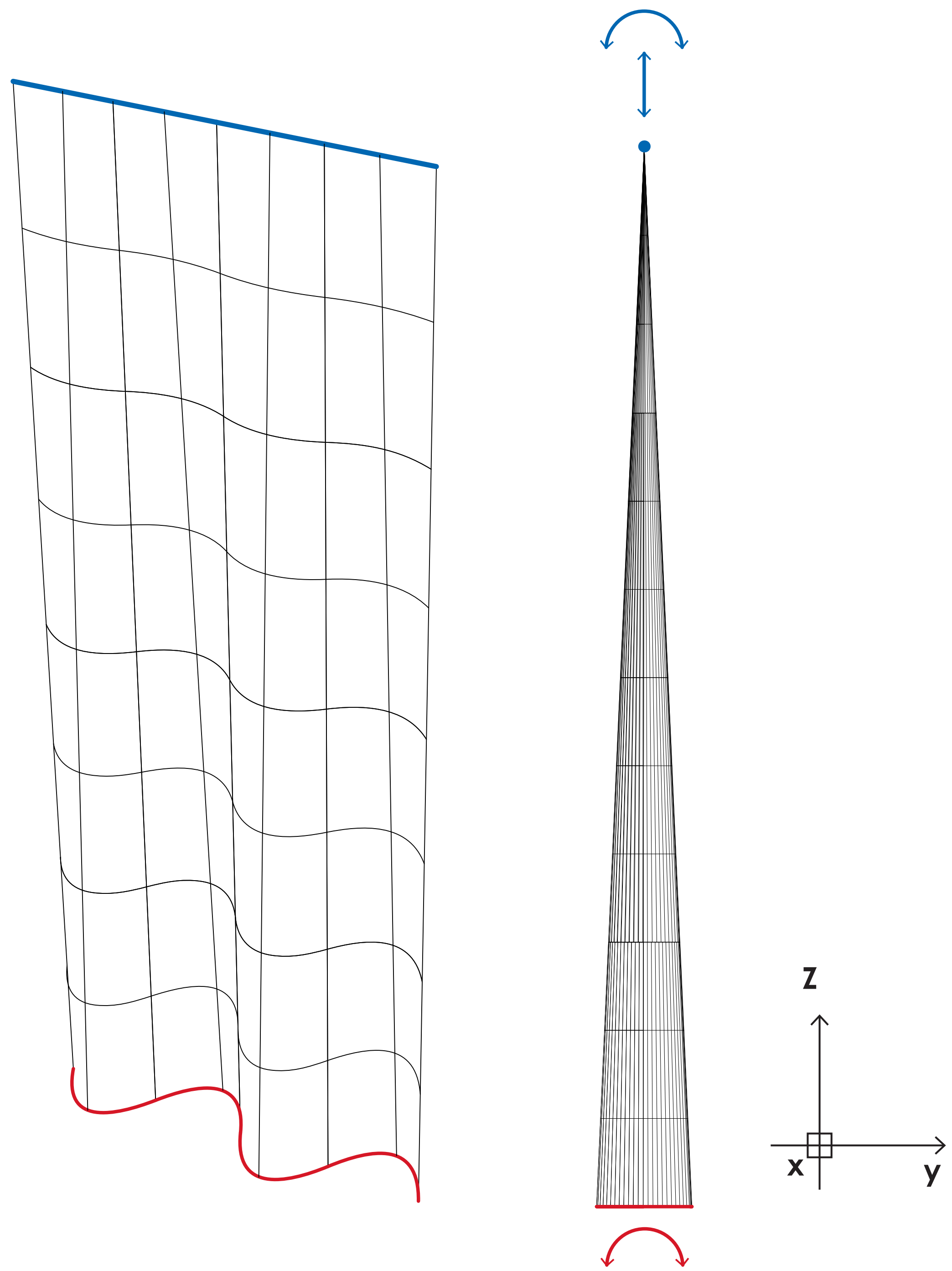



SGP foils
Stainless steel spacer
Edge protection
Soft metal (aluminium)
12
12
20
12
12

LOAD BEARING SCHEME







Dead load is carried in stacking

_Keeps the glass under compression
_Avoid vertical substructure
_Increase transparency in vertical joints

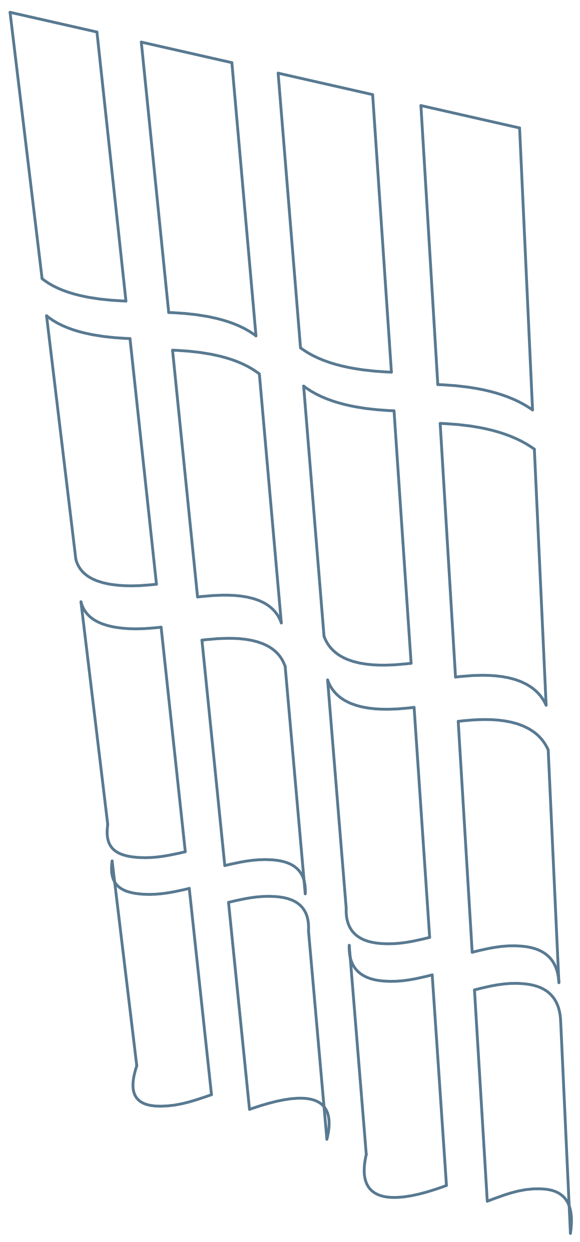
Wind load is counteracted by stiff geometry

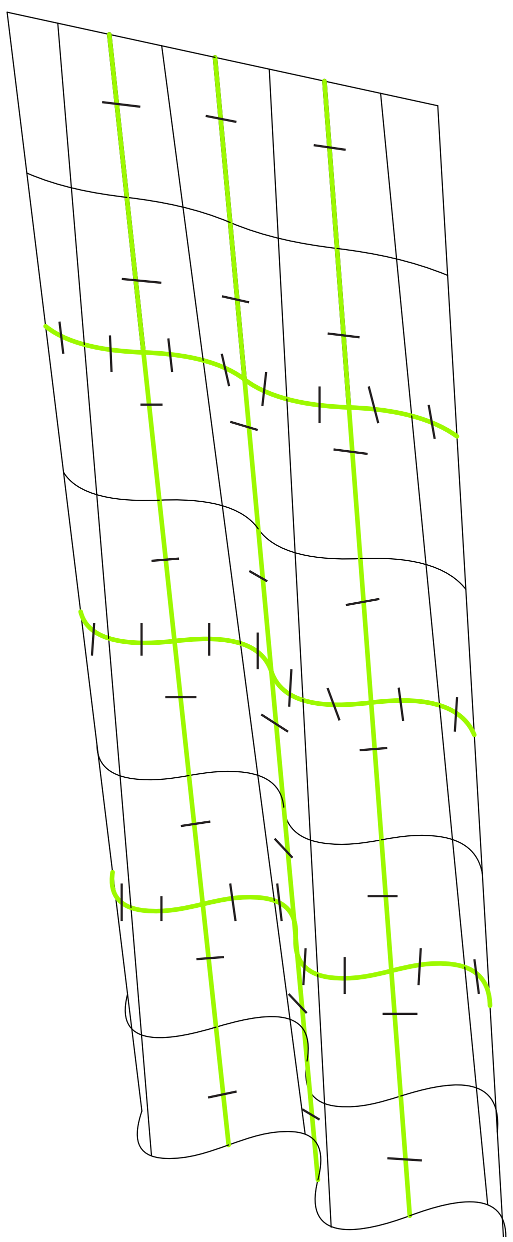
_Waveheight to 1/20 of the span
_Bottom wave **1800** mm
_Middle wave **1000**mm
_Symmetrical
_Pyramidoid scheme that enhances stability
_Low gravity center

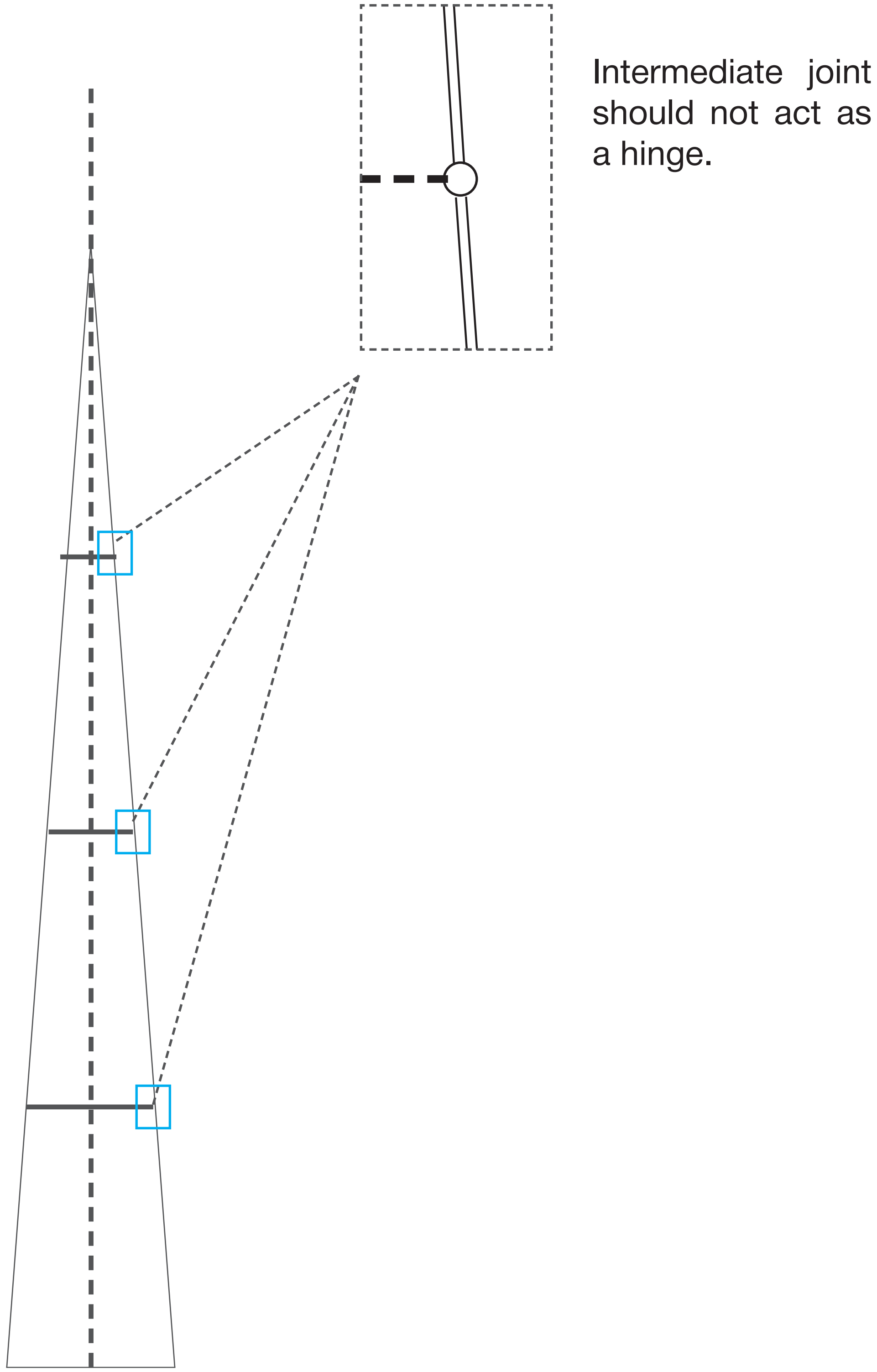
Edge supports

_Bottom linear (hinge)
_Top linear (roller) z - axis
_Sides are free to move

LOAD BEARING SCHEME / CONDITIONS







Segmentation of the facade

_4 segments vertically
_4 segments horizontally
_ Maximum manufacturable sizes

Intermediate connections

_ Secure continuity of surface
_ Transfer forces and moments (Firm)
_ Should not perform as hinge

01 **Strength**

The connections to bear the loads imposed on the facade:
_Dead load
_Lateral loads

02 **Geometry**

Their geometry should ensure continuity of the surfaces.Take into account the complexity of the surface.

03 **Robustness**

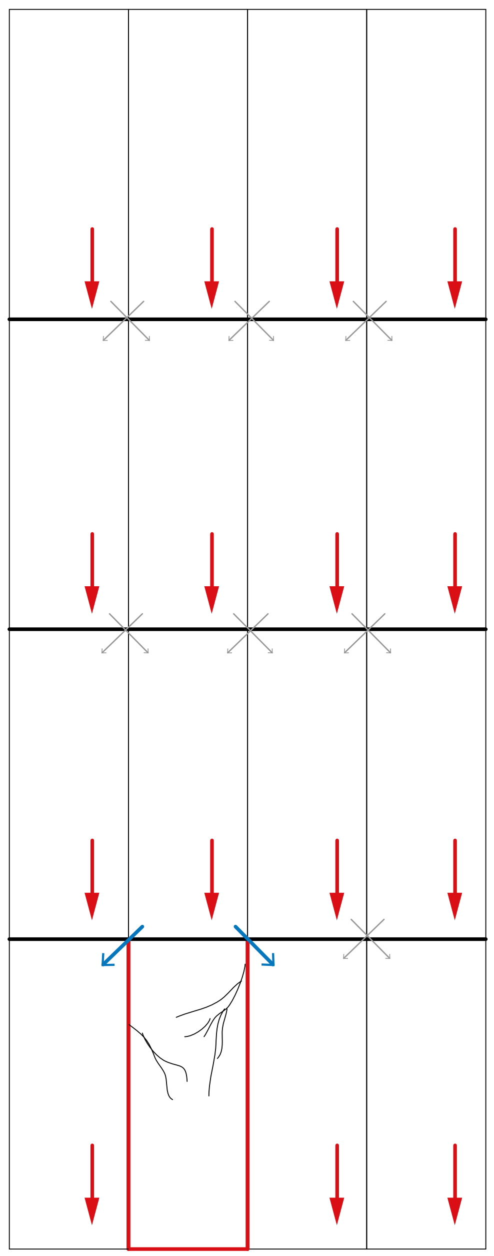
Provide alternative load paths in case of failure of one panel or more.

04 **Size**

Increase the level of transpareny by being as small as possible. Smallest existing size now **150mm**.

05 **Installation**

Take into account the assembly process with the appropriate tolerances.

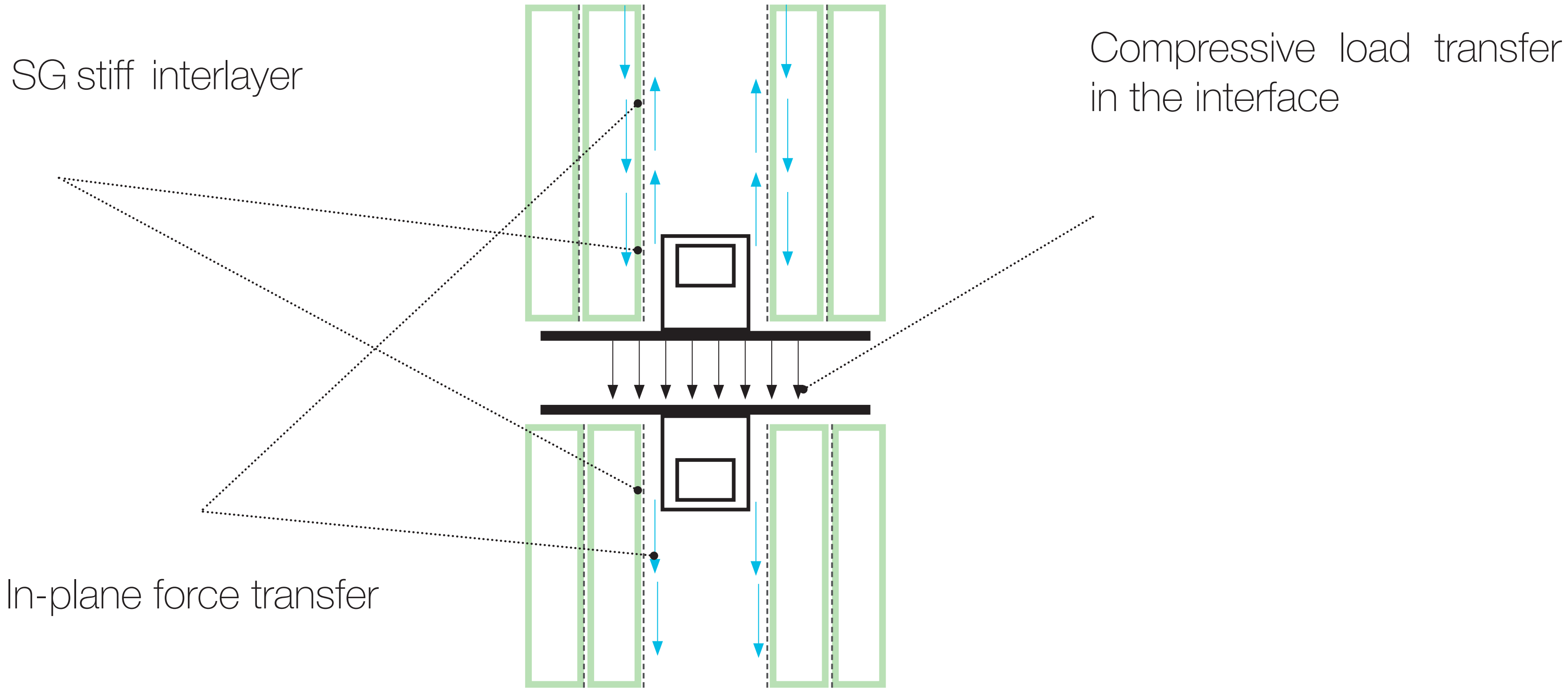


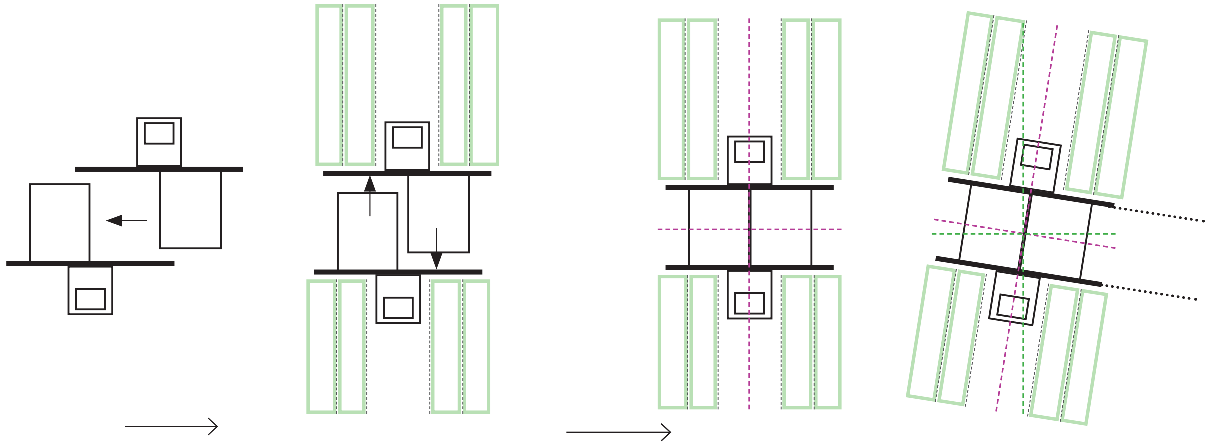
01 Avoid contact of glass with hard materials

02 Structural spacer and edge used as an interface to transfer the forces between the glass.

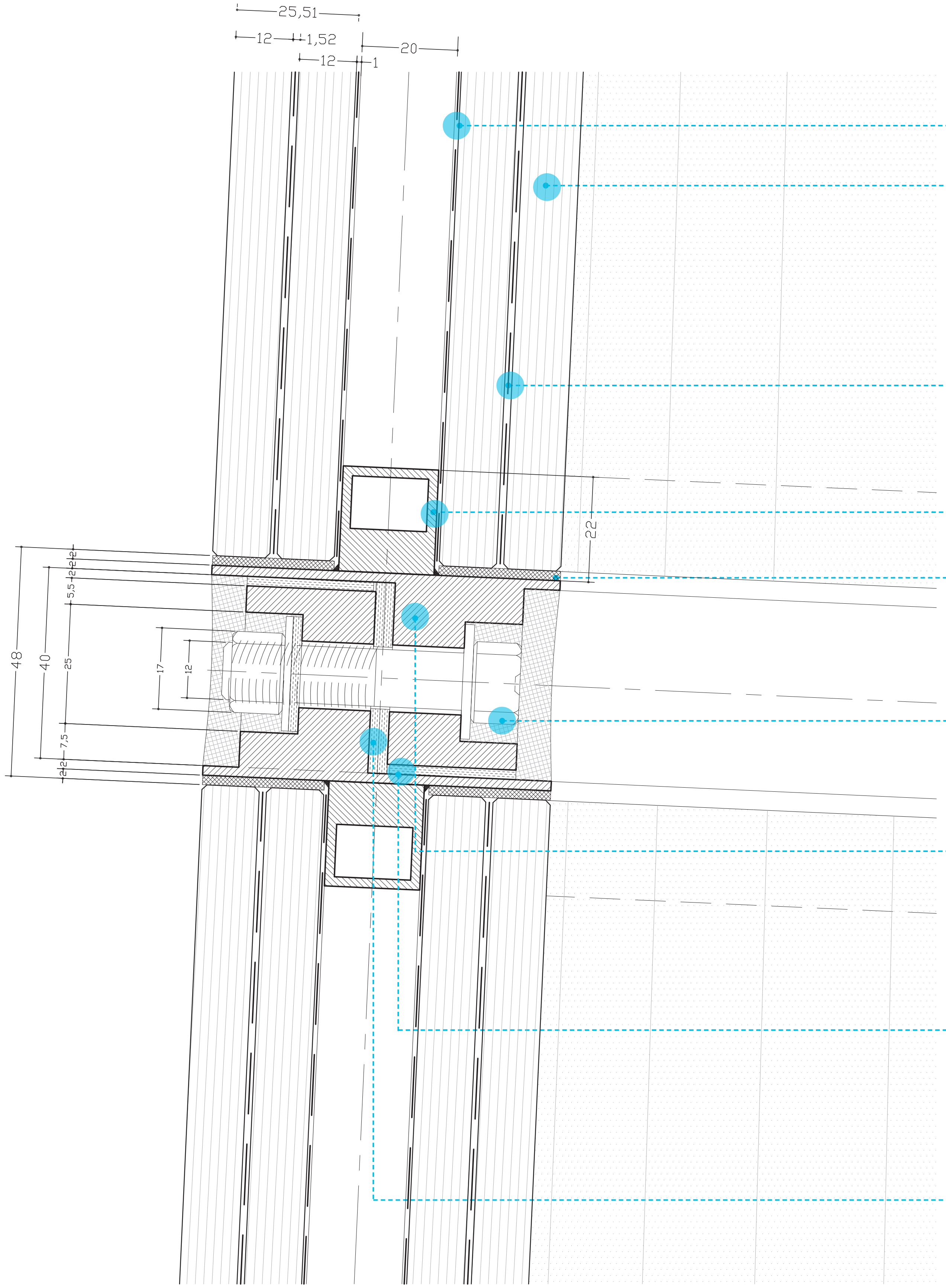
03 The geometry of the joint should follow the perpendicularity of the curved surface.

04 According to the fabrication deviations +- 2mm tolerances are introduced as intended to avoid overlapping profiles.





Interlocking geometry following the normals of the surface



Sentry Glas Interlayer
Used in the inner side of the ply to laminate the to stainless steel spacer with the attached connection.

12 mm HS Soda Lime Glass
The annealed glass is being hot bended and afterwards processed to achieve by water jet cutting the perpendicularity of the edge. After that it can be tempered to prestress it.

Sentry Glas Plus Interlayer
The SGP is used to laminate the plies for securing post breaking behavior.

20/22 mm hollow stainless steel spacer
Produced by special extrusion, bending and twisted

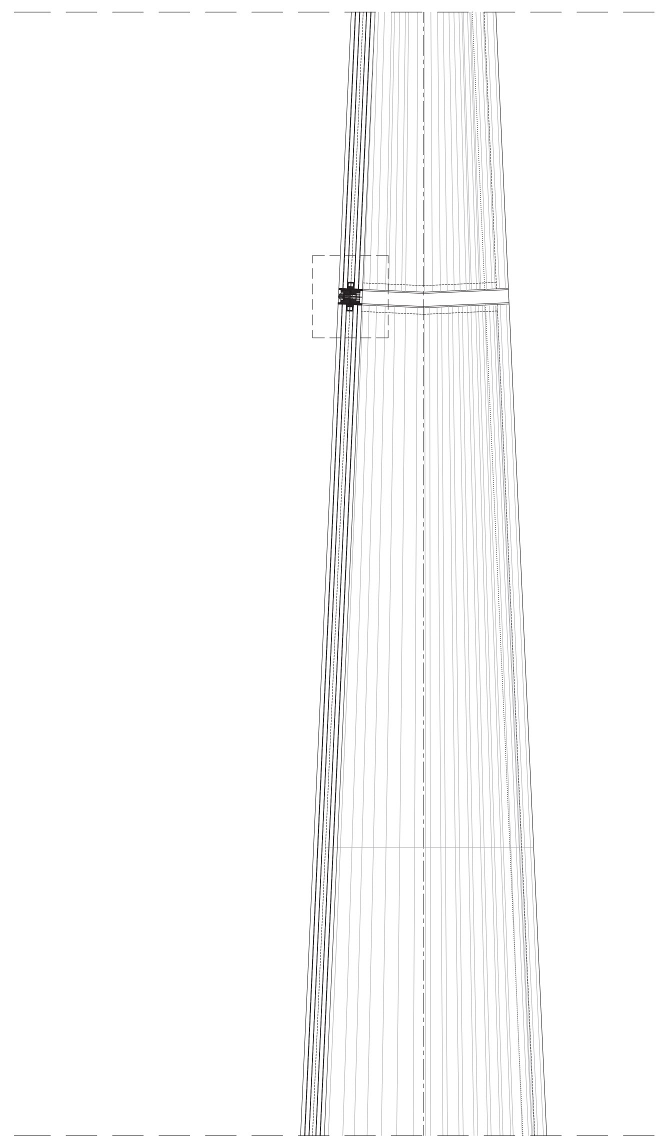
2mm Silicone bushing
Used to take up the tolerances between the glass and the stainless steel edge. (+- 2mm from the hot bending process)

12mm Bolt
Fastening the two profiles.

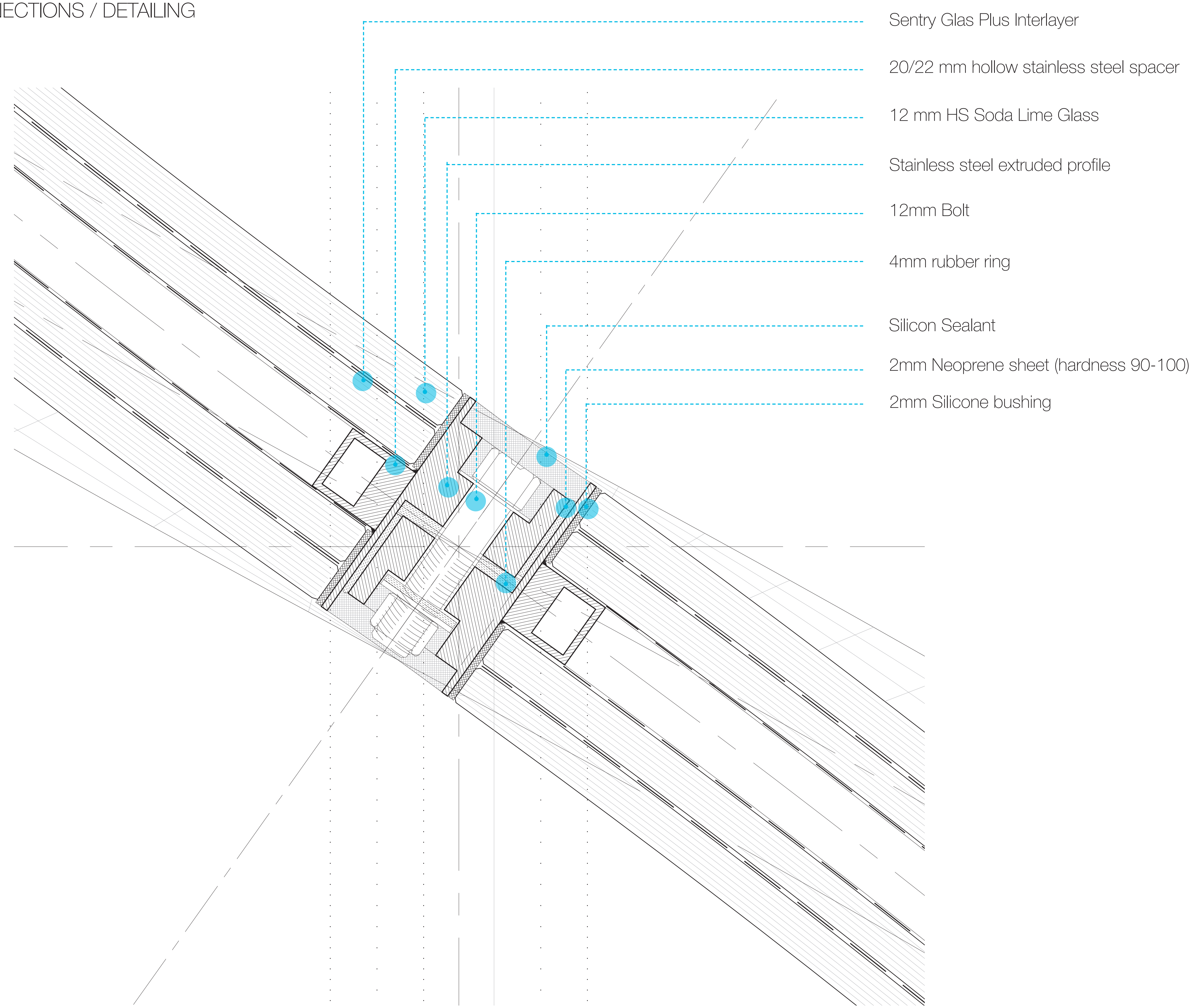
Stainless steel extruded profile
The profile is produced with special extrusion process. After that is bended and twisted to the shape. The tolerances are intended 4mm in the middle (between profiles) to facilitate installation.

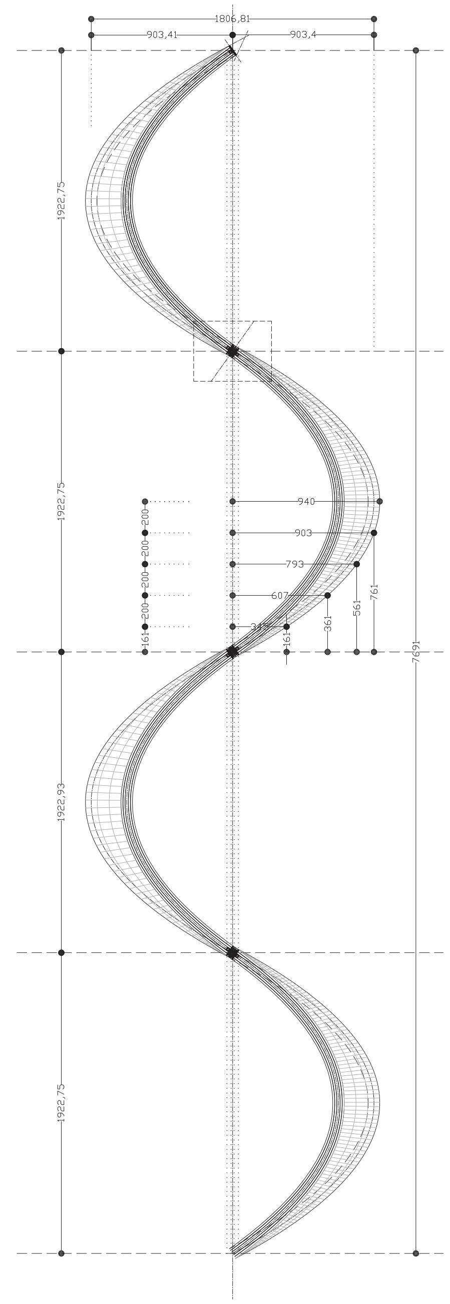
2mm Neoprene sheet (hardness 90-100)
Taking up the tolerances from the profiles manufacturing deviation. This interface has not been completed in design.

4mm rubber ring
Taking up the tolerances from the profiles manufacturing deviation. Helps to provide the buffer for the tightening of the bolt.

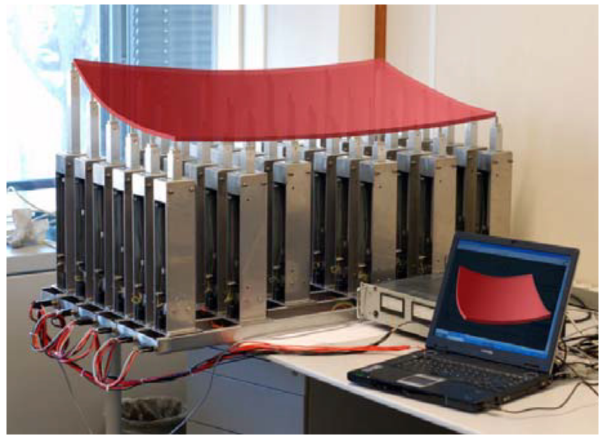


CONNECTIONS / DETAILING





Glass

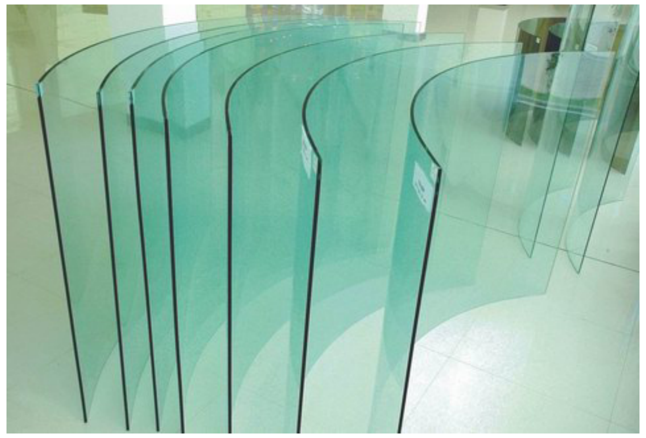


Annealing and bending

Adjustable mould - ‘Flex-rod’ system. Actuators adjusted according to computer model output.

Water jet cutting

Water jet cutting the edges of glass so as to achieve the perpendicularity across the edges.



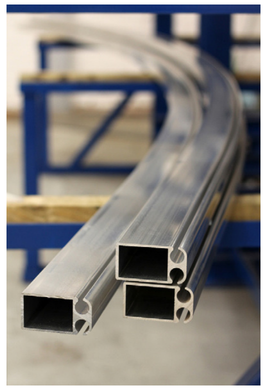
Strengthening

Heat strengthening glass after the bending process. Chemical strengthening could a second option because of the geometry

Connector

Stainless Steel extrusion & forming

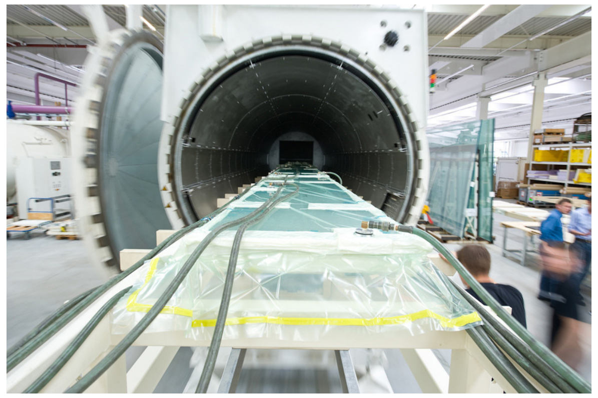
Using special machines for the aircraft industry stainless steel extrusions that fit the diameter of 140 mm are possible.Used for producing the spacers. After that the shapes can be bent and twisted.

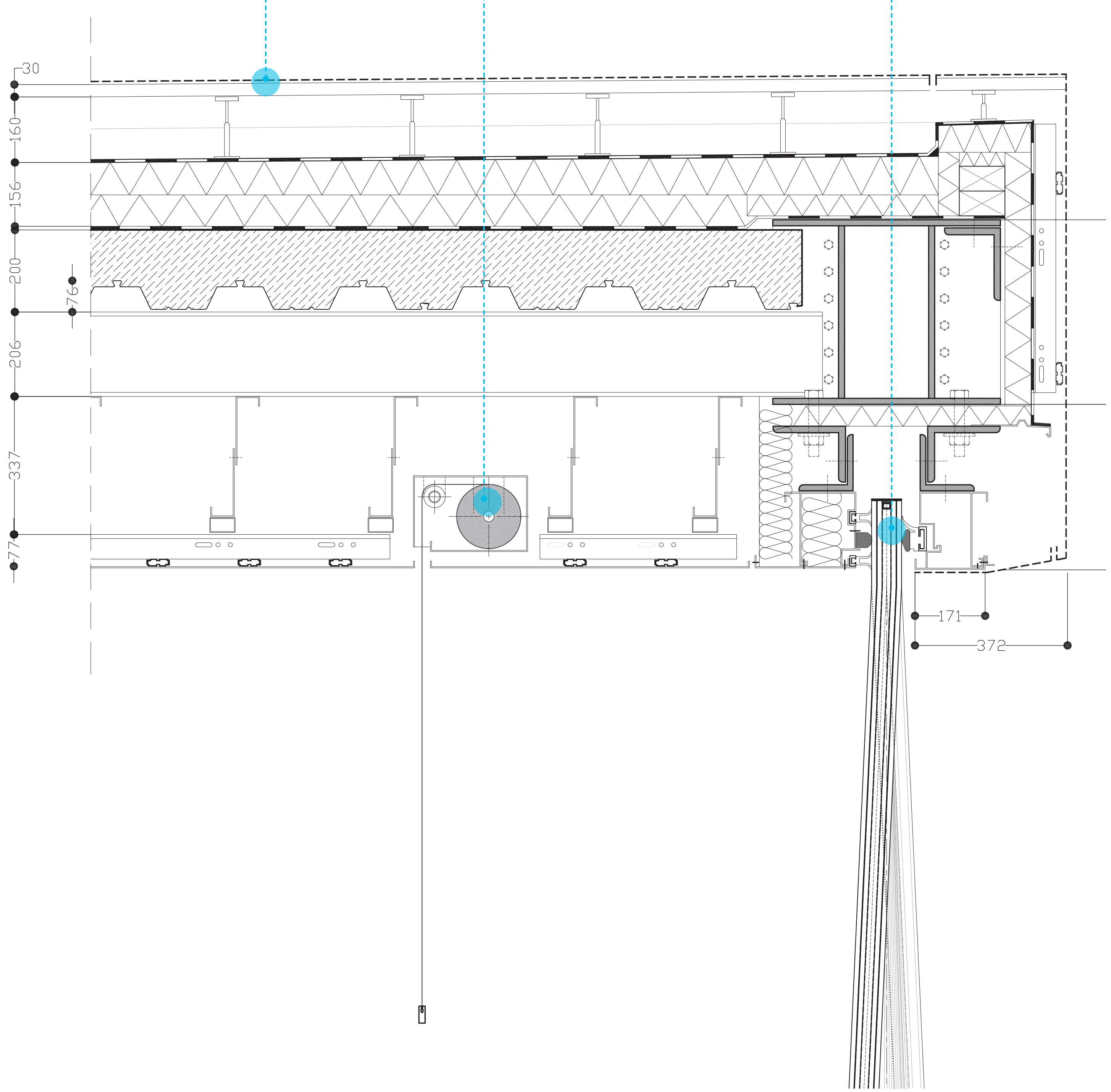


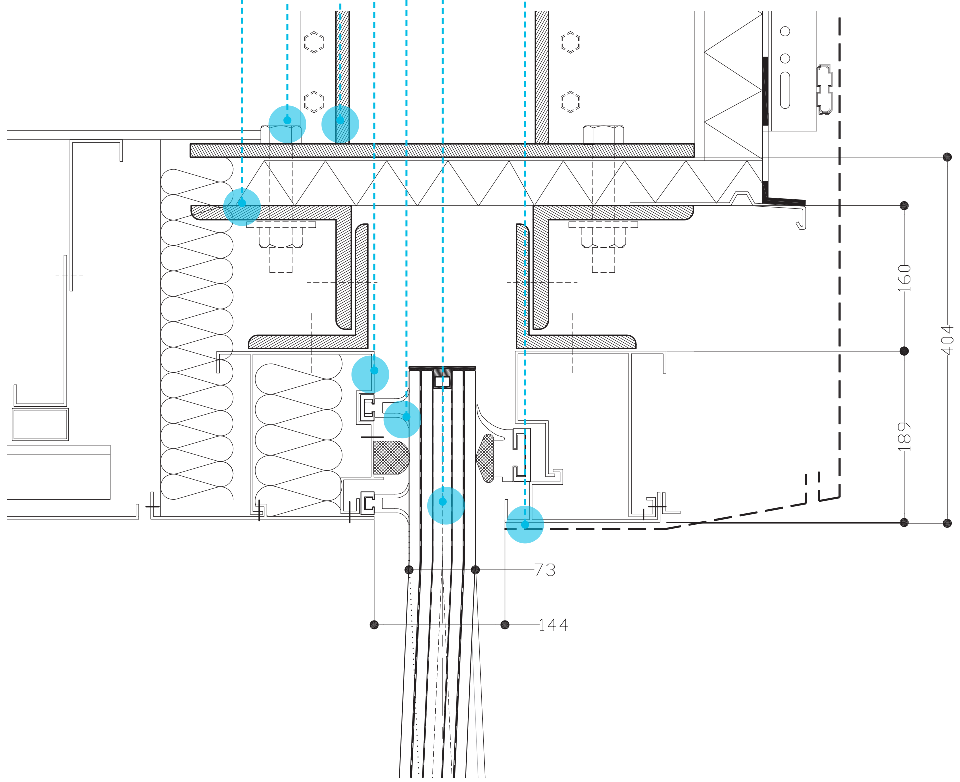
Aluminium extrusion & forming

Aluminium extruded parts are used for producing the connector and edge piece later on they are bended and twisted together to form the final profile shape.

Lamination of the components into one element / panel




Sun Screen
Roof Build up
2 mm perforated red bruss
Bituminous layer
Foam glass / Insulation
Concrete 200 mm
Corrugated metal sheet
200 mm H steel beam
Dropped ceiling
Roller Detail
30
160
156
200
76
206
337
77
171
372


L profile 100/ 100 /10
Bolt 24 mm
Custom made steel beam
Extruded aluminium profile
EPDM Gaskets
Glass Panel
EPDM Gasket
160
189
404
73
144

Floor Stone tiles 30mm

Steel profile custom made

Bolt 24 mm

Steel plate

Steel plate 10 mm

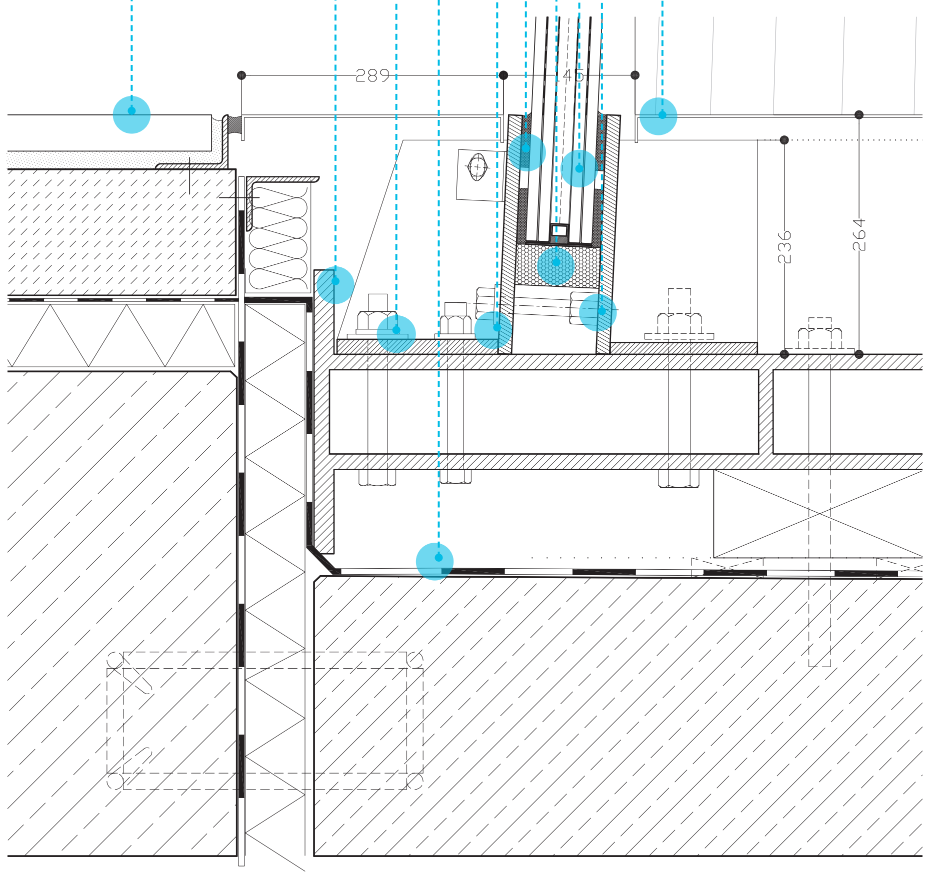
Neoprene layer 10.5 mm

Setting Block

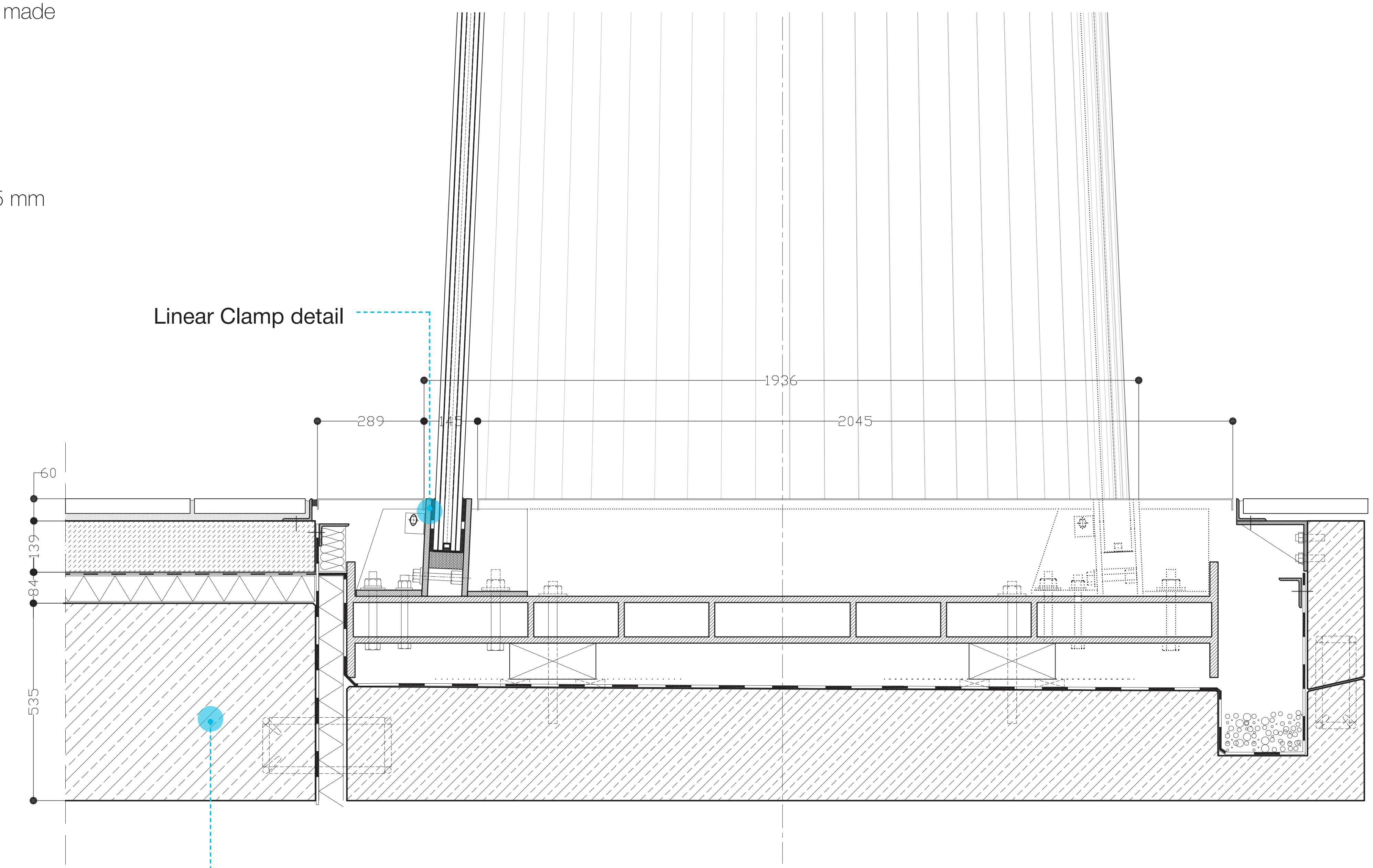
Glass panel

Bolt 18 mm

Aluminium sheet



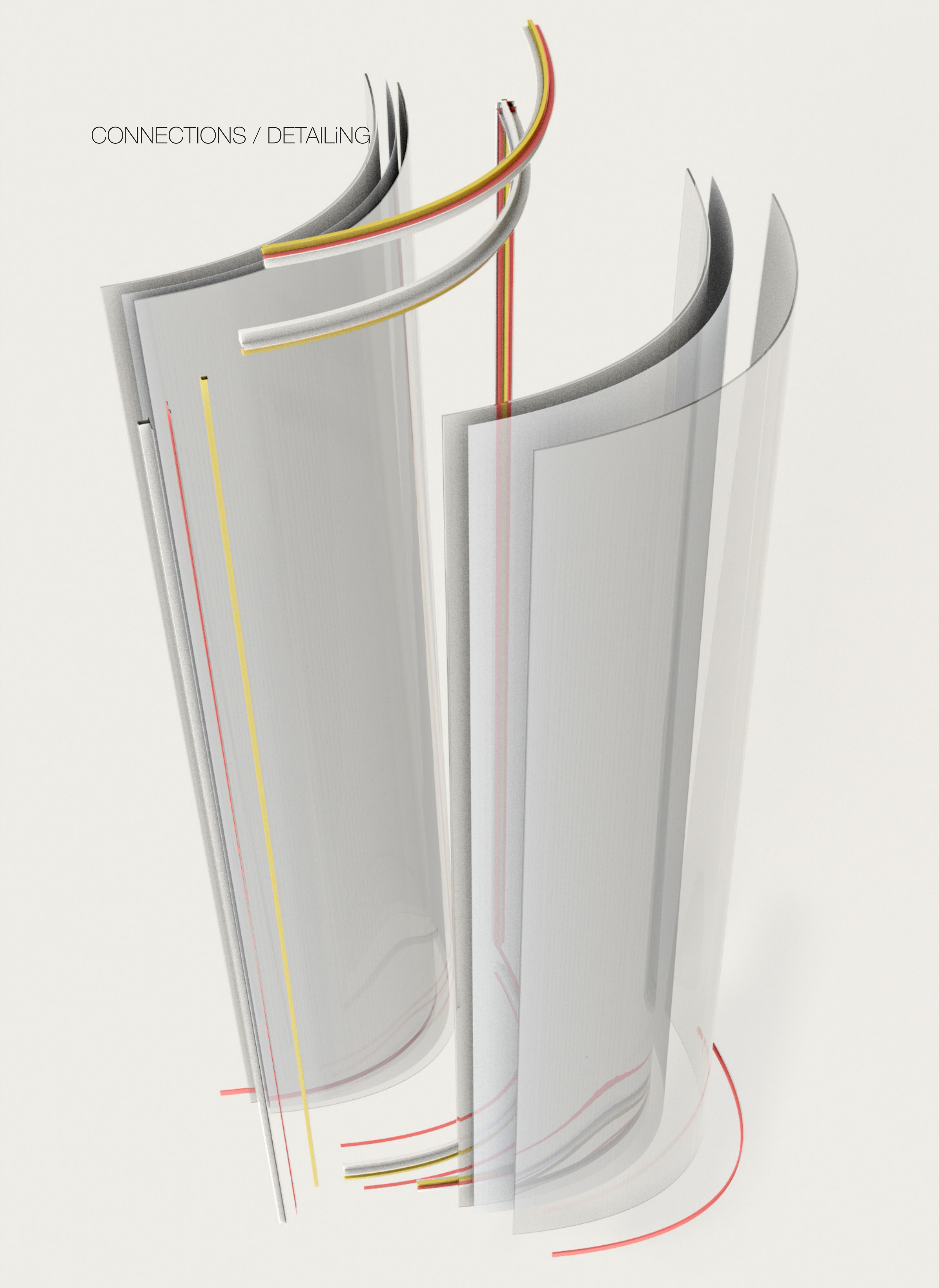
Linear Clamp detail



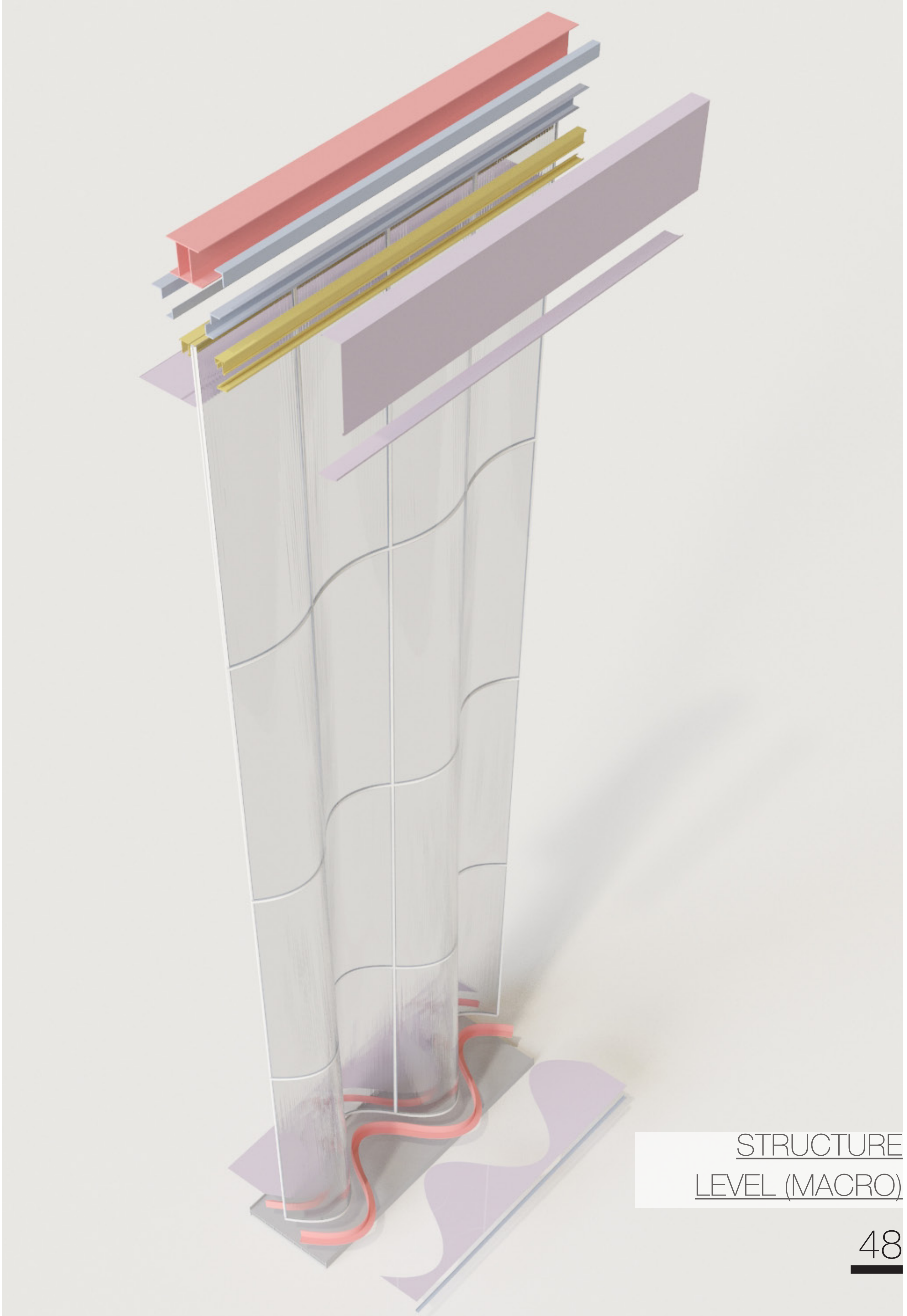
Floor Build up

Stone tiles 30mm
Mortar 20mm
Cement screed 140mm
Polyethylene membrane
Insulation
Concrete 530mm

CONNECTIONS / DETAILiNG



STRUCTURE LEVEL (MACRO)



MODEL DESCRIPTION

Simplified model

_**24 mm** monolithic glass

_**One surface** top to bottom

_**No separations** between the panels

_Model of **one segment**

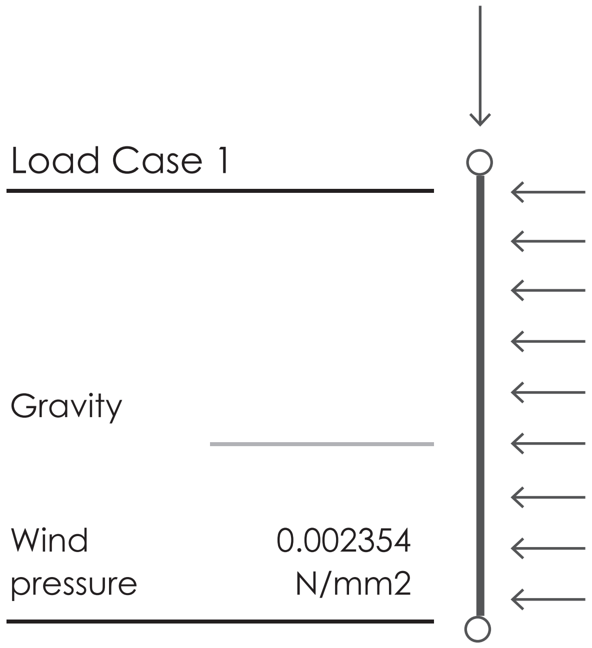
_**One material** (Soda Lime Glass)

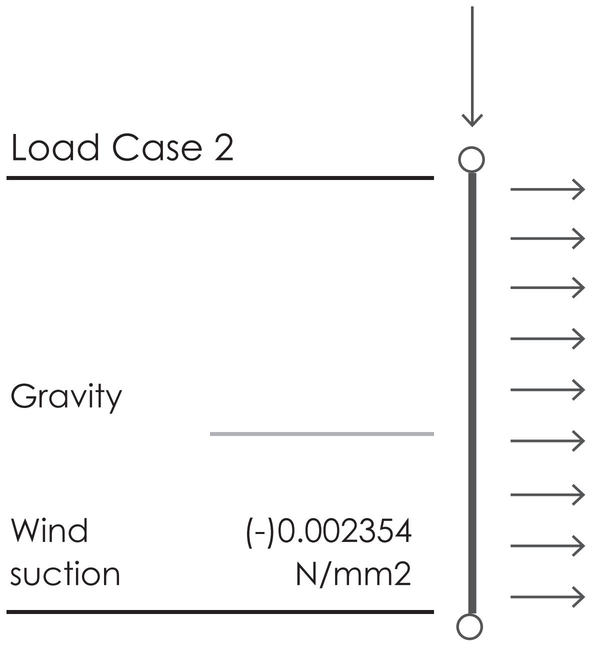
_No joints modelled

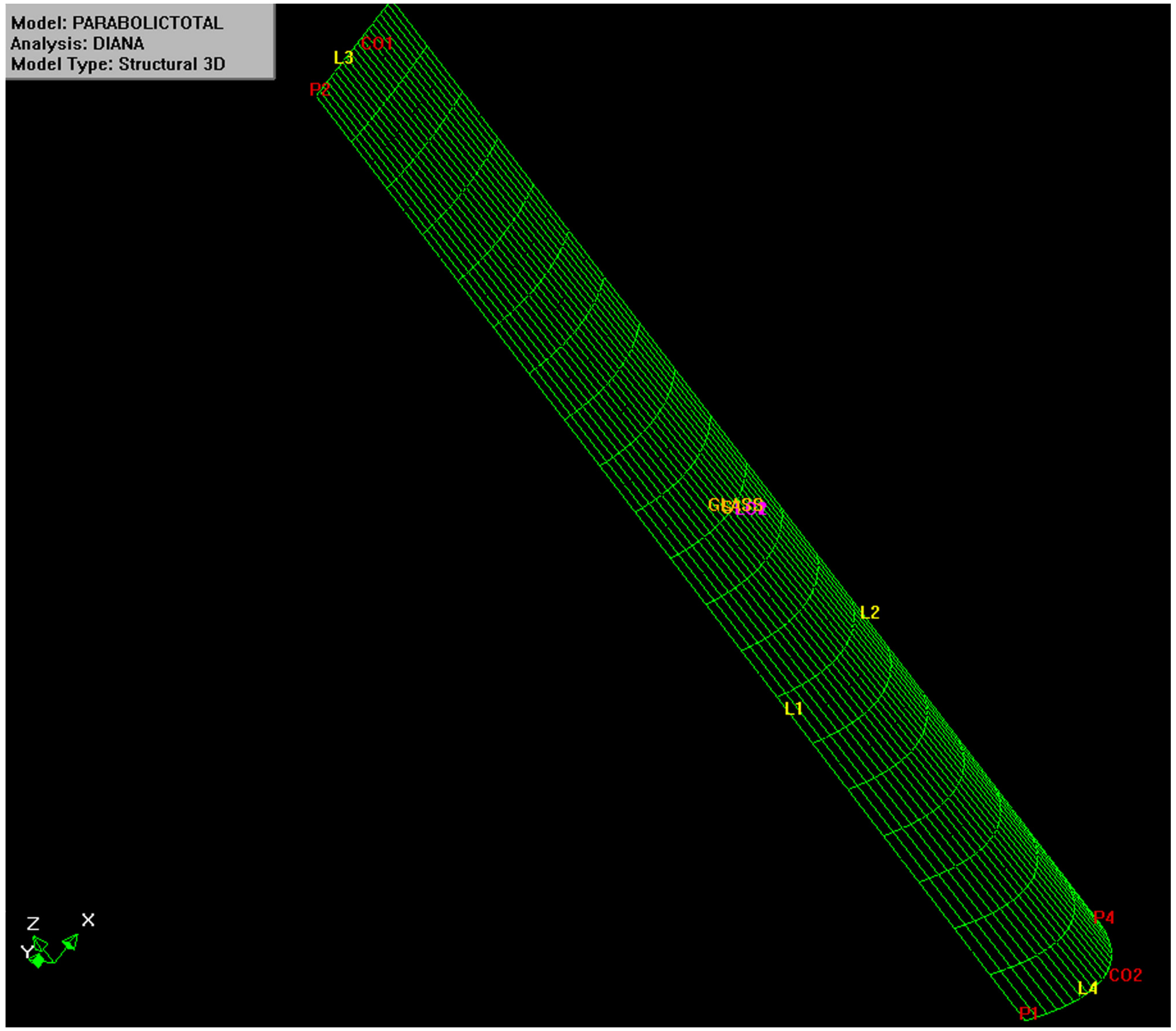
_Restraint at the **top** and **bottom**

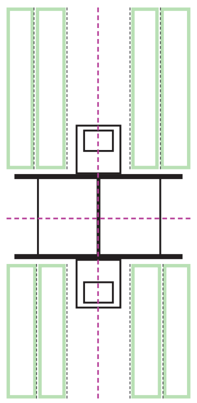
_**2** Loading scenarios

_Mesh type curved shell **QU8 CQ40S**

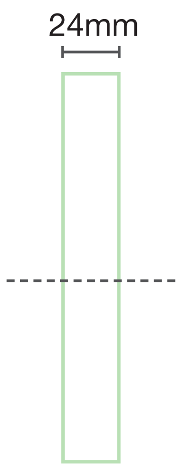






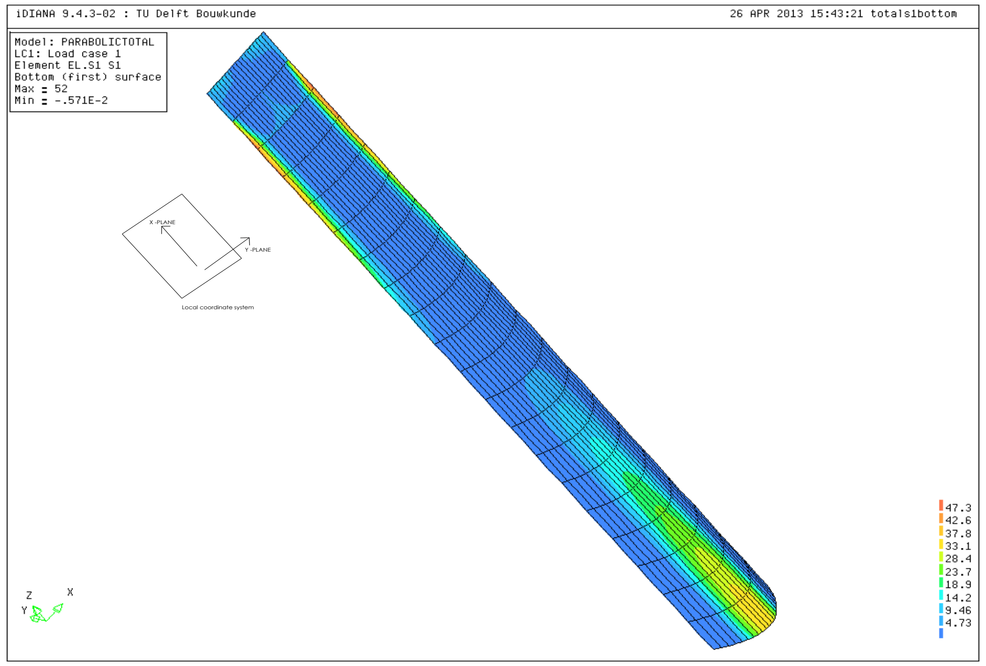


Physical



Simplified

ULTIMATE LIMIT STATE



Load Case 1	Max	Min
EL. S1. S1/ Principle stress 1 (algebraic largest) (N/mm2)		
Bottom surface	52	-5.71E-03
Top surface	113	-5.88E-03

Load case 1
Maximum tensile stress (bottom) = 52MPa
For 2 laminated panes equals the maximum

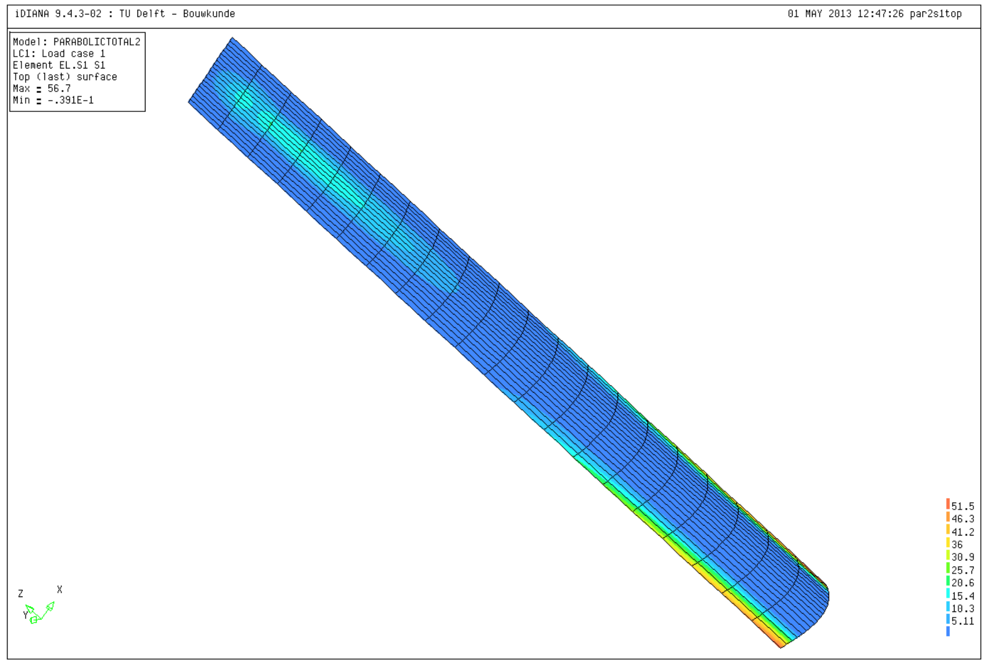
Maximum allowable tensile strength **45MPa (annealed)**

Material Factor $\gamma_{M;A} = 1.8$

Load factor (wind load) $\gamma_G = 1.6$

↓

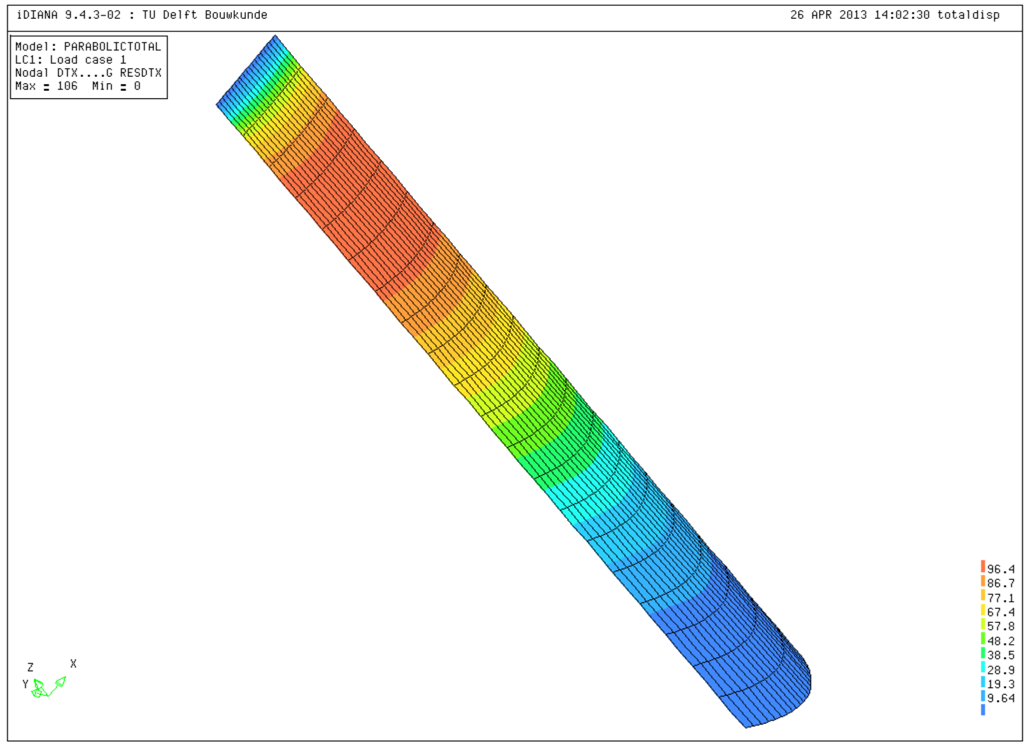
Design load <= 26Mpa



Load Case 2	Max	Min
EL. S1. S1/ Principle stress 1 (algebraic largest) (N/mm2)		
Bottom surface	60.2	-3.62E-02
Top surface	56.7	-3.91E-02

Load case 2
Maximum tensile stress (top) = 56.7MPa
For 2 laminated panes is just above the maximum

SERVICEABILITY LIMIT STATE



Load Case 1	Max	Min
FBX...G RESFBX / support reaction	1.37E+05	
DTX...G RESDTX / total displacement	106	

Maximum allowable deflection: 1/65 of span

OR

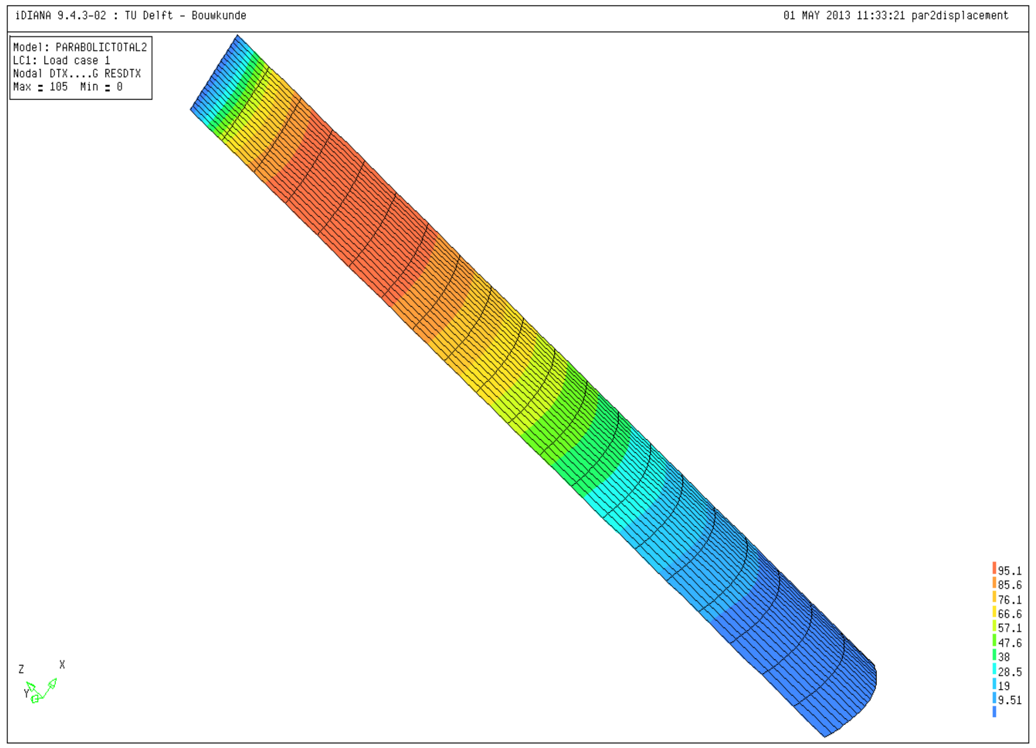
50 mm

Span: 20000 mm

↓

Allowable deflection: 307 mm

Load case 1
Maximum displacement 106 mm < 307 mm



Load Case 2	Max	Min
FBX...G RESFBX / support reaction	1.33E+05	
DTX...G RESDTX / total displacement	105	

Load case 2
Maximum displacement 105 mm < 307 mm

Ultimate Limit State

1 | Increase accuracy in the modelling of the surface

2 | Conduct additional laboratory test on specimens

3 | Increase the thickness of the glass

4 | Use Fully Tempered glass

Serviceability Limit State

1 | We cannot take into account the lower limit of 5omm deflection since it is not given for the certain geometry

2 | Increase the accuracy of the calculations / The spacer stiffness could have spring action.

3 | The connection of the facade to the wall should allow for deflections of 100mm

1 | The maximum transparency can be achieved for a glass facade of large scale by utilizing a self –supporting geometry like the one proposed

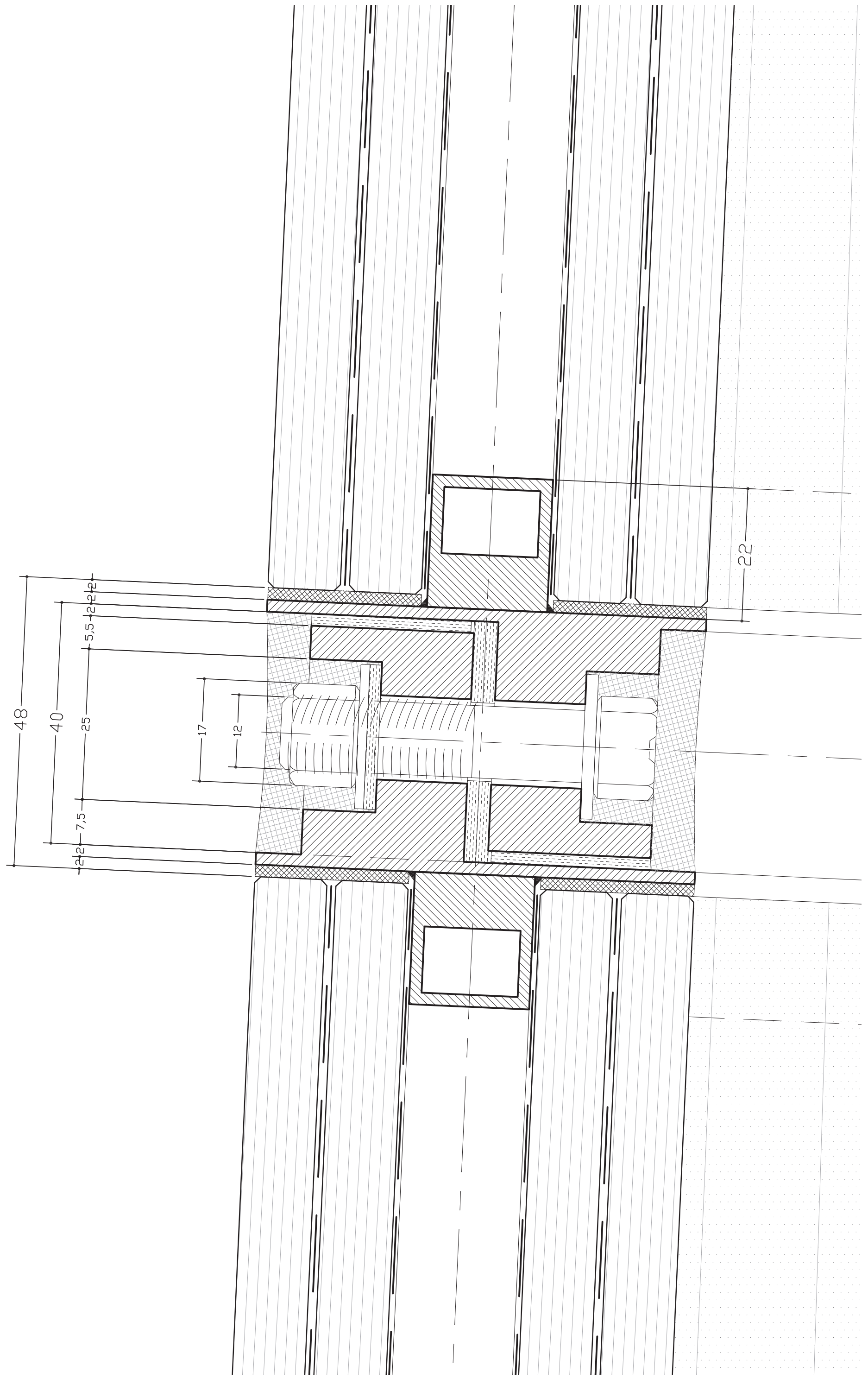
2 | We can improve the structural performance through the stiff-ness of the curved geometry and provide a safe structure

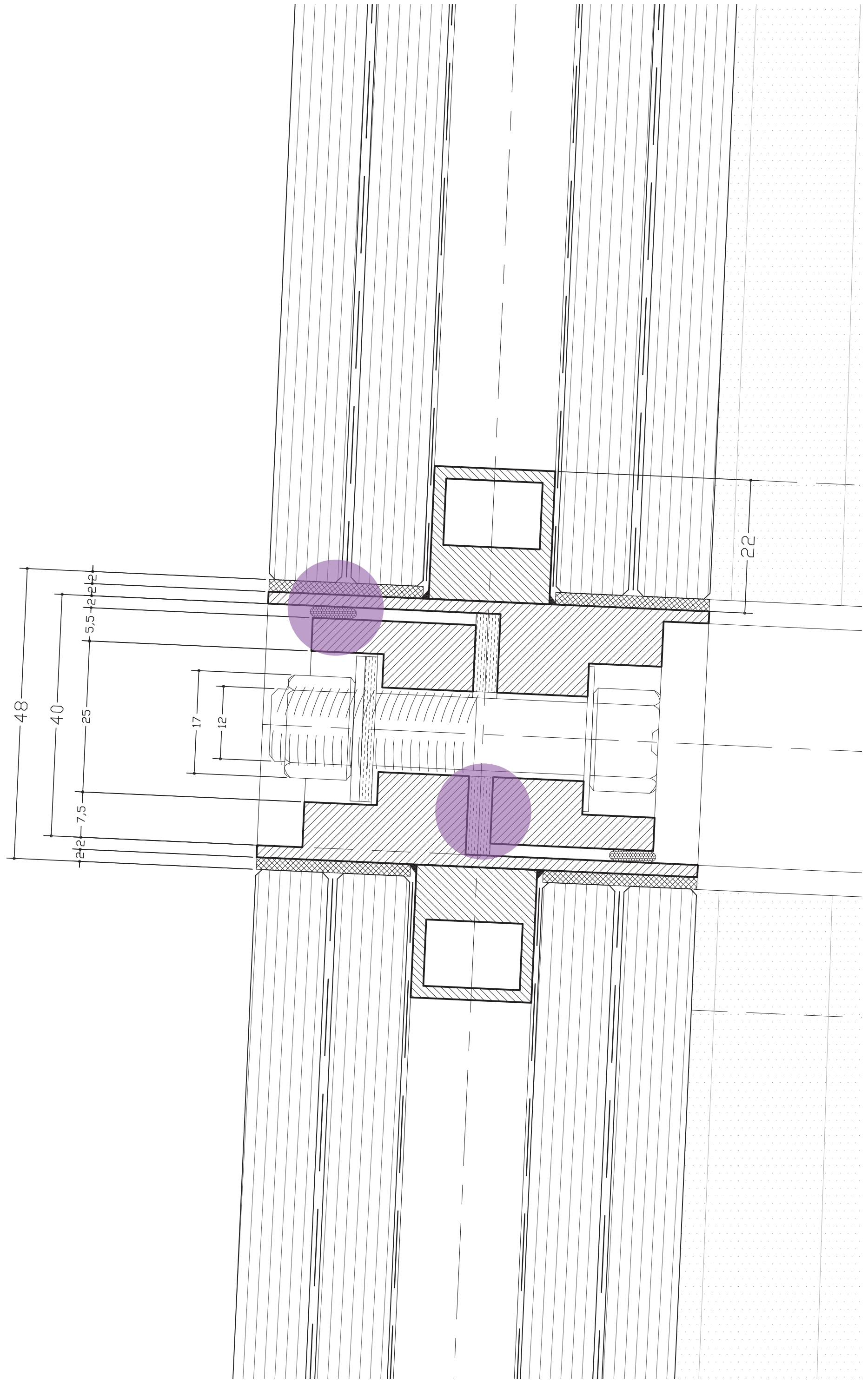
3 | We can maximize transparency in the curved geometry by using the special type of joint that is embedded in the laminate and can transfer forces via the spacer and an interlocking geometry

4 | The size of connection achieved can be 33 mm

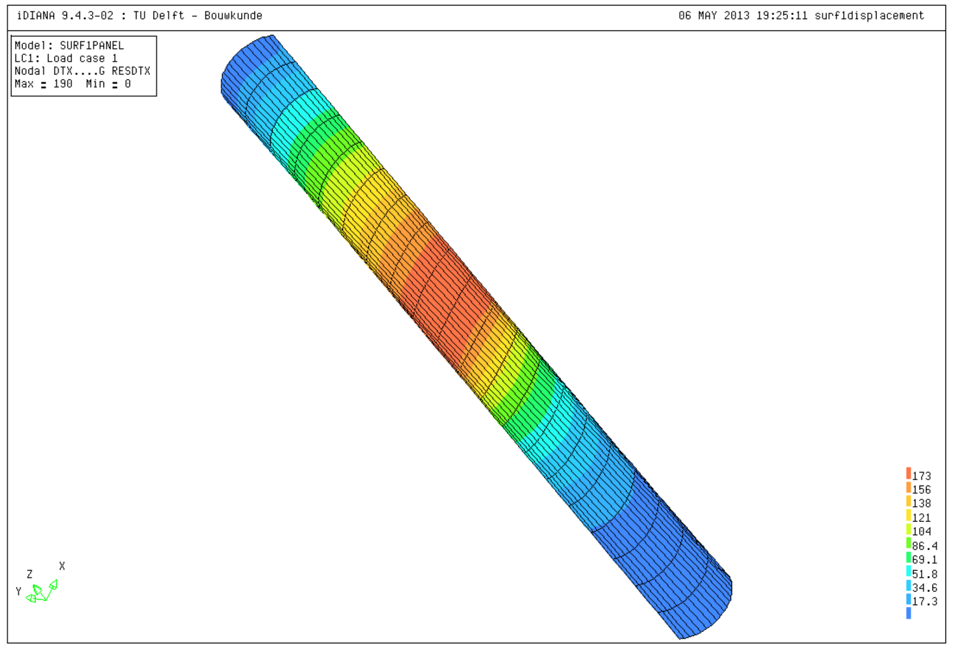
/// Thank you ///

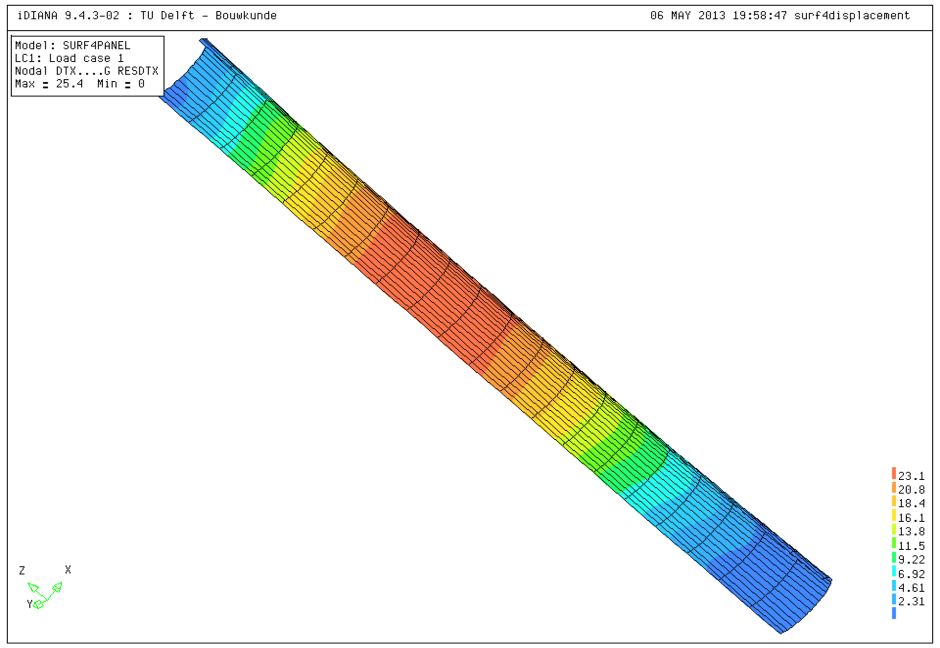
APPENDIX / ALTERNATIVES OF CRITICAL DETAIL

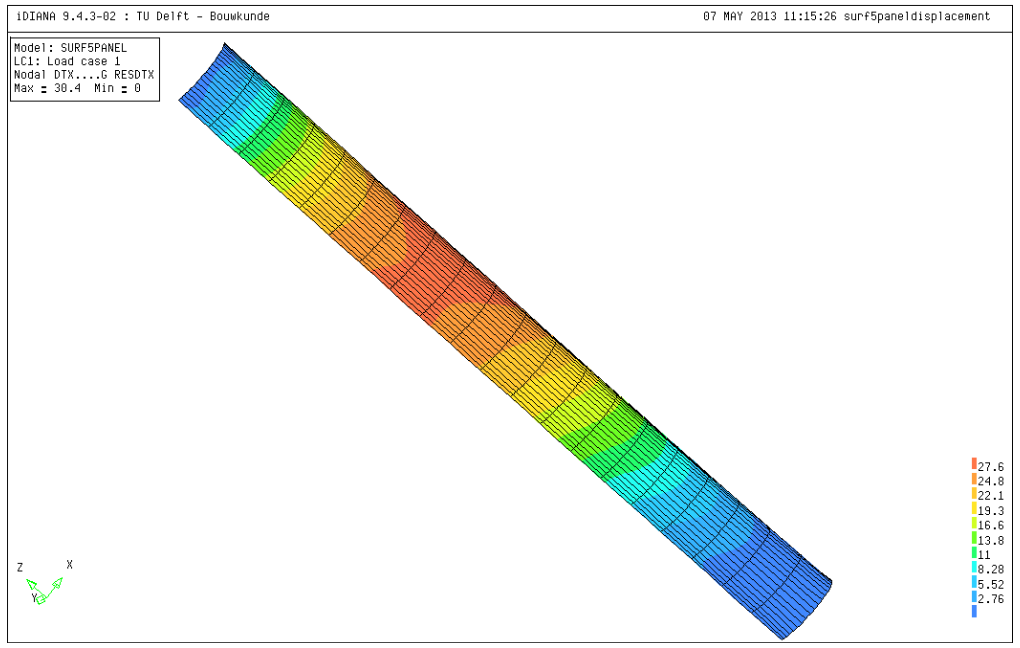




APPENDIX / ALTERNATIVES SURFACES SIMULATION







Panel 1 / Twisted along middle

Nr. of Surfaces	1
Nr. of Lines	4
Nr. of Points	4
Mesh type surface	qu8 cq40s
Mesh type midlines	
Material surface	Glass
Material midlines	
Load Case 1	
Gravity	
Wind pressure	0.002354 N/mm2

Load Case 1	Max	Min
FBX...G RESFBX / support reaction	1.14E+05	1.20E+02
DTX...G RESDTX / total displacement (mm)	190	0
EL. S1. S1/ Principle stress 1 (algebraic largest) (N/mm2)		
Bottom surface	49.7	-2.47E-01
Top surface	38.5	-3.15E-02
EL. S1. S2/ Principle stress 2 (N/mm2)		
Bottom surface	13.2	-5.11E+00
Top surface	10.6	-1.06E+01
EL. S1. S3/ Principle stress 3 (algebraic smallest) (N/mm2)		
Bottom surface	3.01E-02	-8.99E+01
Top surface	2.82E-02	-1.14E+02

Panel 2 / Corrugated (reduced in the middle)

Nr. of Surfaces	1
Nr. of Lines	4
Nr. of Points	4
Mesh type surface	qu8 cq40s
Mesh type midlines	
Material surface	Glass
Material midlines	
Load Case 1	
Gravity	
Wind pressure	0.002354 N/mm2

Load Case 1	Max	Min
FBX...G RESFBX / support reaction	7.25E+04	4.48E+02
DTX...G RESDTX / total displacement (mm)	25.4	0
EL. S1. S1/ Principle stress 1 (algebraic largest) (N/mm2)		
Bottom surface	26.8	-1.97E-02
Top surface	27.8	-2.09E-02

Panel 1 / Corrugated (reduced towards the top)

Nr. of Surfaces	1
Nr. of Lines	4
Nr. of Points	4
Mesh type surface	qu8 cq40s
Mesh type midlines	
Material surface	Glass
Material midlines	
Load Case 1	
Gravity	
Wind pressure	0.002354 N/mm2

Load Case 1	Max	Min
FBX...G RESFBX / support reaction	7.86E+04	8.68E+01
DTX...G RESDTX / total displacement (mm)	30.4	0
EL. S1. S1/ Principle stress 1 (algebraic largest) (N/mm2)		
Bottom surface	29.4	-2.15E-02
Top surface	28.3	-2.00E-02