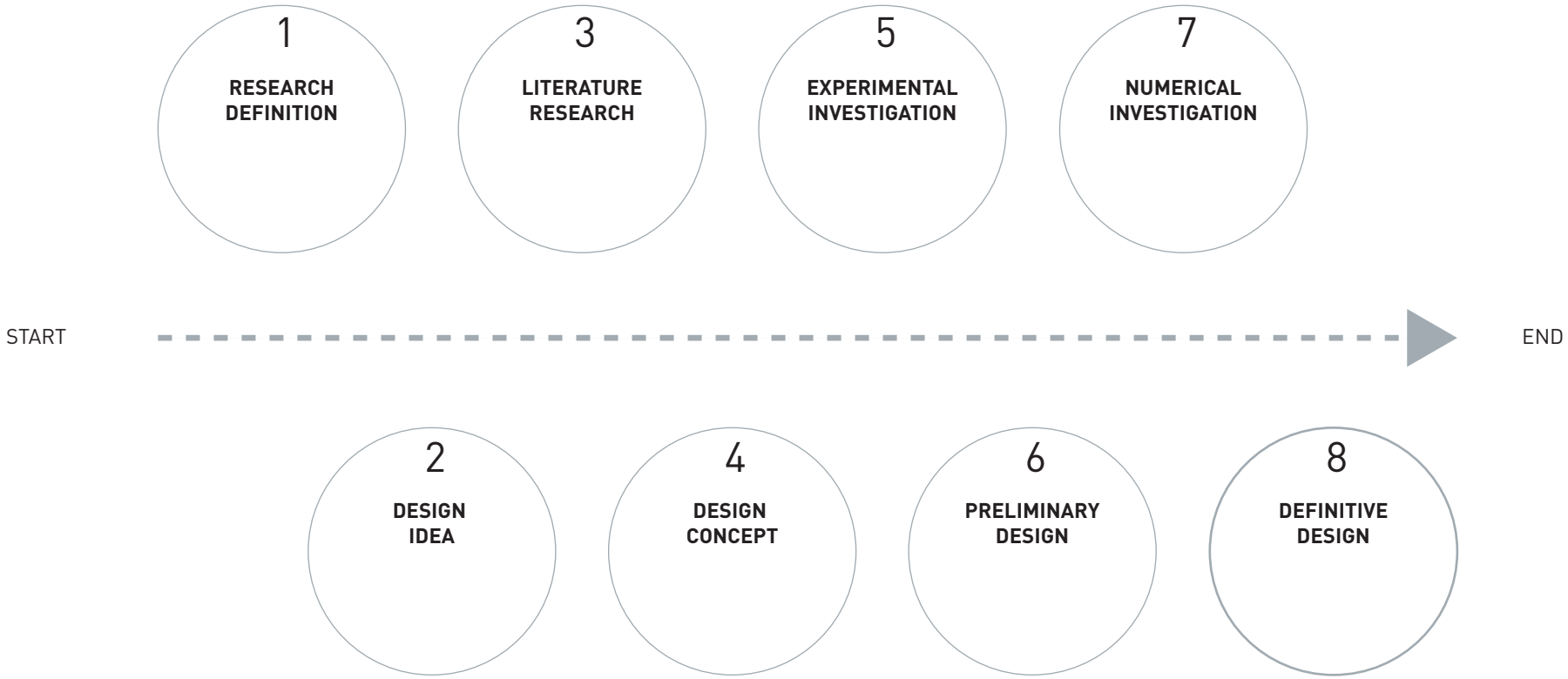
RENS OTTENS P5 PRESENTATION JANUARY 30TH, 2018

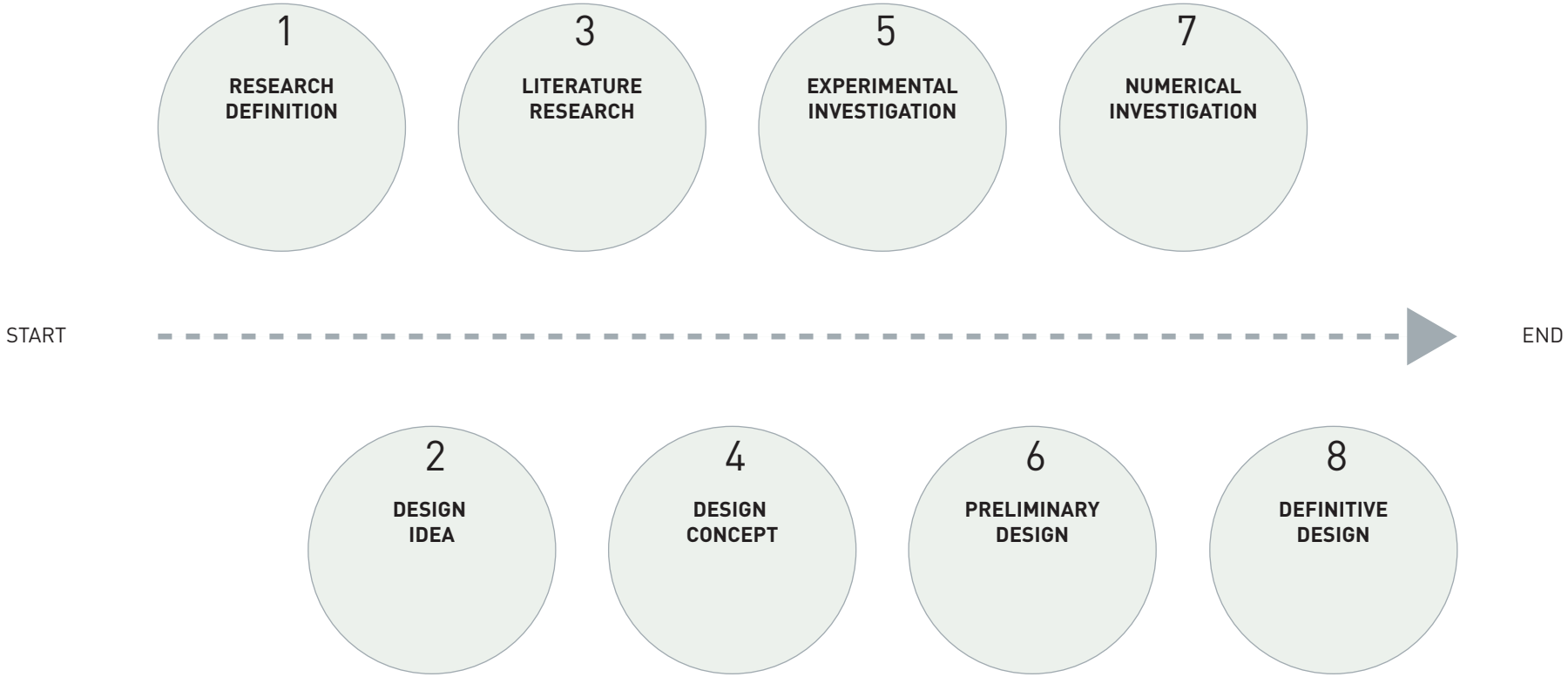
HIGH STRENGTH THIN GLASS
AS
STIFF STRUCTURAL FABRIC

TU Delft

CONTENT PRESENTATION



CONTENT PRESENTATION



INTRODUCTION

HIGH STRENGTH THIN GLASS
AS
STIFF STRUCTURAL FABRIC

USED IN CONSUMER ELECTRONICS

USED IN CONSUMER ELECTRONICS

Thinner

Stronger

Flexible

USED IN CONSUMER ELECTRONICS

Thinner

Stronger

Flexible

Exceptional scratch resistance

Lightweight

Higher impact resistance

USED IN CONSUMER ELECTRONICS

Thinner

Stronger

Flexible

Exceptional scratch resistance

Outstanding optical clarity

Superior touch sensitivity

Lightweight

Higher impact resistance

Durable

HIGH STRENGTH
THIN GLASS

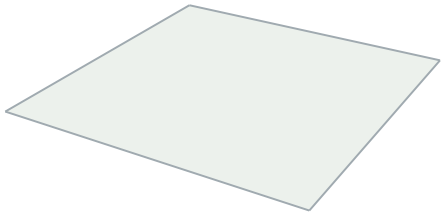
POTENTIALS

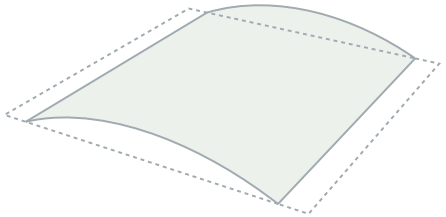
KNOWLEDGE GAP

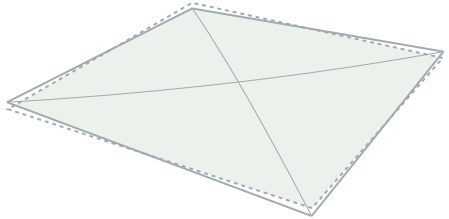
MIGHT RESULT INTO MORE LIGHTWEIGHT, CURVED, TRANSPARENT STRUCTURES

TU Delft

HIGH STRENGTH THIN GLASS SHAPES





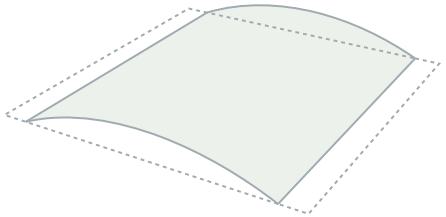


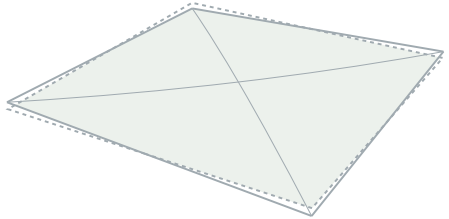
1. Flat
   creating lightweight facades

2. Single curved
   creating curved facades

3. Double curved
   creating curved & geometrical complex facades

EARLIER DONE RESEARCH HIGH STRENGTH THIN GLASS





1. Flat

   by I. van der weijde (TU Delft, 2017)

2. Single curved

   creating curved facades

3. Double curved

   creating curved & geometrical complex facades

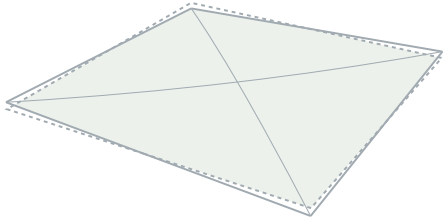
EARLIER DONE RESEARCH HIGH STRENGTH THIN GLASS

1. Flat

by I. van der weijde (TU Delft, 2017)

2. Single curved

by C. Simoen (TU Delft, 2016)



3. Double curved

creating curved & geometrical complex facades

EARLIER DONE RESEARCH HIGH STRENGTH THIN GLASS

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by I. van der weijde (TU Delft, 2017)

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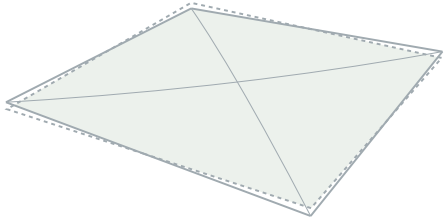
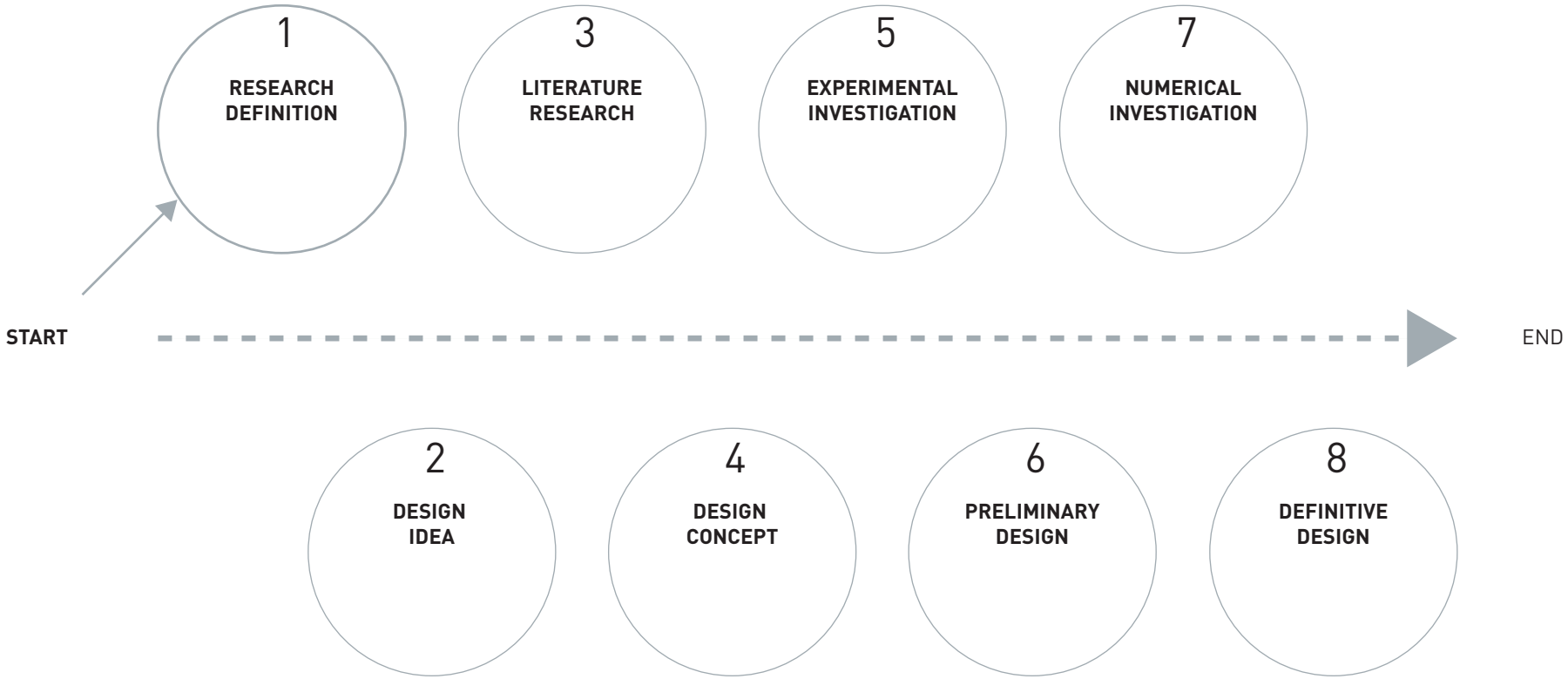


?

3. Double curved

No scientific information


1
RESEARCH DEFINITION
3
LITERATURE RESEARCH
5
EXPERIMENTAL INVESTIGATION
7
NUMERICAL INVESTIGATION
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END
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DESIGN IDEA
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PRELIMINARY DESIGN
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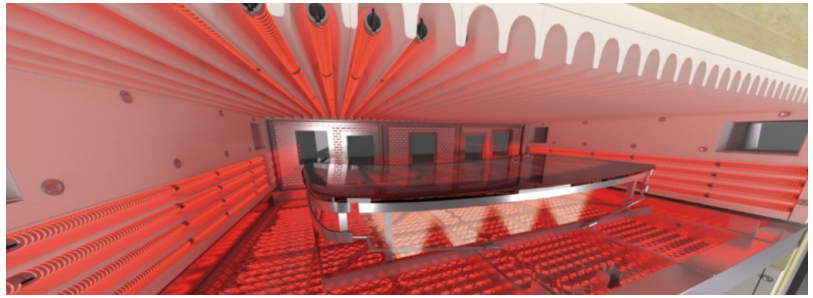
DEFINITIVE DESIGN

RESEARCH DEFINITION

DOUBLE CURVED GLASS

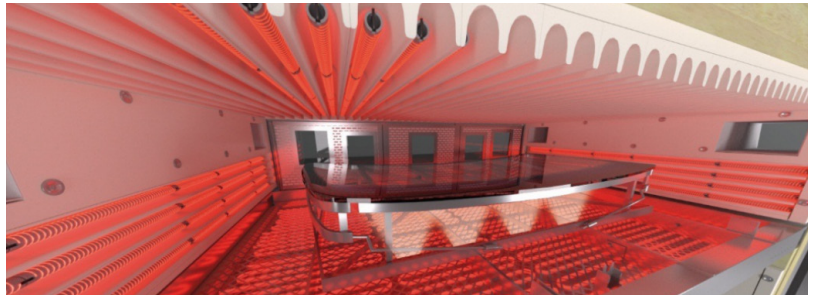


1. Hot bent glass

2. Cold bent glass

Can only be cold bent with a curvature in the opposite way: ***anticlastic***

DOUBLE CURVED GLASS

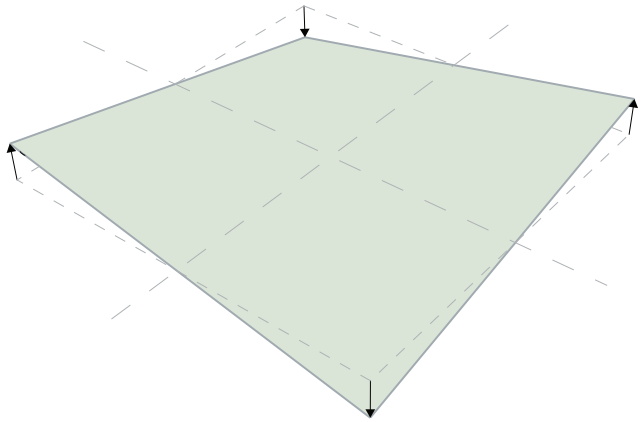


1. Hot bent glass

2. Cold bent glass

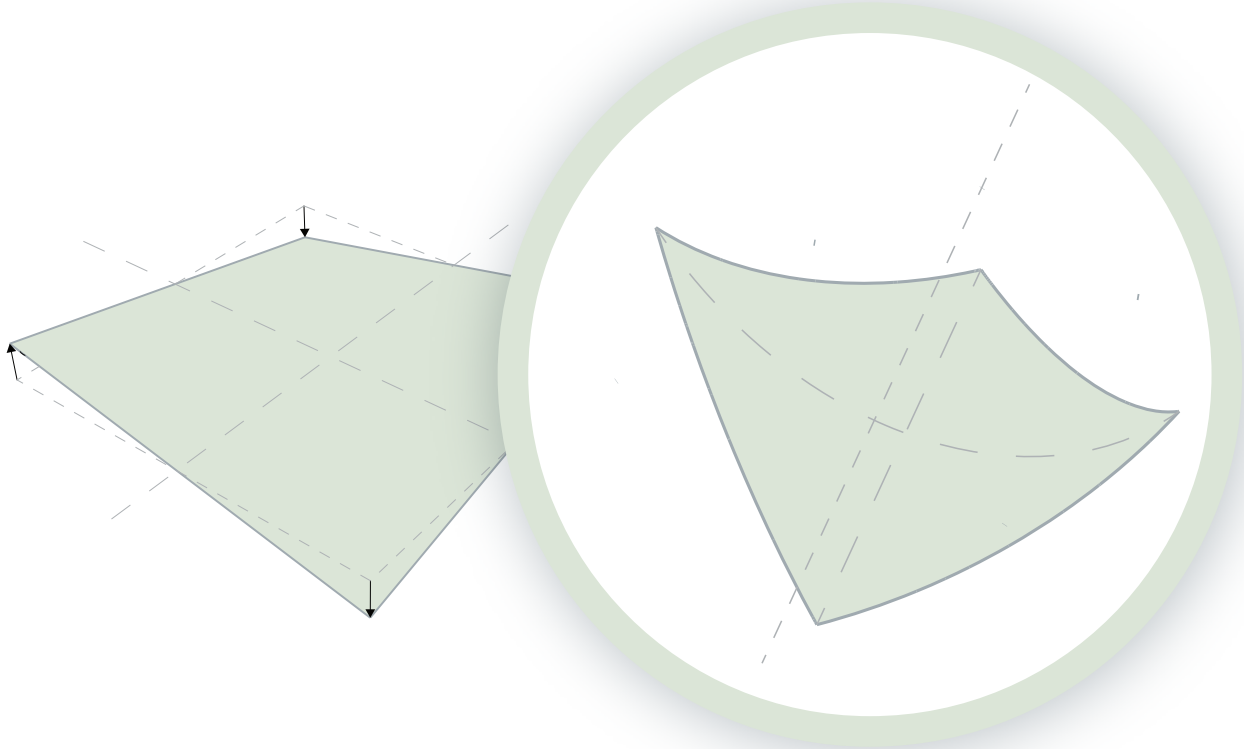
Research into anticlastic cold bent thin glass....

ANTICLASTIC COLD BENT THIN GLASS



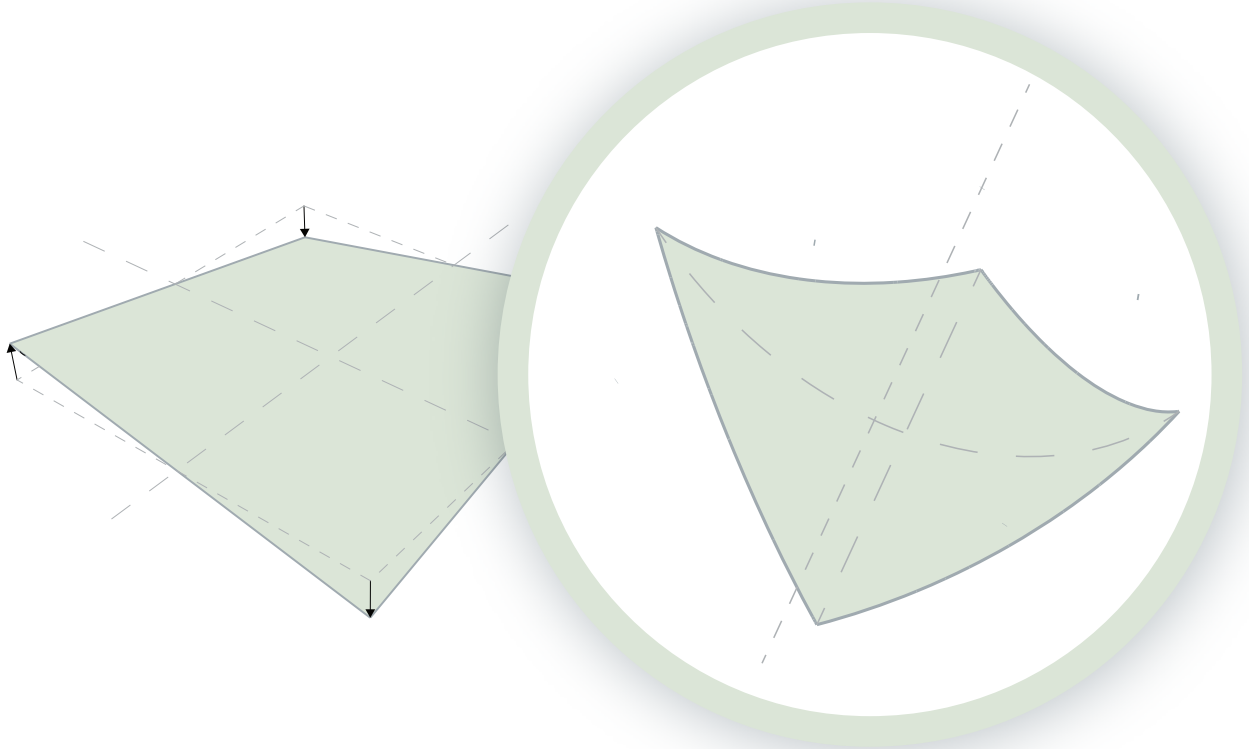
Although it is easier to bend...

DOUBLE COLD BENT THIN GLASS



Although it is easier to bend... **thin glass is more sensitive to buckling.**

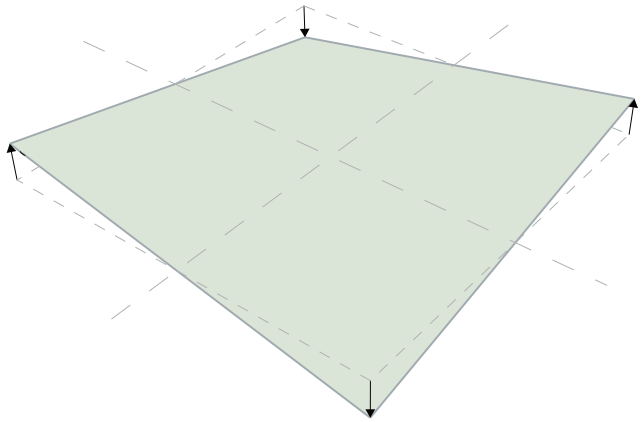
DOUBLE COLD BENT THIN GLASS



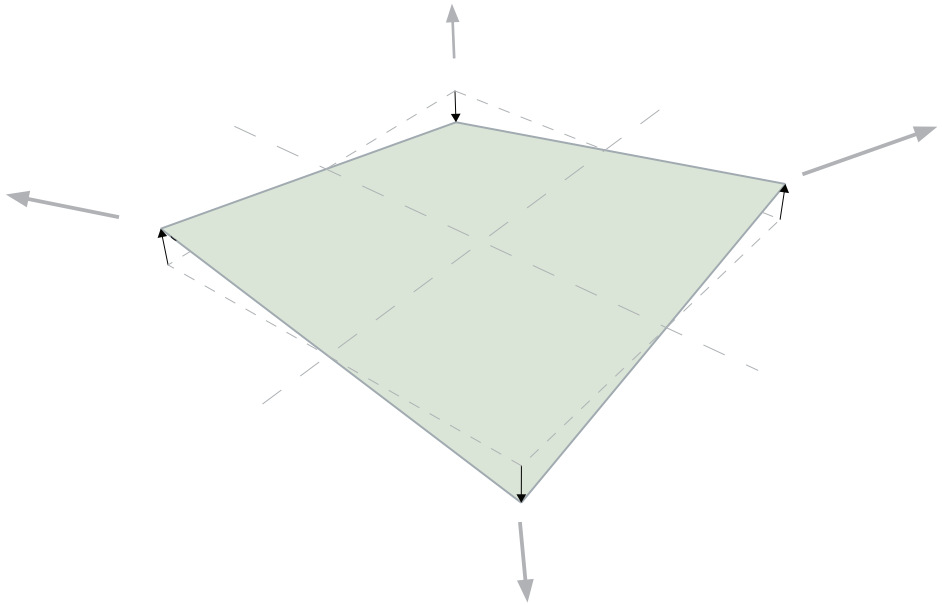
Although it is easier to bend... **thin glass is more sensitive to buckling.**

Because of lack of sustain any compressive normal forces: ***membrane behaviour****.*
Thin glass probably never have the chance to come in a ***metastable configuration****.*

BASED ON THE **HIGH STRENGTH & MEMBRANE BEHAVIOUR**...

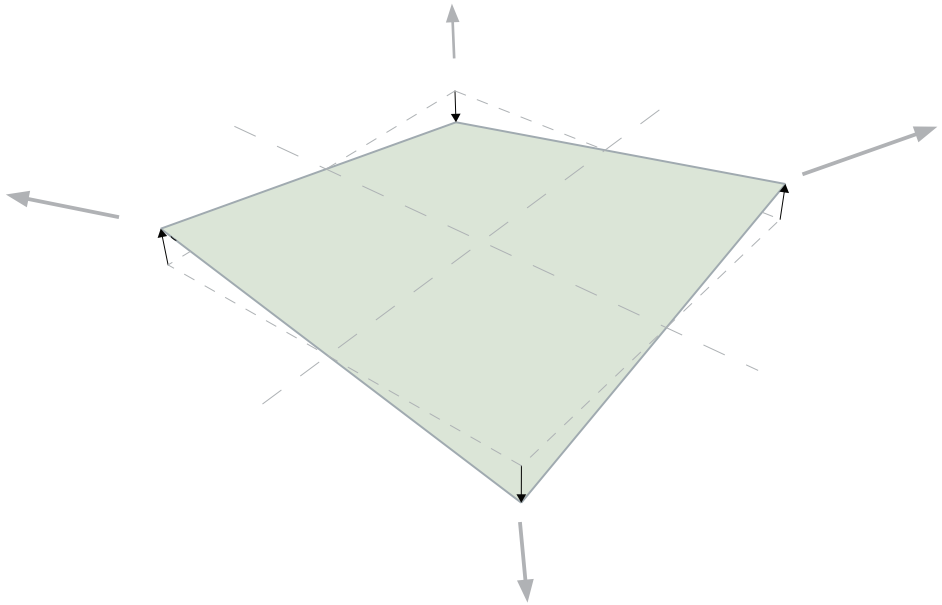


BASED ON THE **HIGH TENSILE STRENGTH & MEMBRANE BEHAVIOUR**...

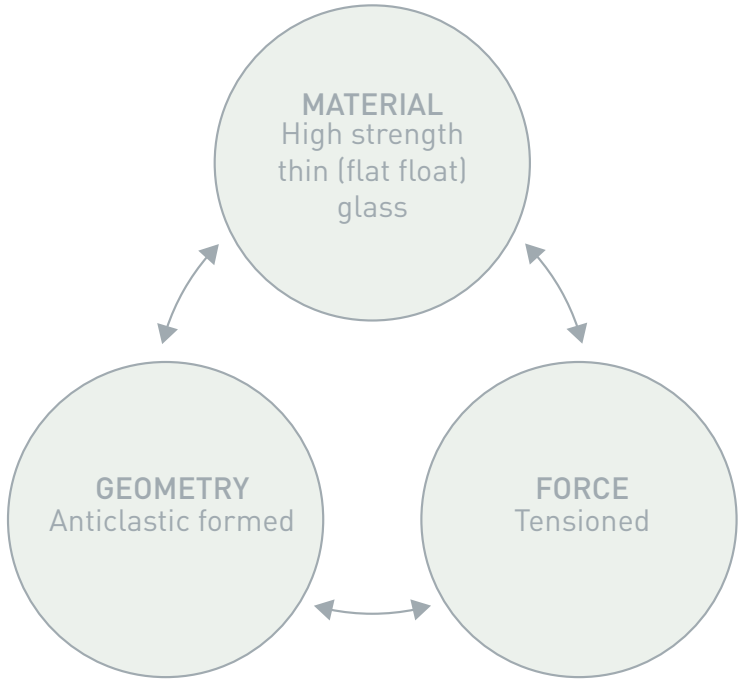


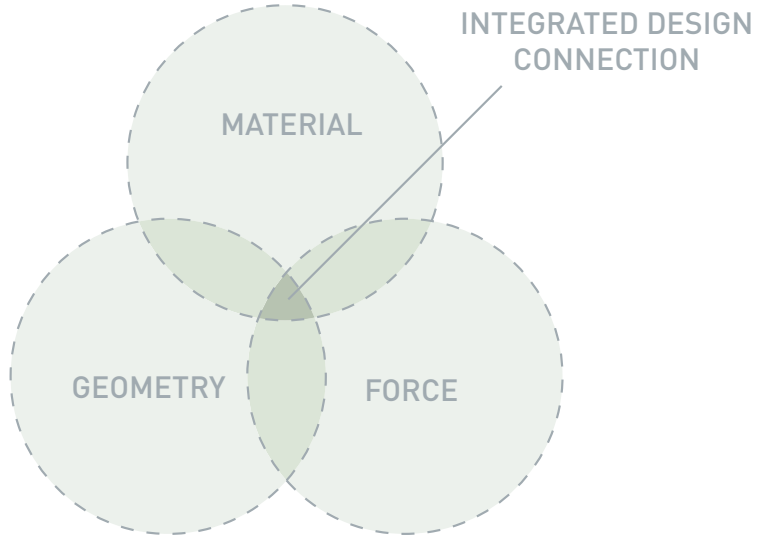
INDUCE THE TWISTING BY APPLYING (IN-PLANE) TENSION LOAD

"TO WHAT EXTENT IS IT POSSIBLE TO CURVE A FLAT SHEET OF THIN GLASS INTO A DOUBLE ANTICLASTIC BENT SURFACE BY ADDING TENSION TO THE CURRENTLY USED COLD TWISTING TECHNIQUE?"

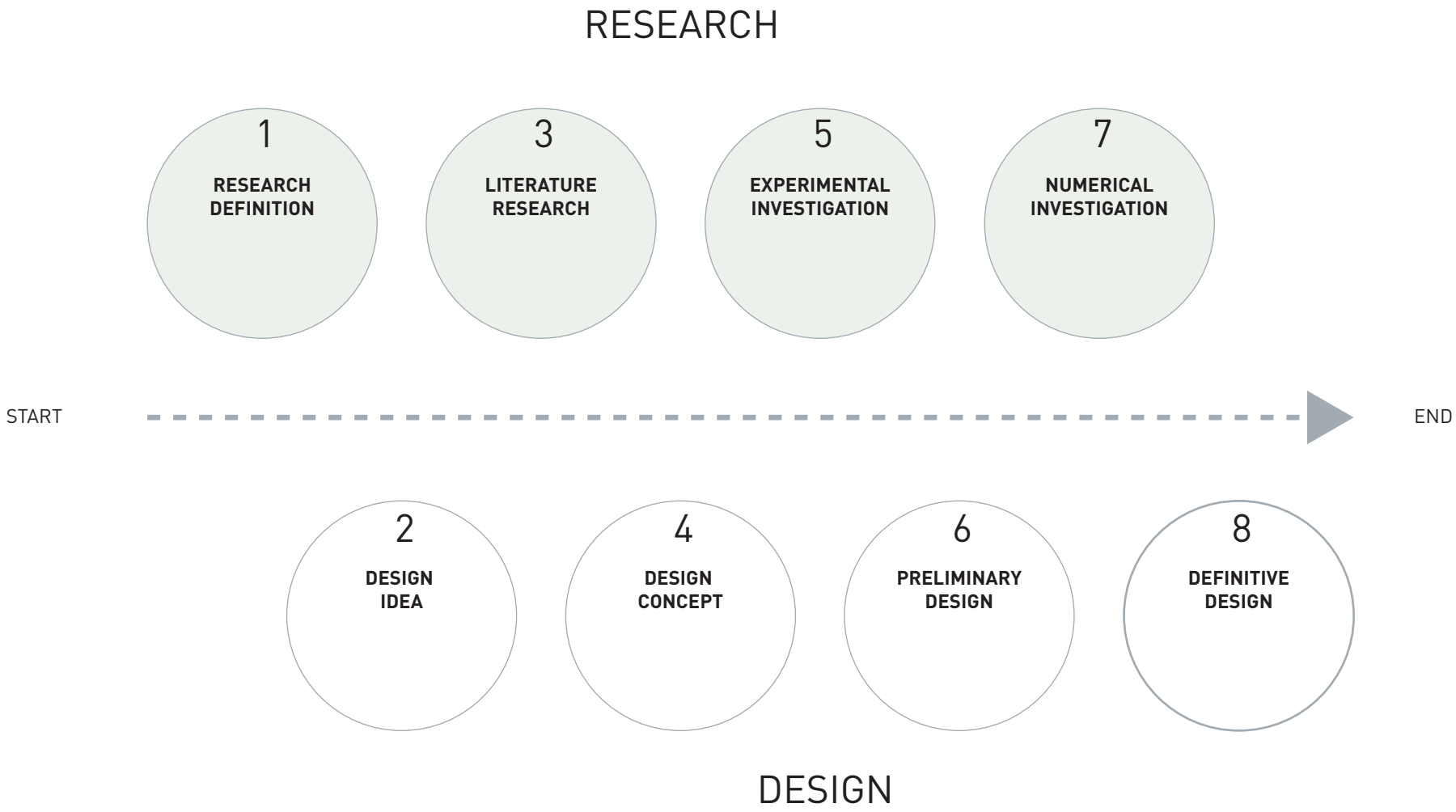


FROM **DESIGN IDEA** TO **DEFINITIVE DESIGN**

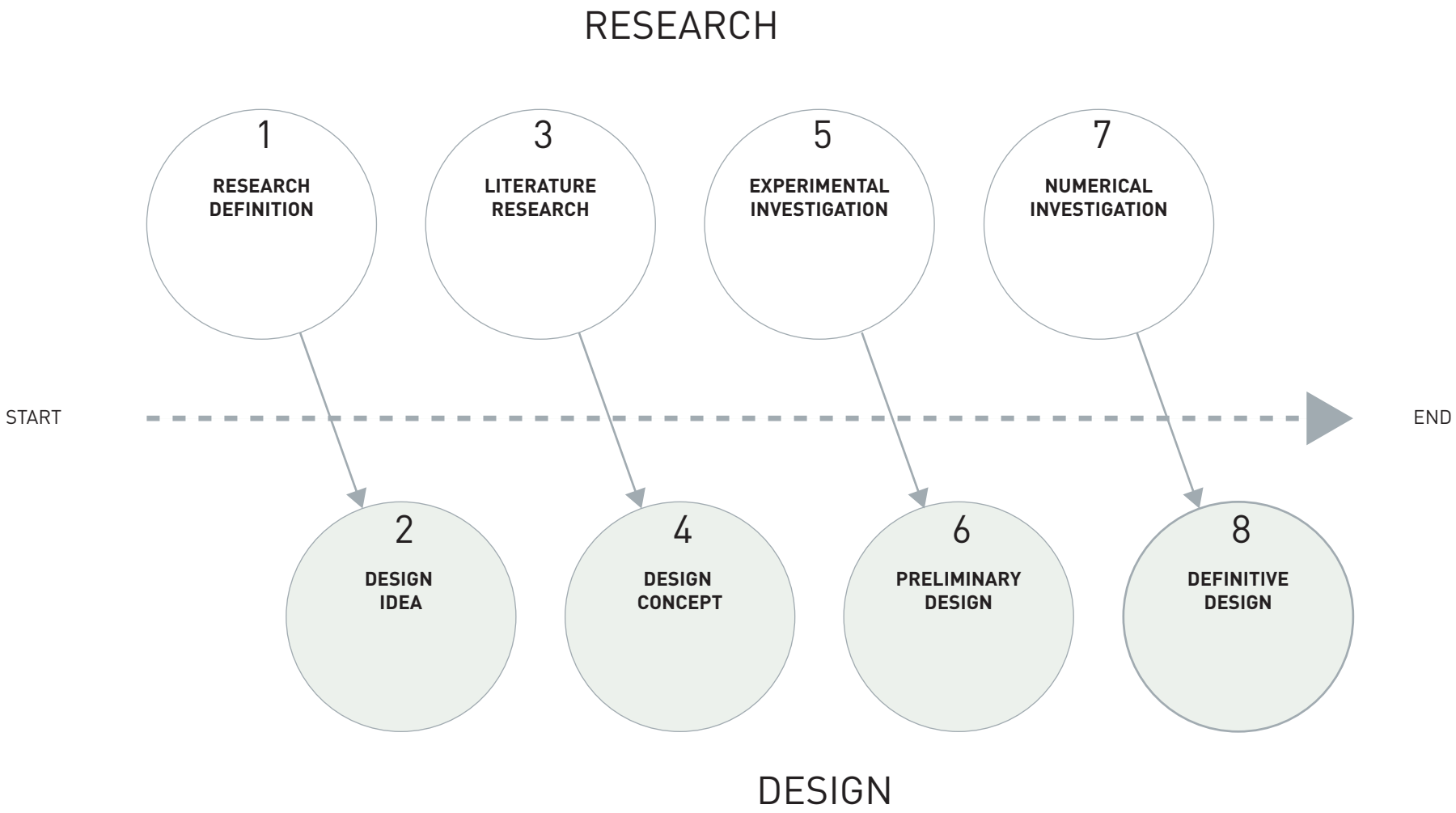


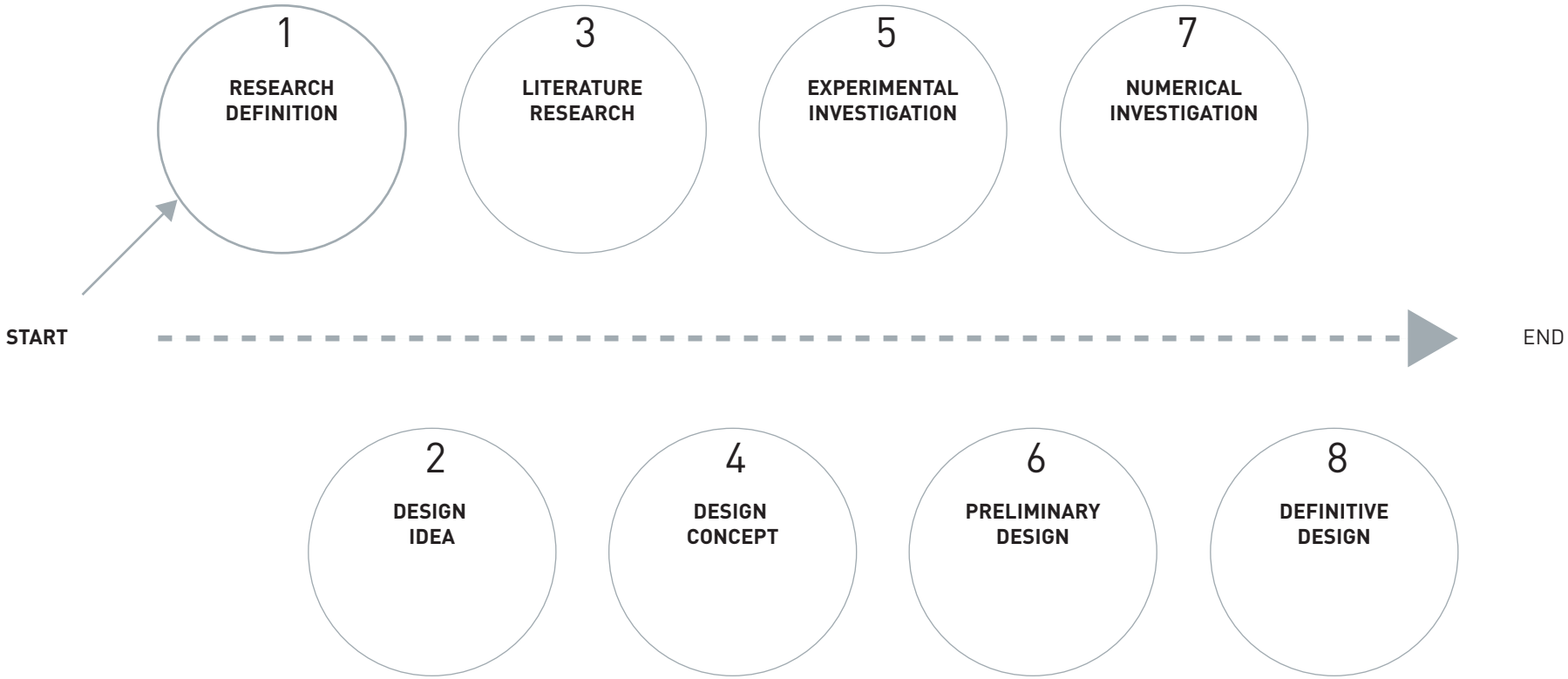


DESIGN BY **RESEARCH**



DESIGN BY **RESEARCH**

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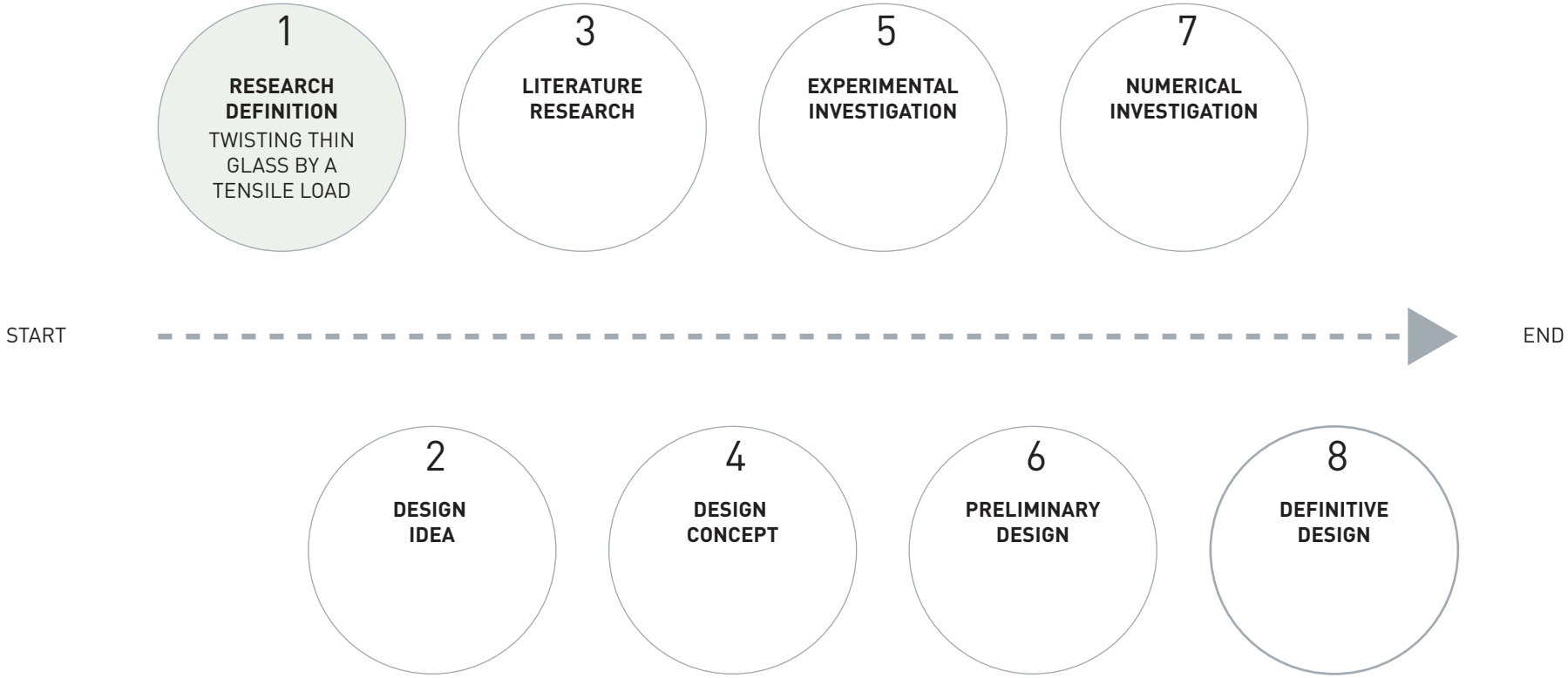
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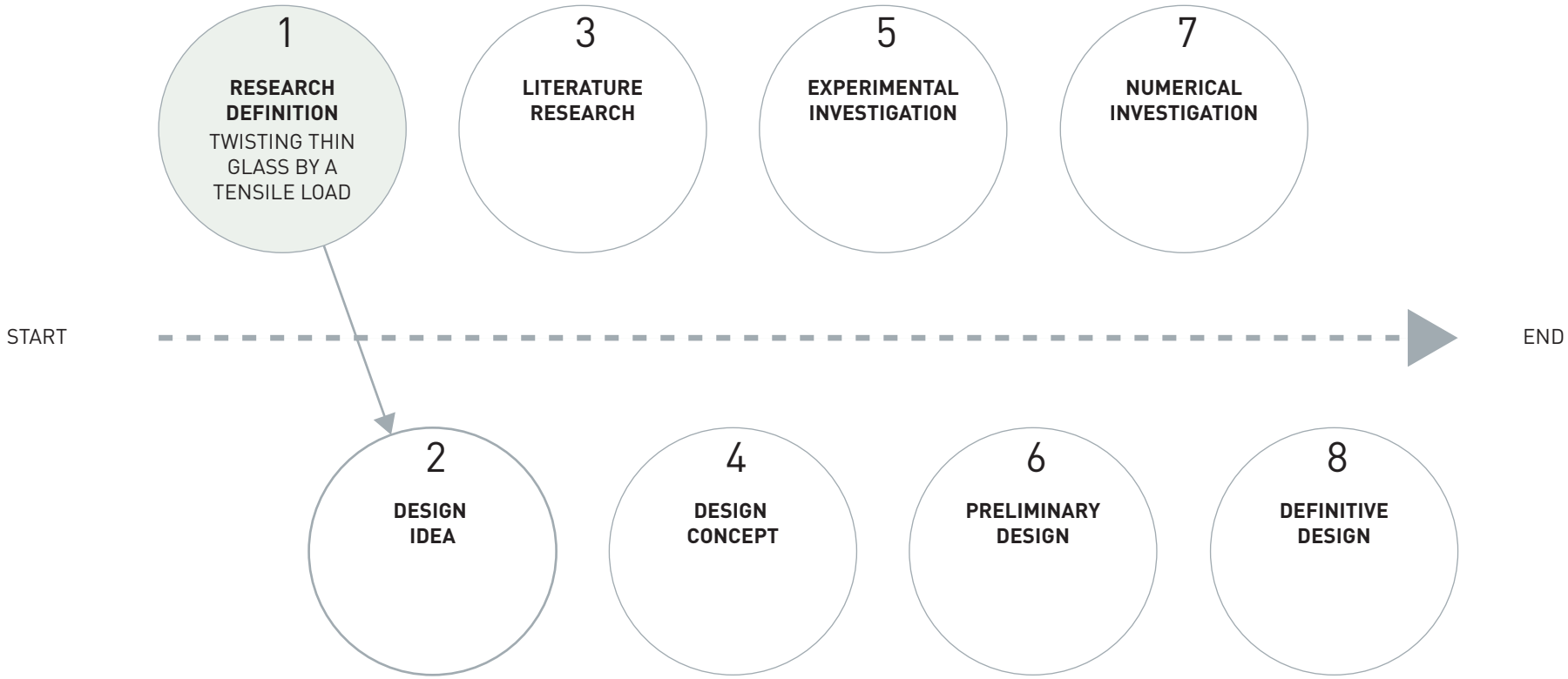
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DESIGN IDEA

Four point fabric structure
design by Frei Otto
Kassel, 1955

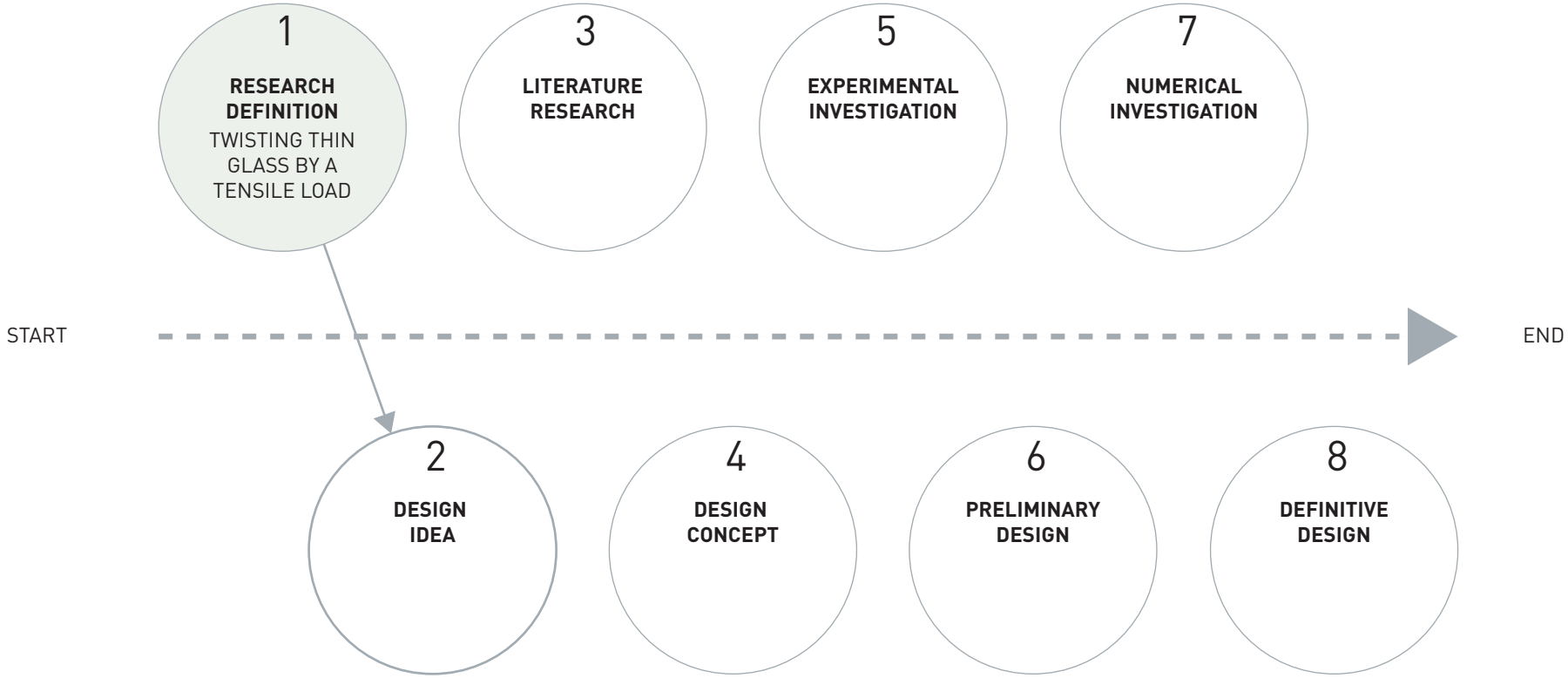
Curved glass
demonstrated by Carlyn Simoen
Delft, 2016

IMAGINE TENT STRUCTURES **BUILT OUT OF GLASS**

Four point fabric structure
design by Frei Otto
Kassel, 1955

Curved glass
demonstrated by Carlyn Simoen
Delft, 2016

IMAGINE TENT STRUCTURES **BUILT OUT OF *HIGH STRENGTH THIN* GLASS**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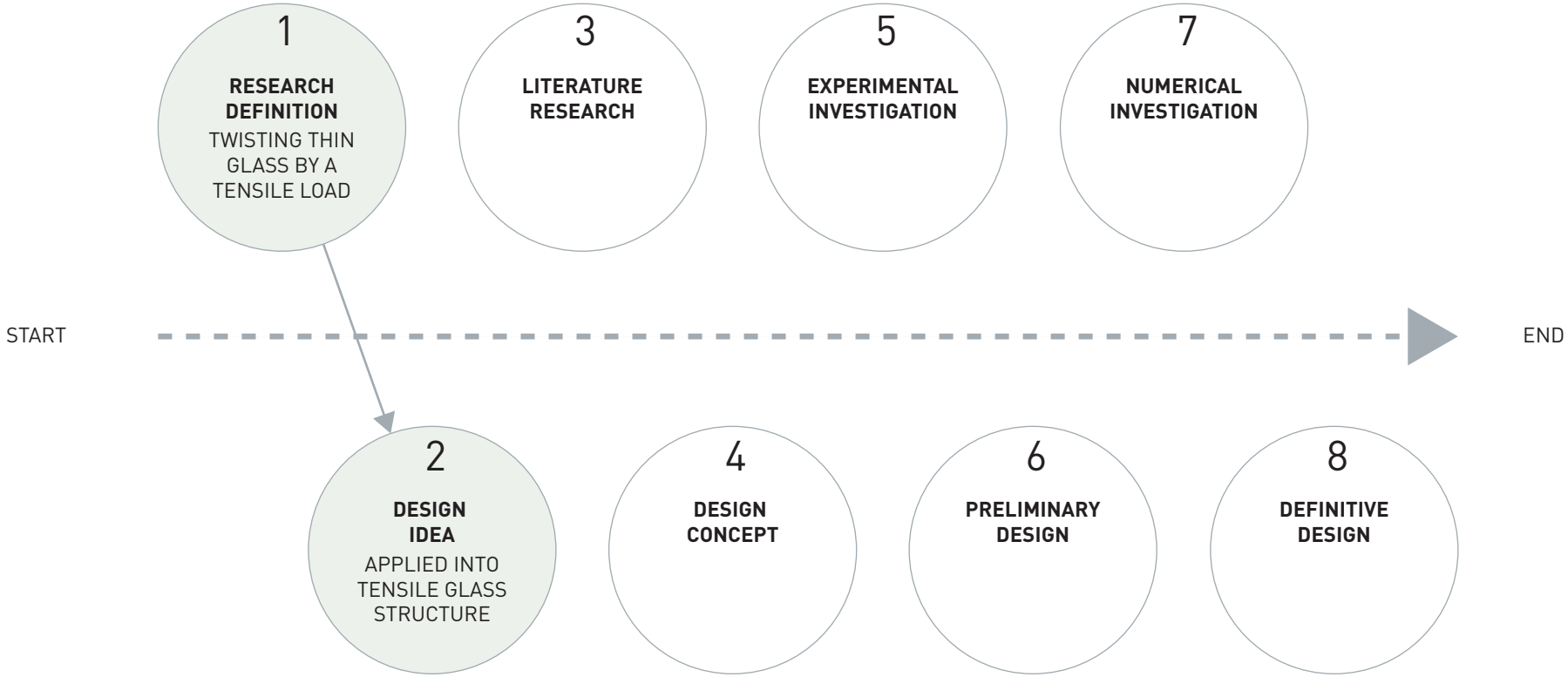
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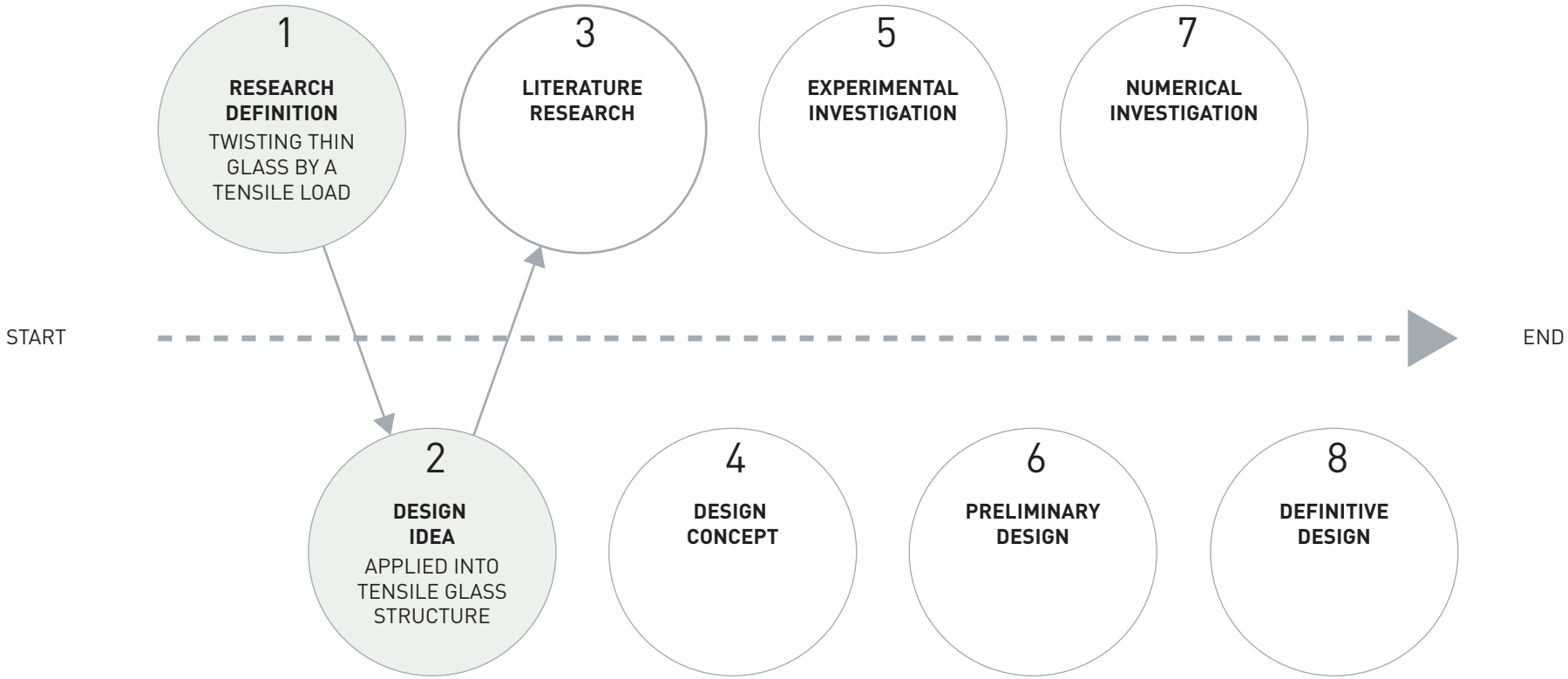
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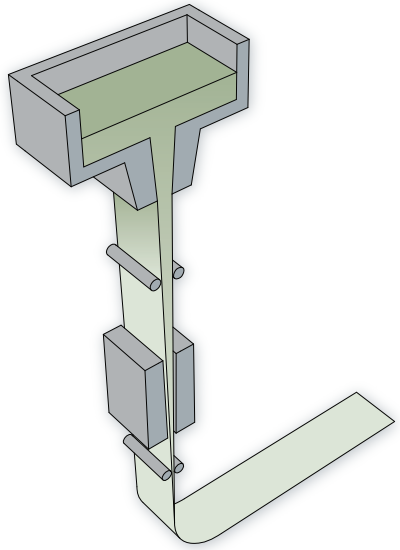
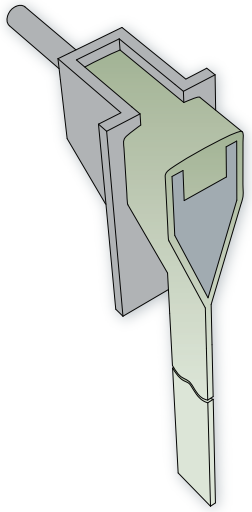
LITERATURE RESEARCH

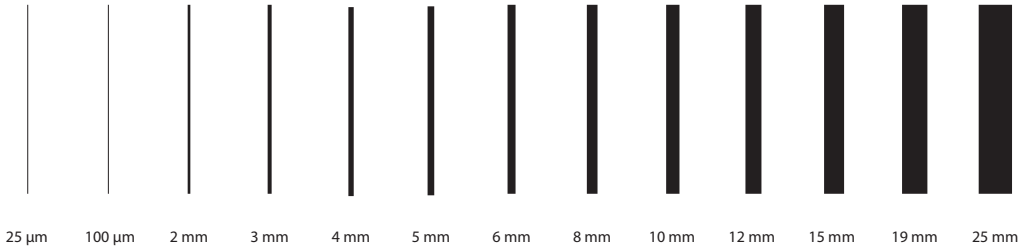
VERTICAL PRODUCTION PROCESS FLAT GLASS



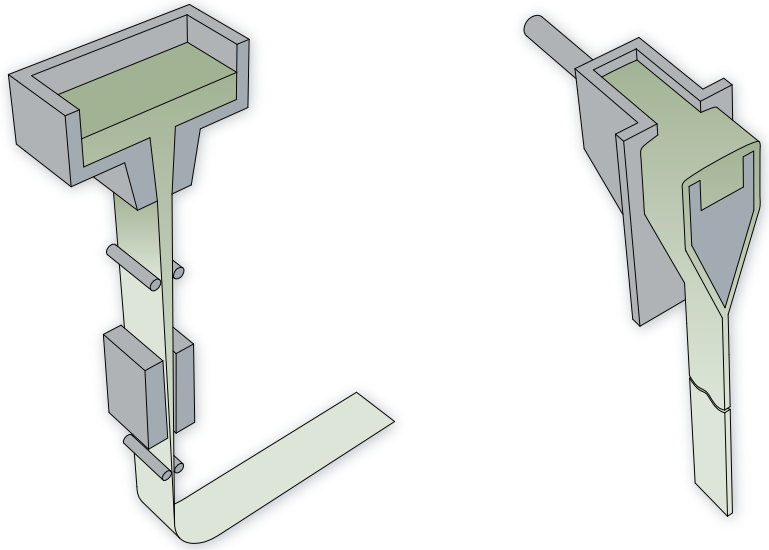
1. Down-drawn



2. Fusion overflow



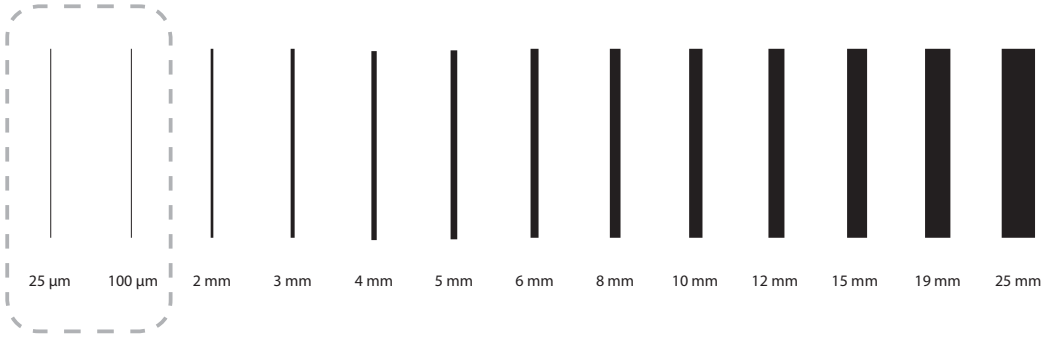
VERTICAL PRODUCTION PROCESS ***(ULTRA-) THIN*** FLAT GLASS



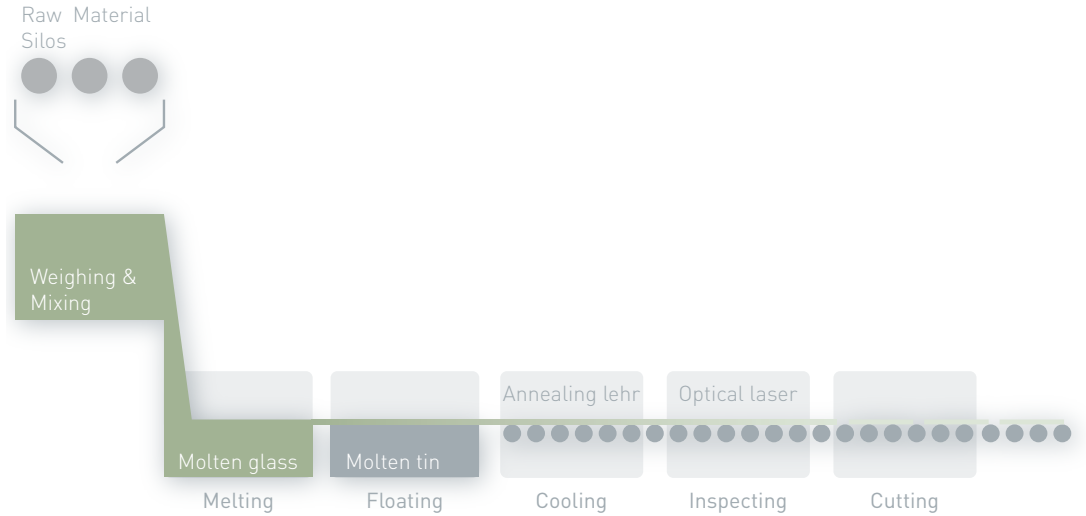
1. Down-drawn

2. Fusion overflow

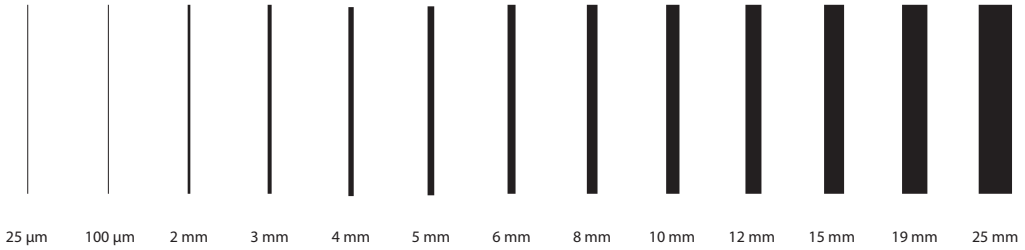
Ultra-thin glass



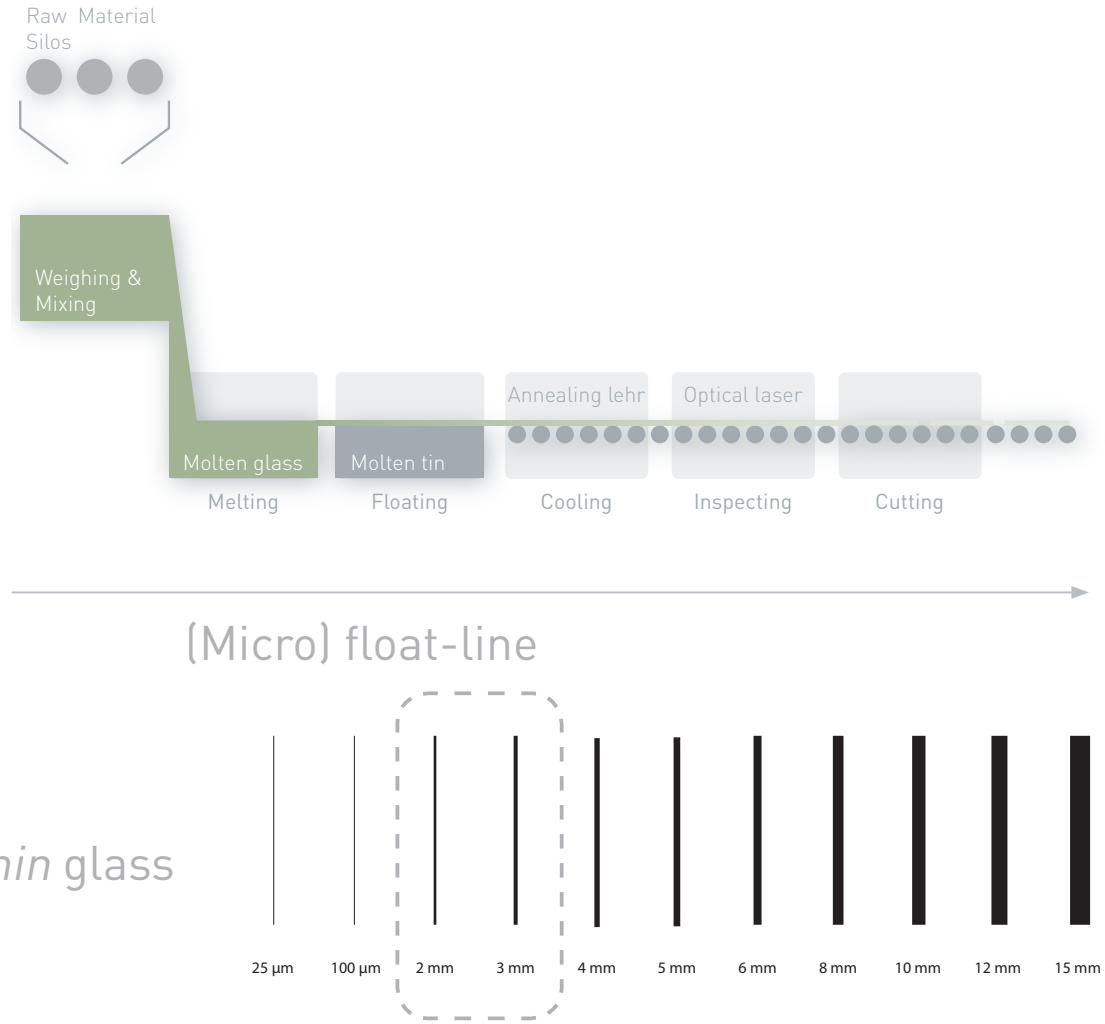
HORIZONTAL PRODUCTION PROCESS FLAT GLASS



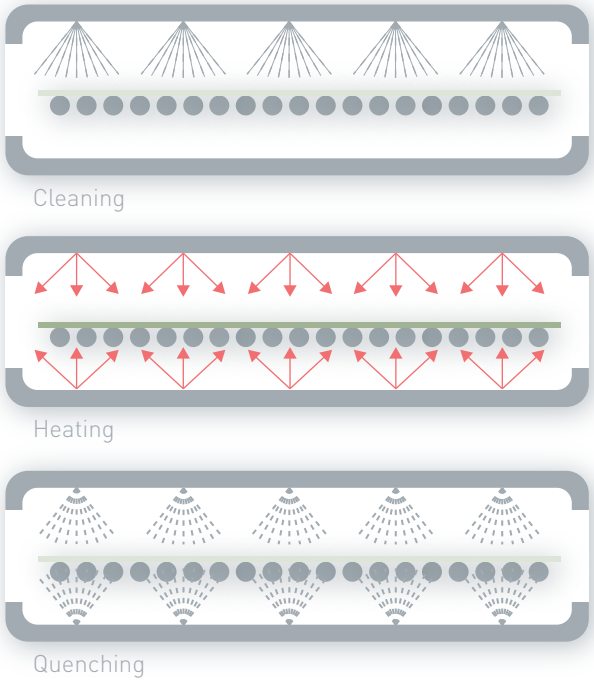
(Micro) float-line



HORIZONTAL PRODUCTION PROCESS ***THIN*** FLAT GLASS



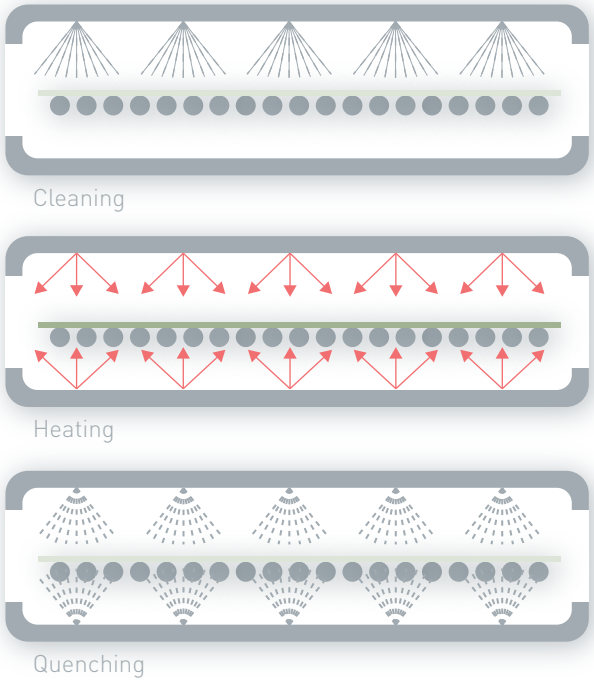
THERMAL TEMPERING



In an oven

by temperature

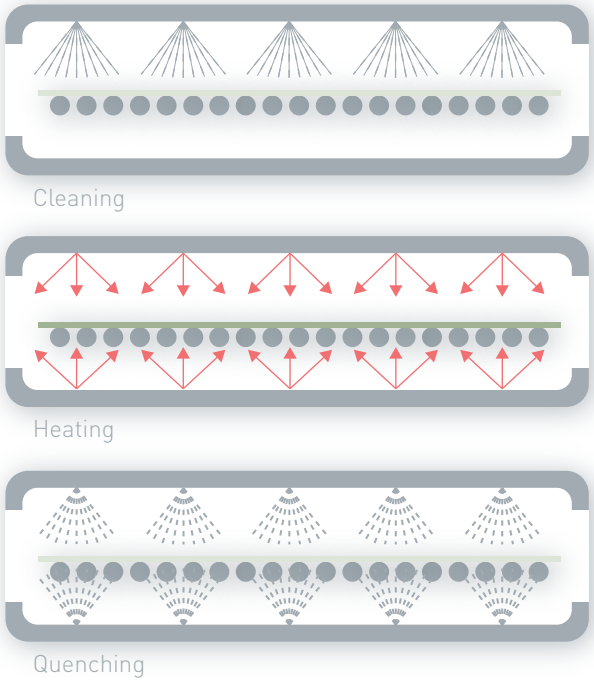
THERMAL TEMPERING **VS.** **CHEMICAL** STRENGTHENING



In an oven
by temperature

In a salt bath
by ion-exchange

THERMAL TEMPERING



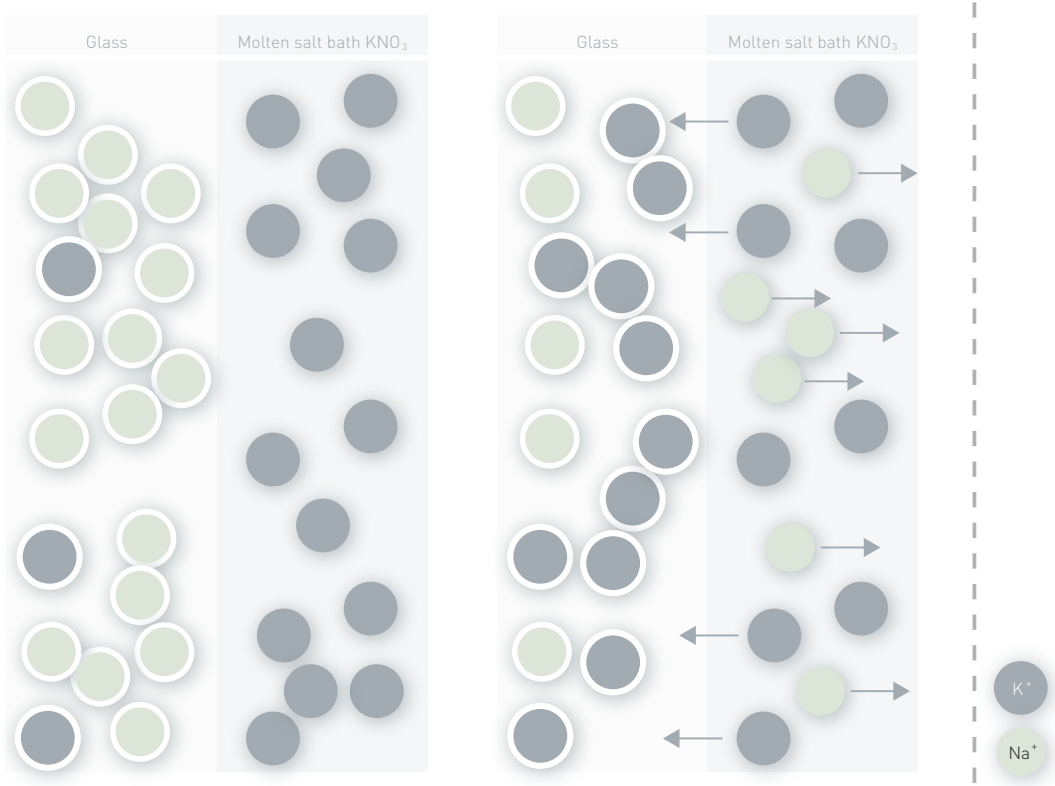
In an oven

by temperature

thickness limited to 2.8mm
size is limited to 3m x 6m

VS.

CHEMICAL STRENGTHENING



In a salt bath

by ion-exchange

thickness not limited
size is limited to 1.5m x 1.5m

Thin glass is designated to

CHEMICAL STRENGTHENING

In a salt bath

by ion-exchange

thickness not limited

size is limited to 1.5m 1.5m

Chemical strengthening method is

8X

tougher

than thermal tempering method

Prestressing method	Value in MPa [N/mm^2]
Annealed	45
Heat-strengthened	70
Fully tempered	120
Chemically strengthened	750-1000*

HIGH STRENGTH THIN GLASS

Chemical strengthening method is

8X

tougher

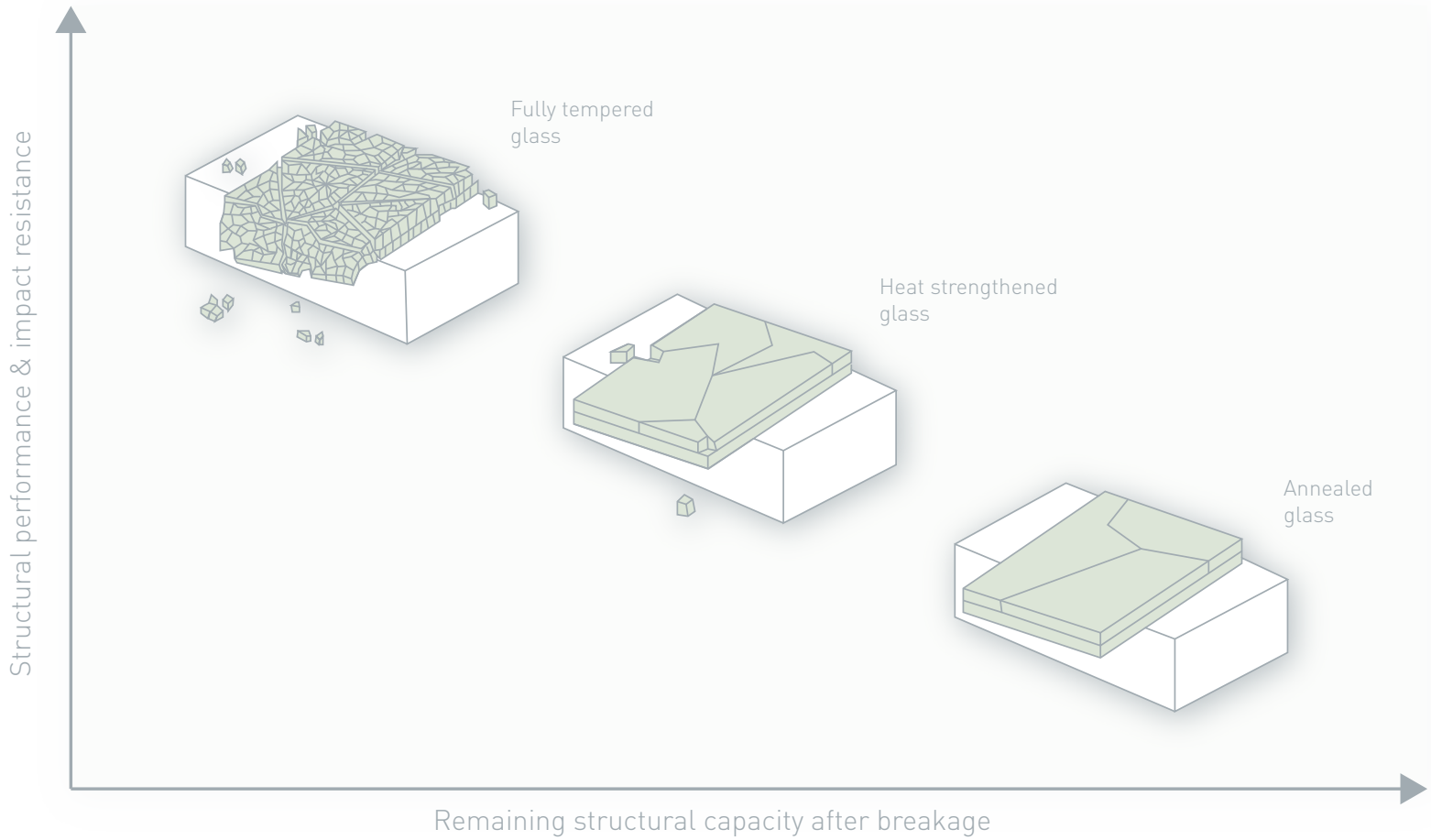
than thermal tempering method

Prestressing method	Value in MPa [N/mm^2]
Annealed	45
Heat-strengthened	70
Fully tempered	120
Chemically strengthened	750-1000*

HIGH STRENGTH THIN GLASS

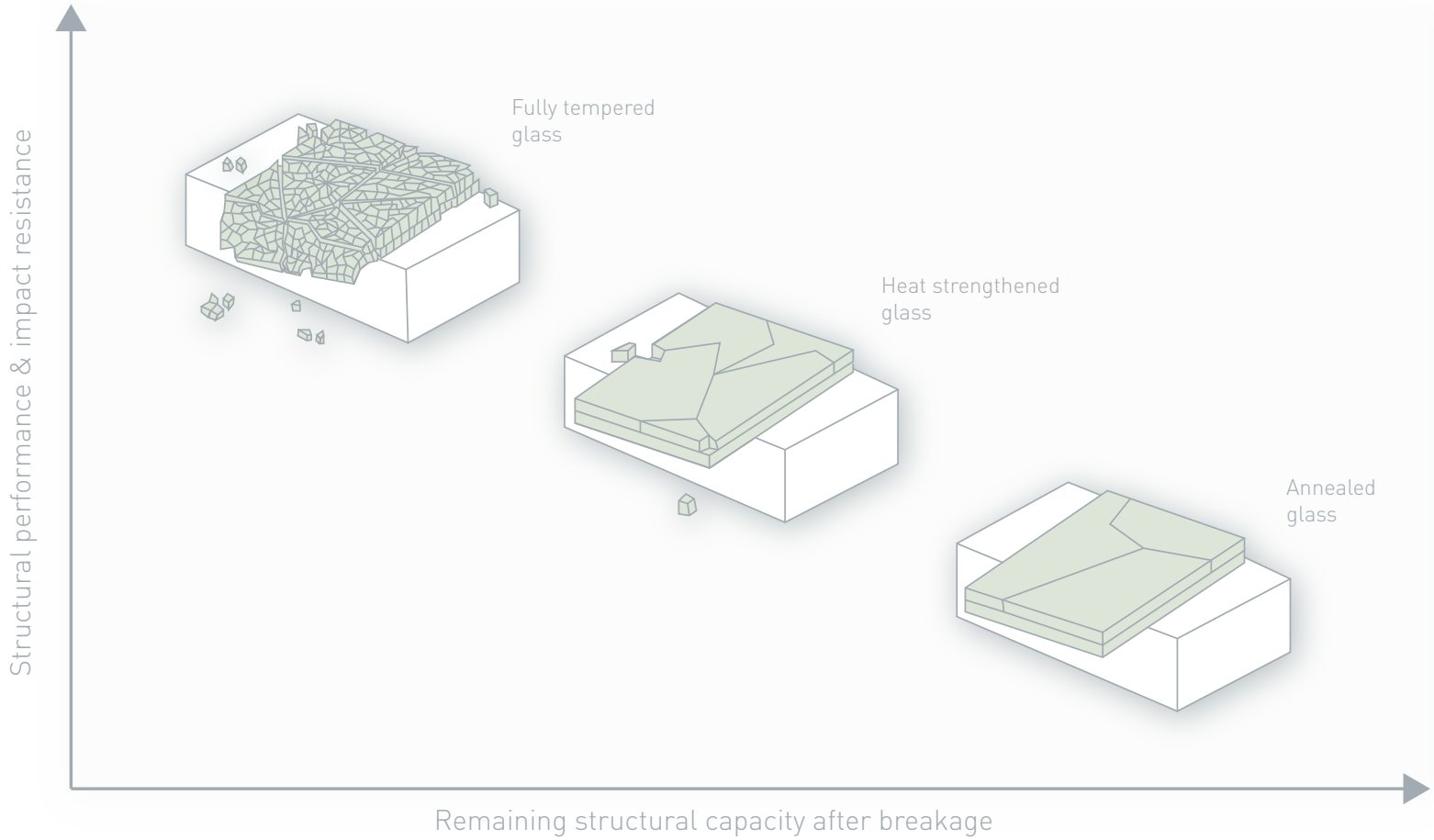
SAFE
STIFF & STABLE
STRONG

+ **SAFETY** BY *ENHANCED SAFETY MECHANISM: LAMINATION*



Breakage behaviour depends on built up elastic energy stored in the pane

WHERE CAN CHEMICALLY STRENGTHENED GLASS BE POSITIONED?



Breakage behaviour depends on built up elastic energy stored in the pane

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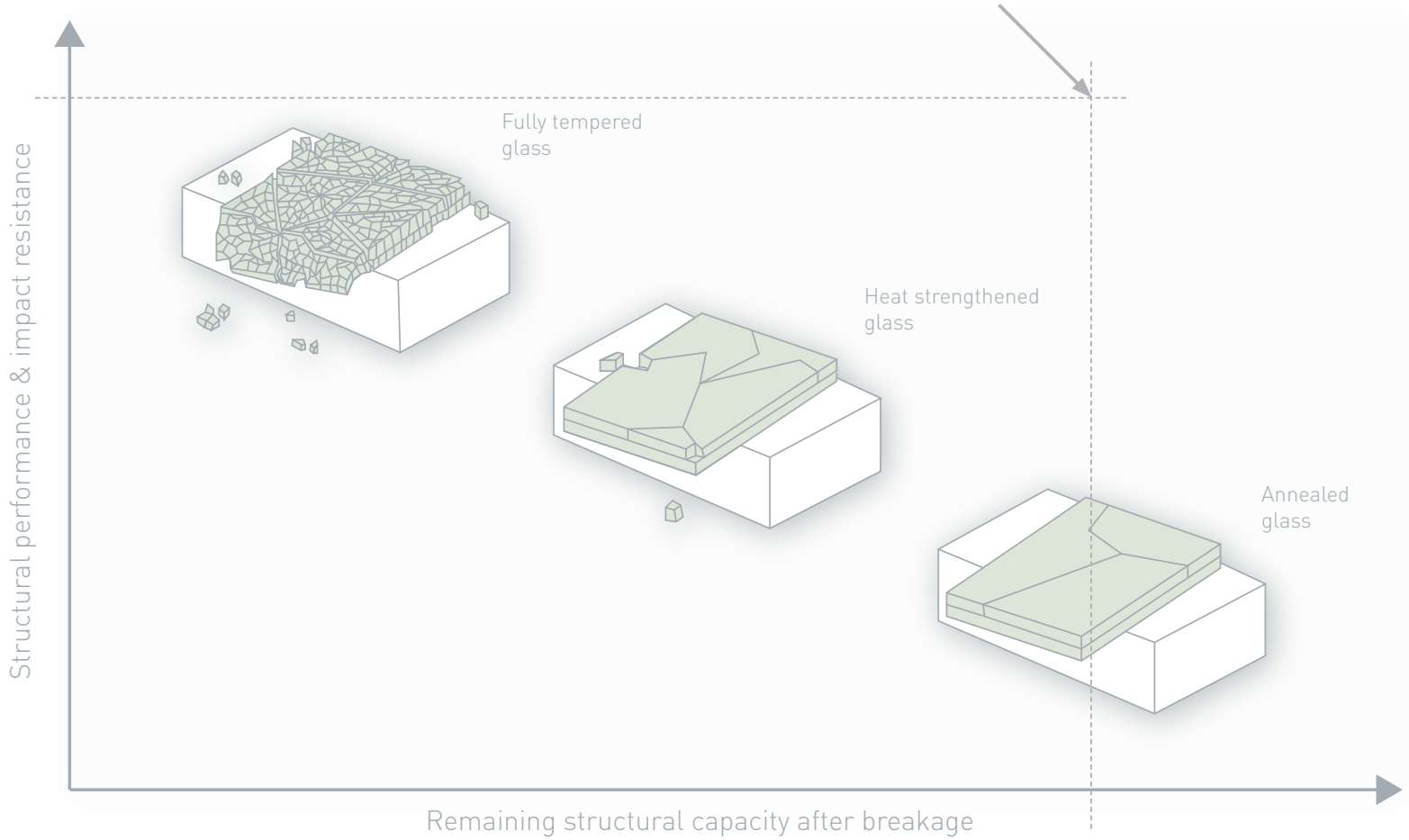
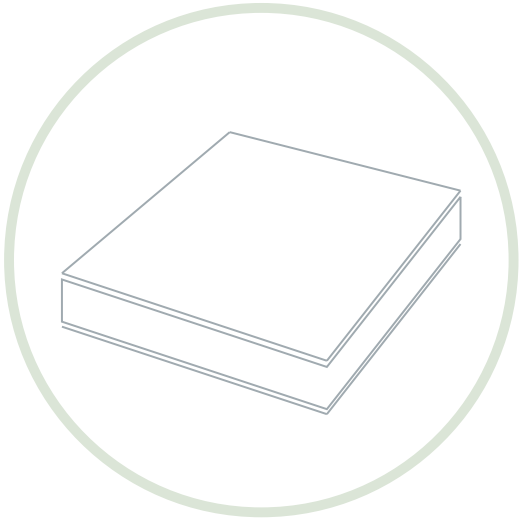
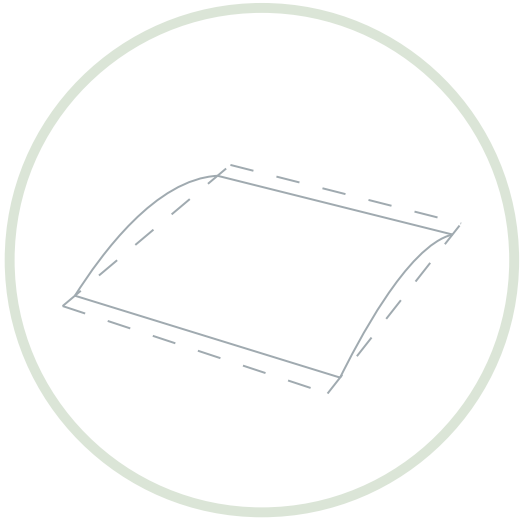


Breakage behaviour depends on built up elastic energy stored in the pane

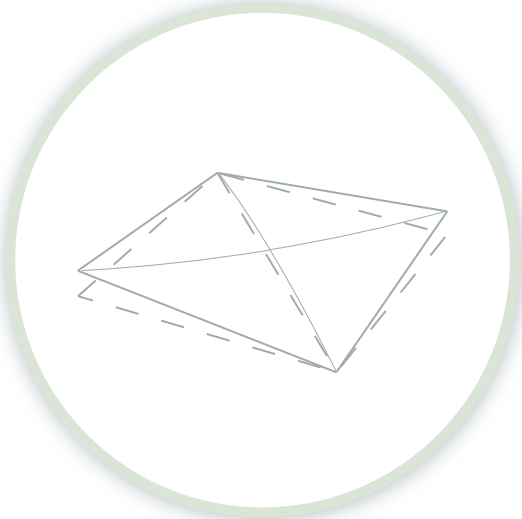
+ **STIFFNESS & STABILITY** BY *ADDING MATERIAL OR GEOMETRY*



1. Flat

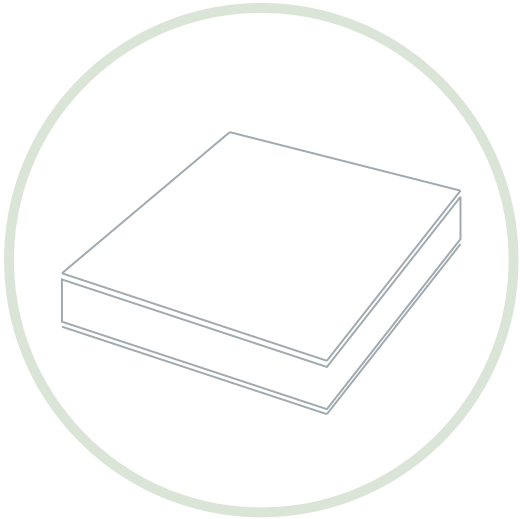


2. Single curved



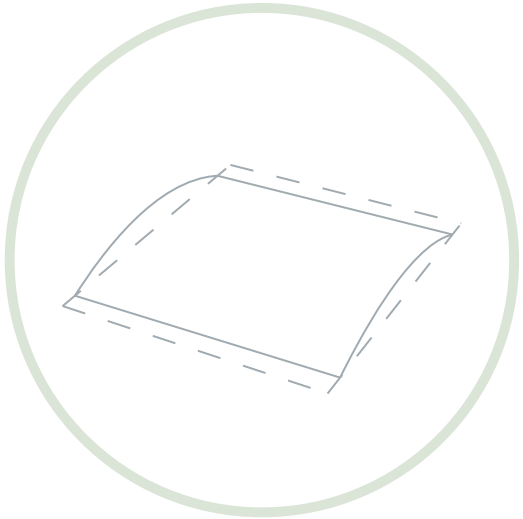
3. Double curved

+ **STIFFNESS & STABILITY** BY *ADDING MATERIAL OR GEOMETRY*



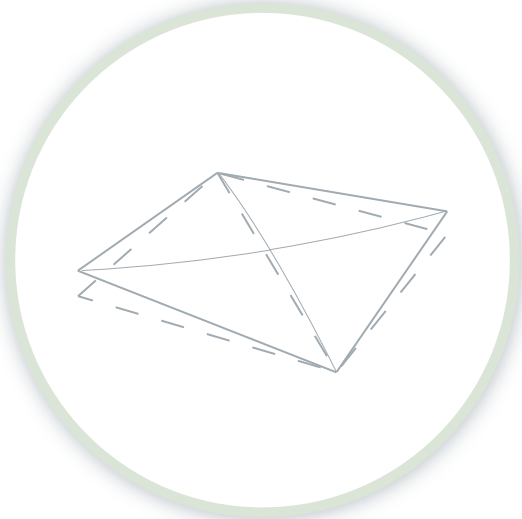
1. Flat

By adding material thickness.



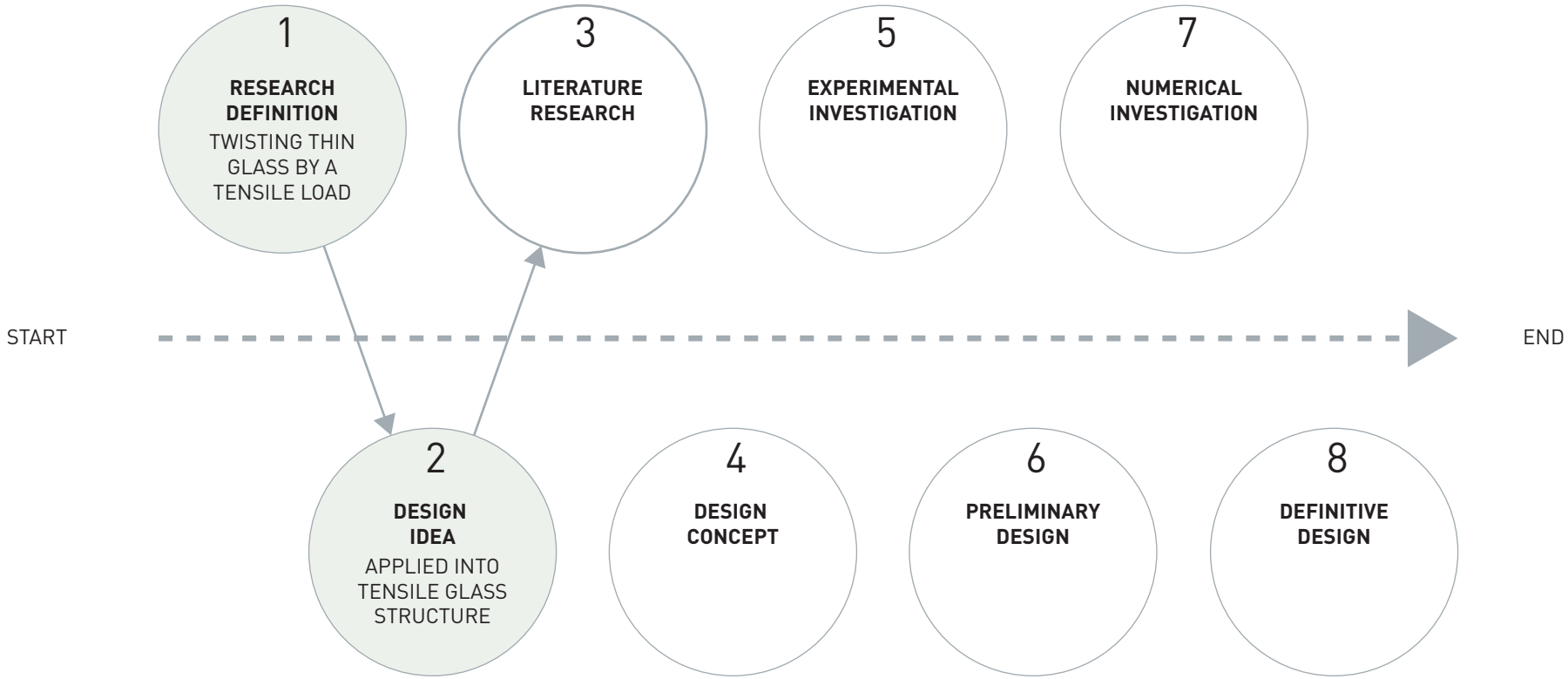
2. Single curved

Through geometrical form.



3. Double curved

Through geometrical form.


1
RESEARCH DEFINITION
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LITERATURE RESEARCH
5
EXPERIMENTAL INVESTIGATION
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NUMERICAL INVESTIGATION
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END
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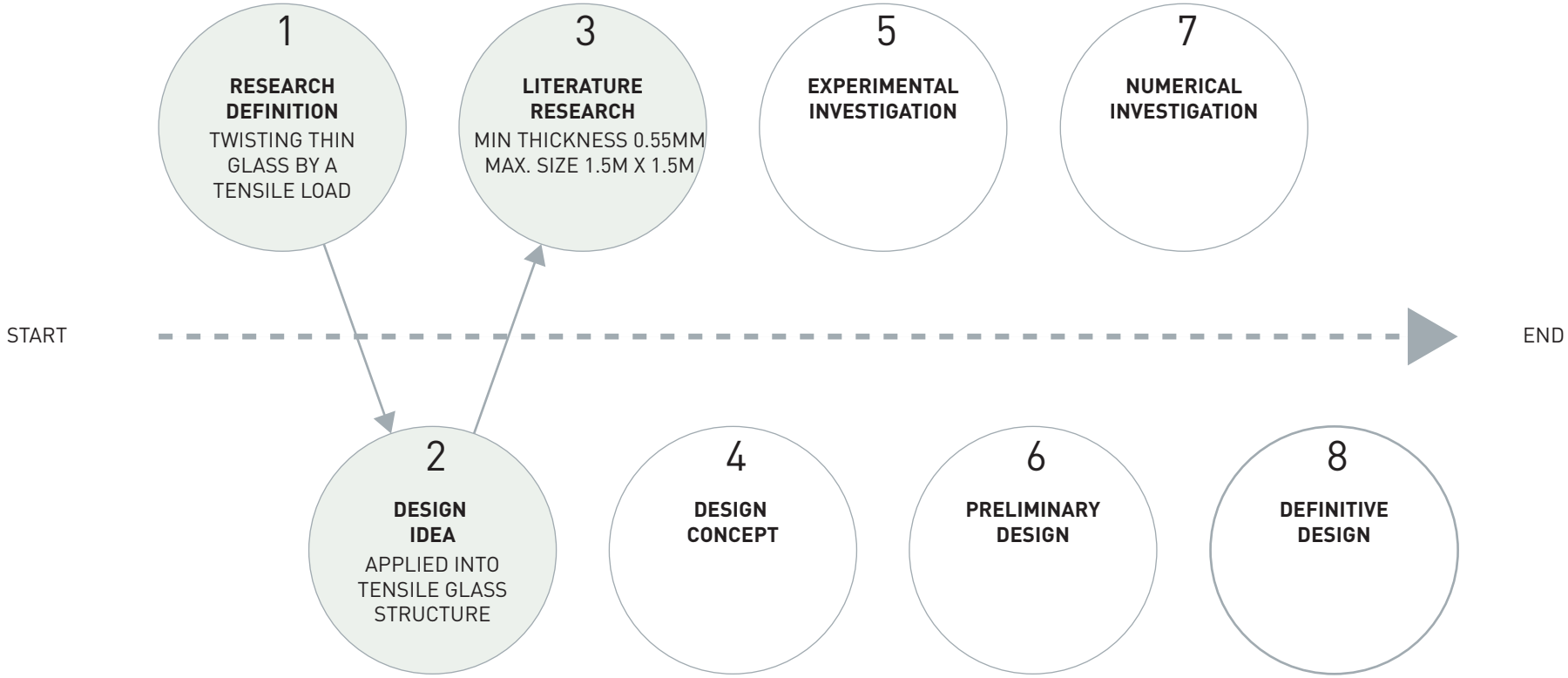
DESIGN IDEA
APPLIED INTO TENSILE GLASS STRUCTURE
4
DESIGN CONCEPT
6
PRELIMINARY DESIGN
8
DEFINITIVE DESIGN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RESEARCH DEFINITION
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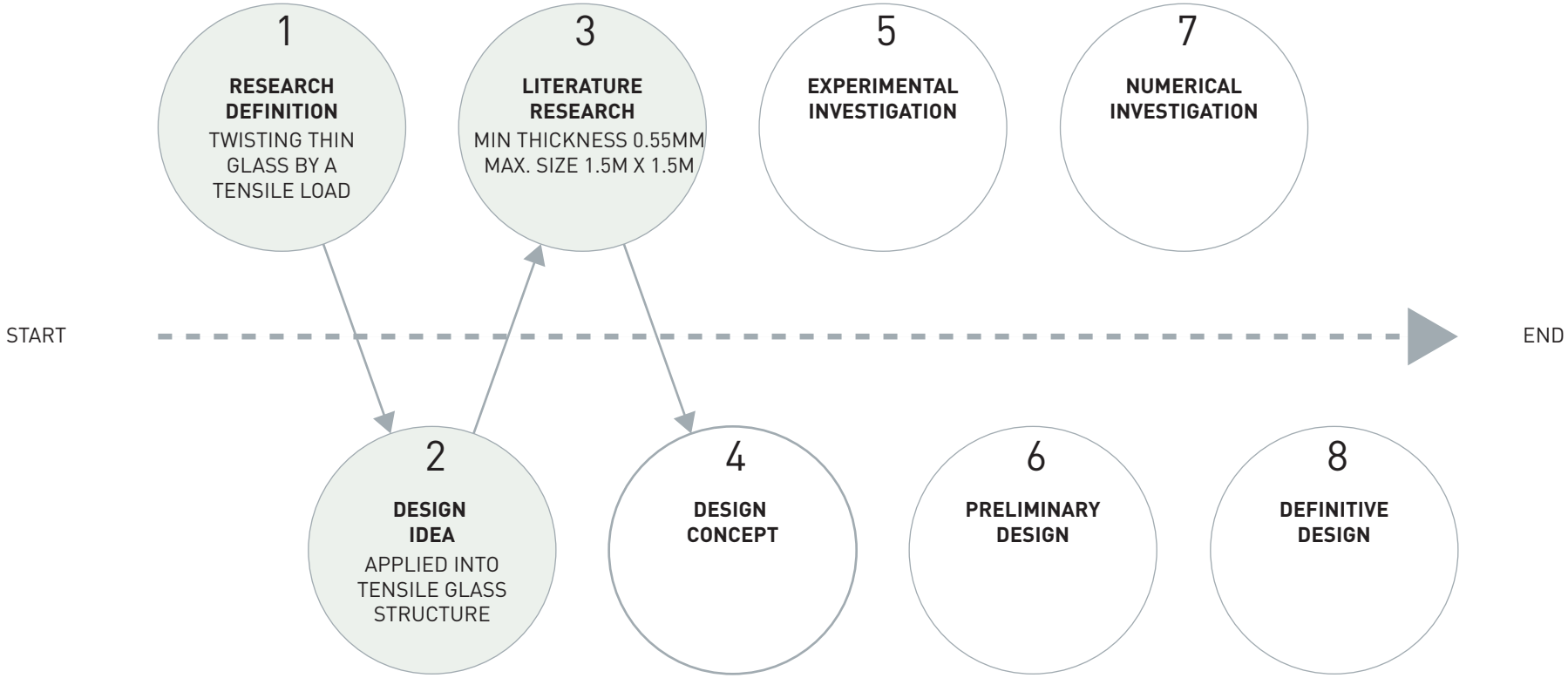
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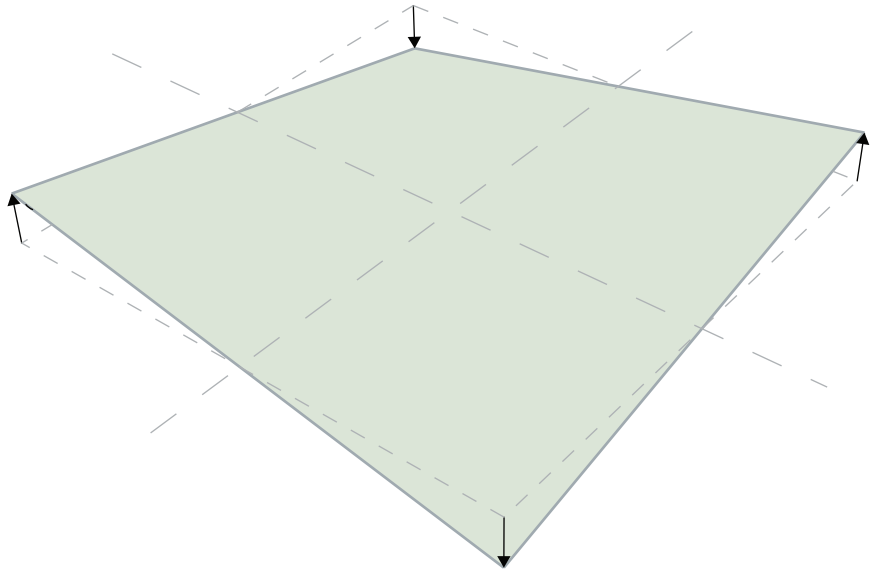
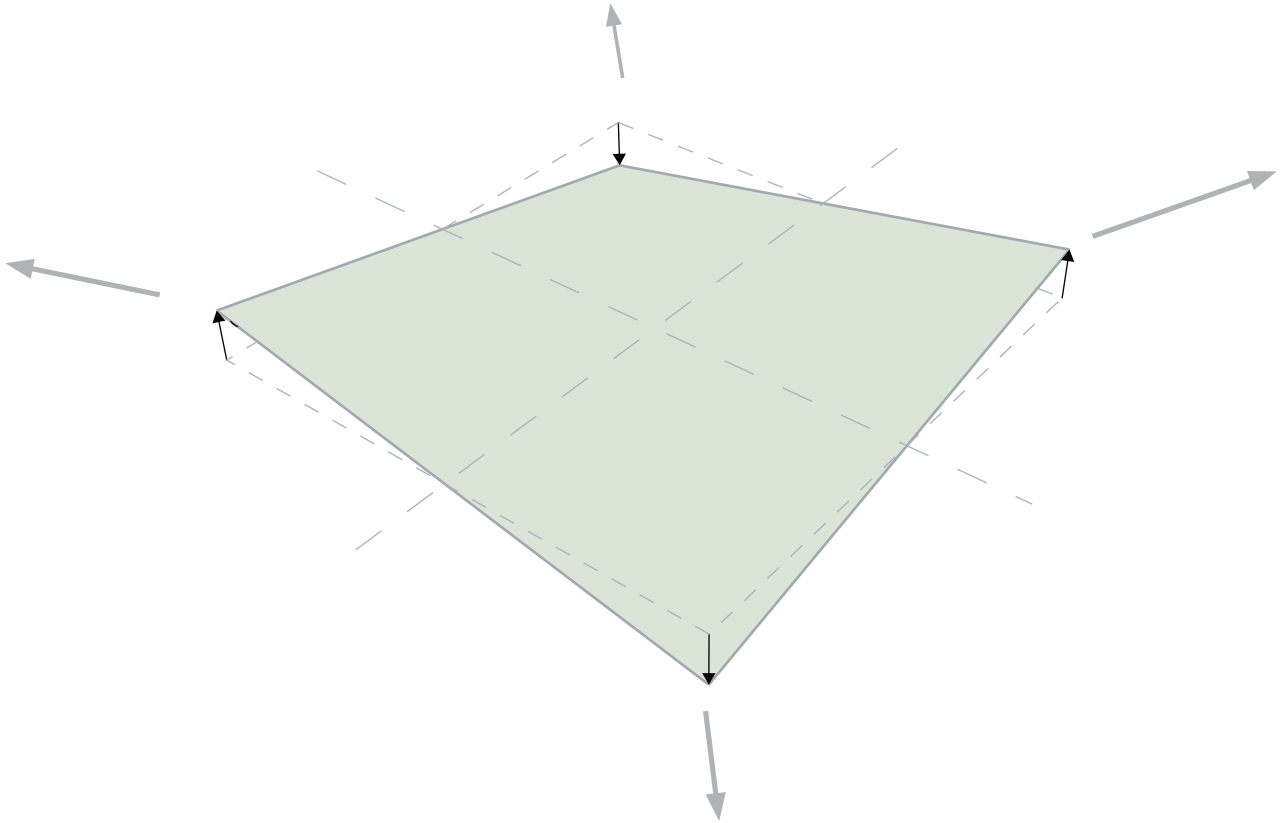
DESIGN CONCEPT

CONVENTIONAL TECHNOLOGY TO CREATE AN ANTICLASTIC SURFACE



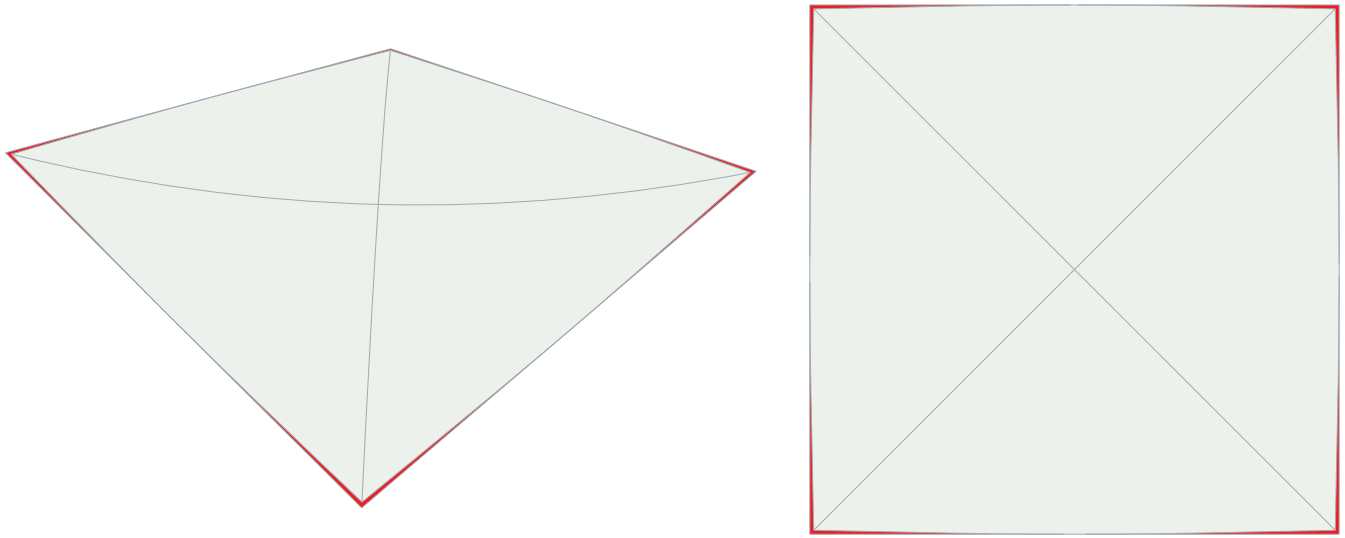
Based on the idea that the pane can **resist COMPRESSION**, and a **little TENSION**

NEW TECHNIQUE TO CREATE AN ANTICLASTIC SURFACE

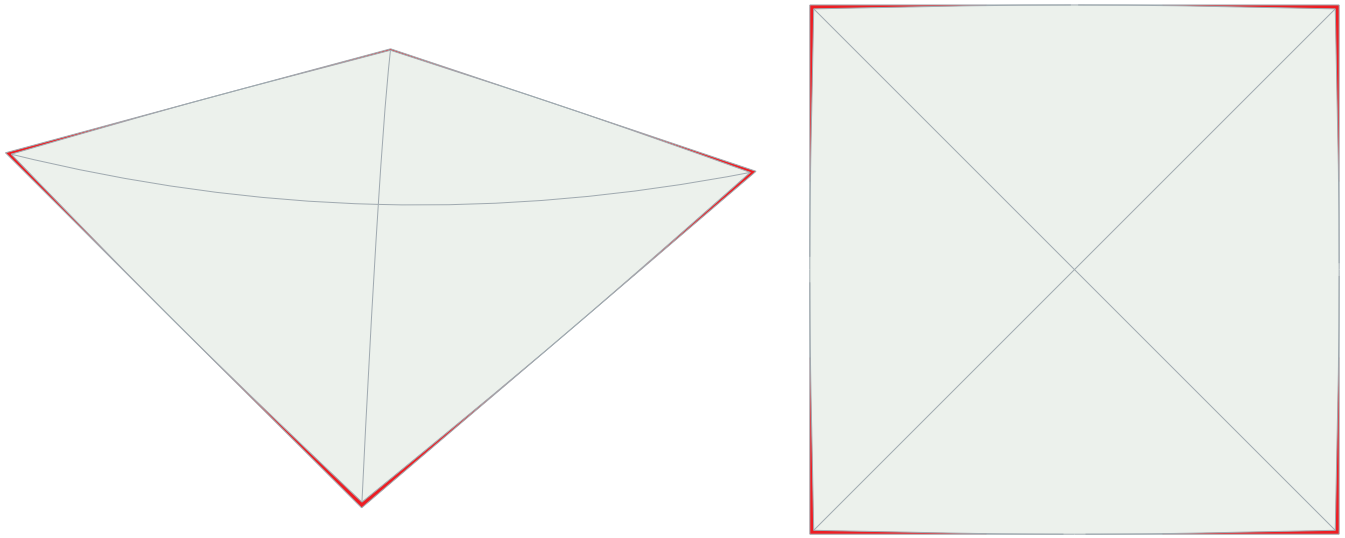


Based on the idea that the pane can **resist *TENSION***, and a **little *COMPRESSION***

CREATED GEOMETRY MAKES IT CHALLENGING *FOR A SUFFICIENT CONNECTION*

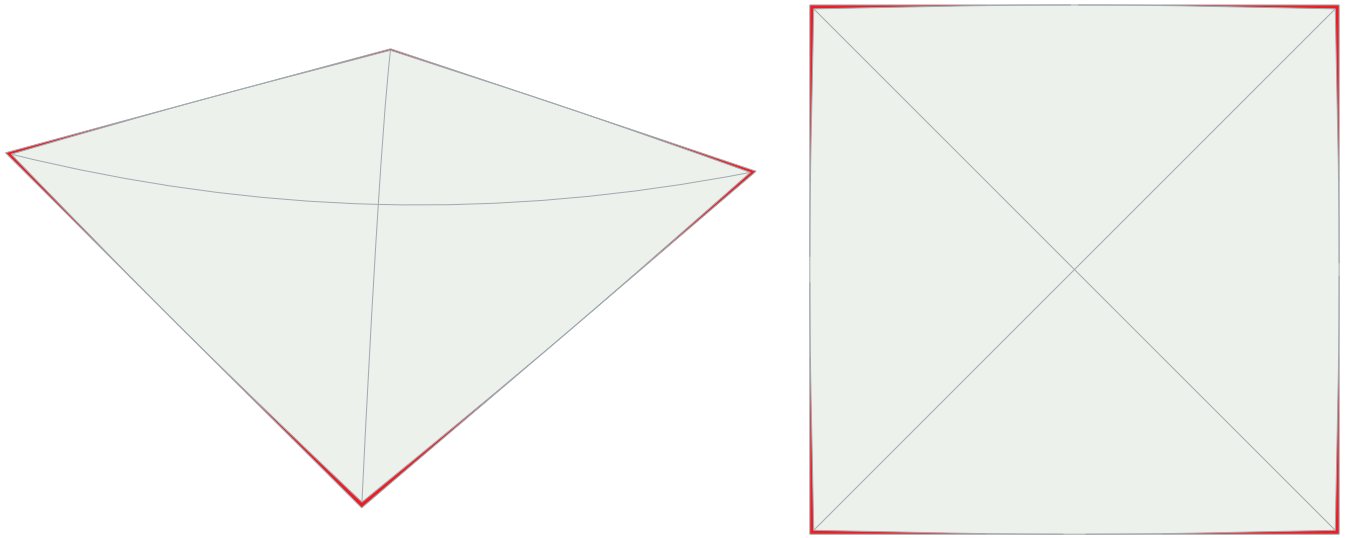


CREATED GEOMETRY MAKES IT DIFFICULT *FOR A SUFFICIENT CONNECTION*



How does the connection need to look like to double cold bend the glass?

CREATED GEOMETRY MAKES IT DIFFICULT *FOR A SUFFICIENT CONNECTION*

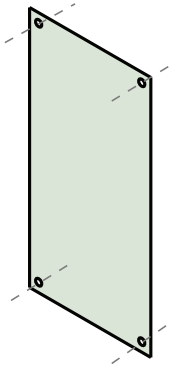


How does the connection need to look like to double cold bend the glass?

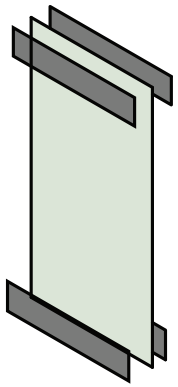
How do you grip?
Where do you grip?

2D TENSIONING TO DETERMINE *STRENGTH*

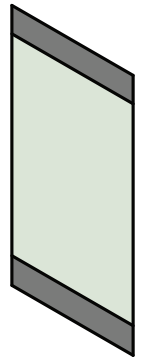
2D TENSIONING TO DETERMINE *STRENGTH*



1. Holes

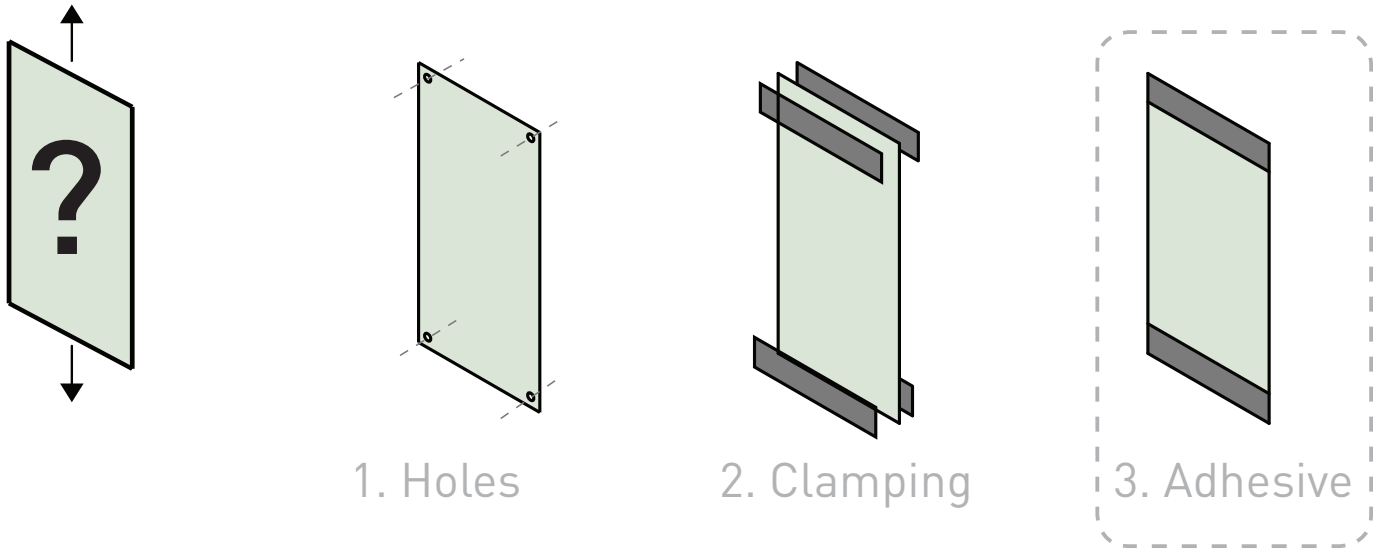


2. Clamping

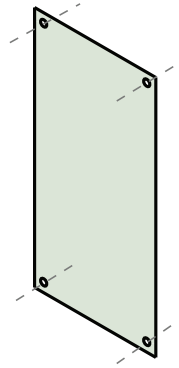


3. Adhesive

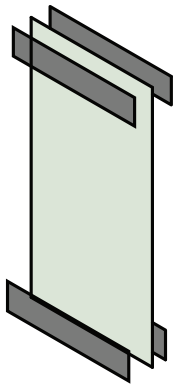
2D TENSIONING TO DETERMINE *STRENGTH*



2D TENSIONING TO DETERMINE *STRENGTH*



1. Holes



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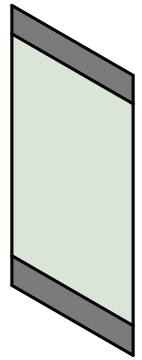
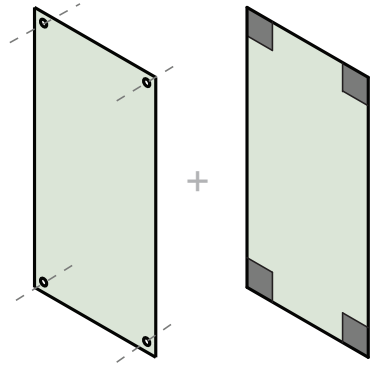
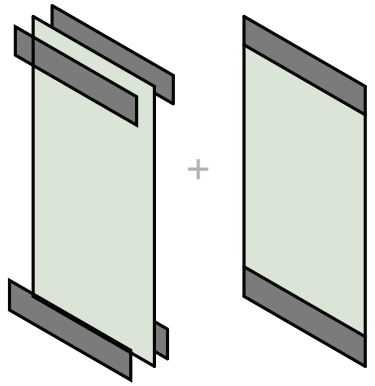
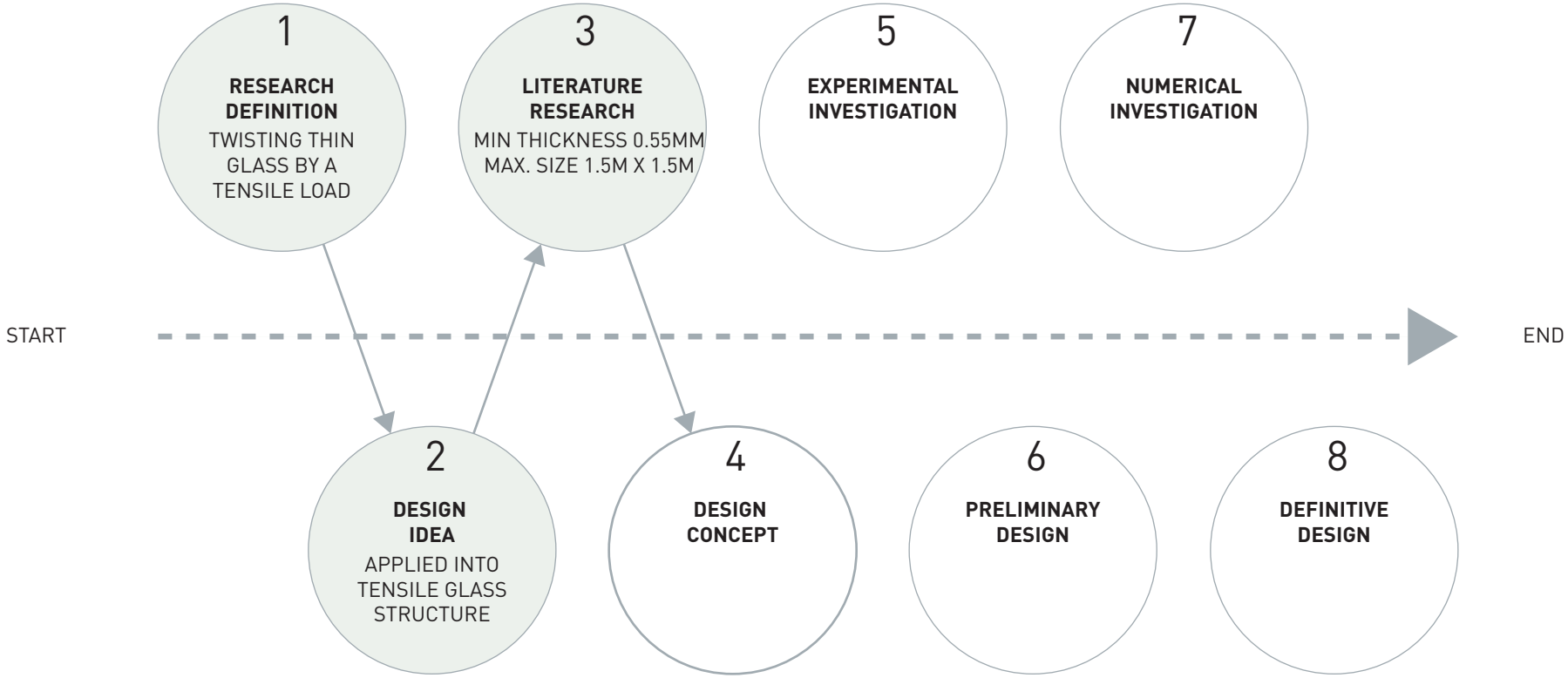


3. Adhesive





Combinations are also possible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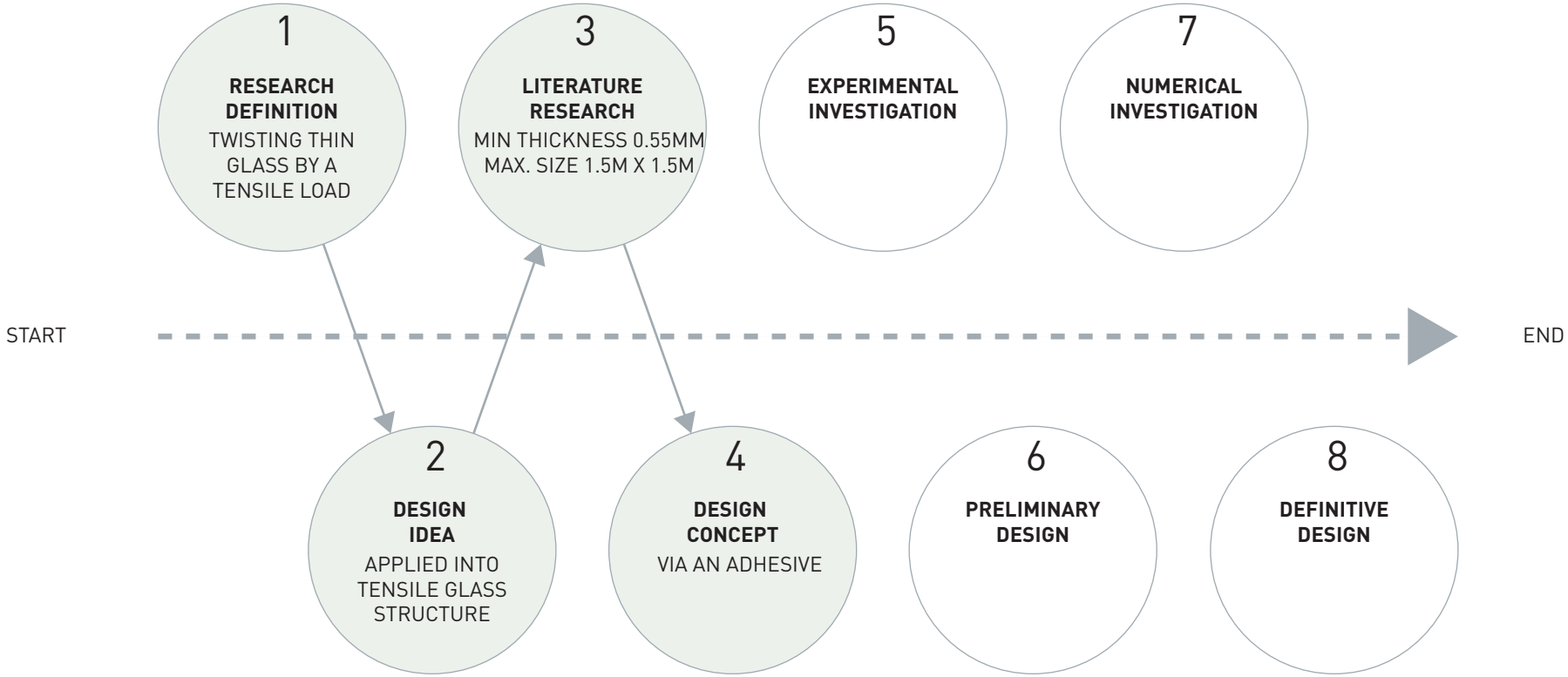
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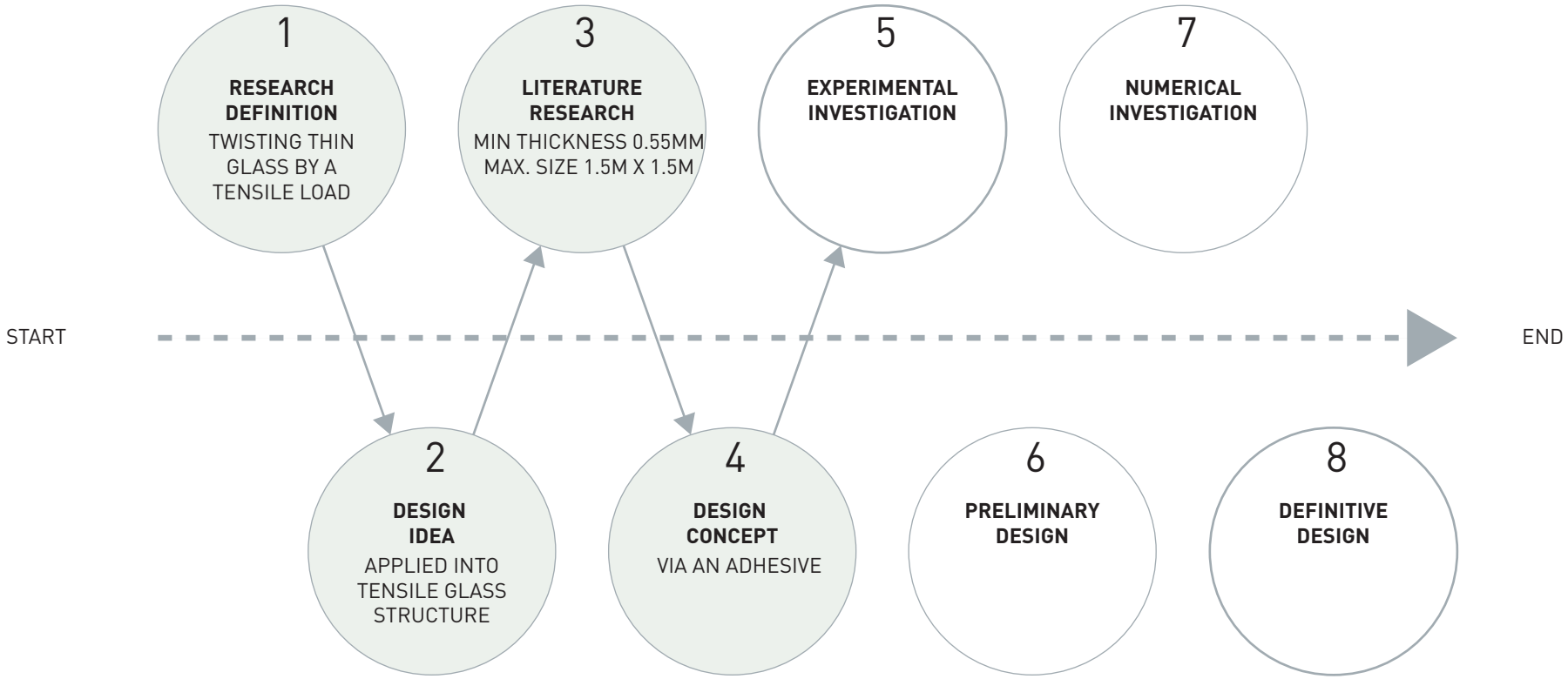
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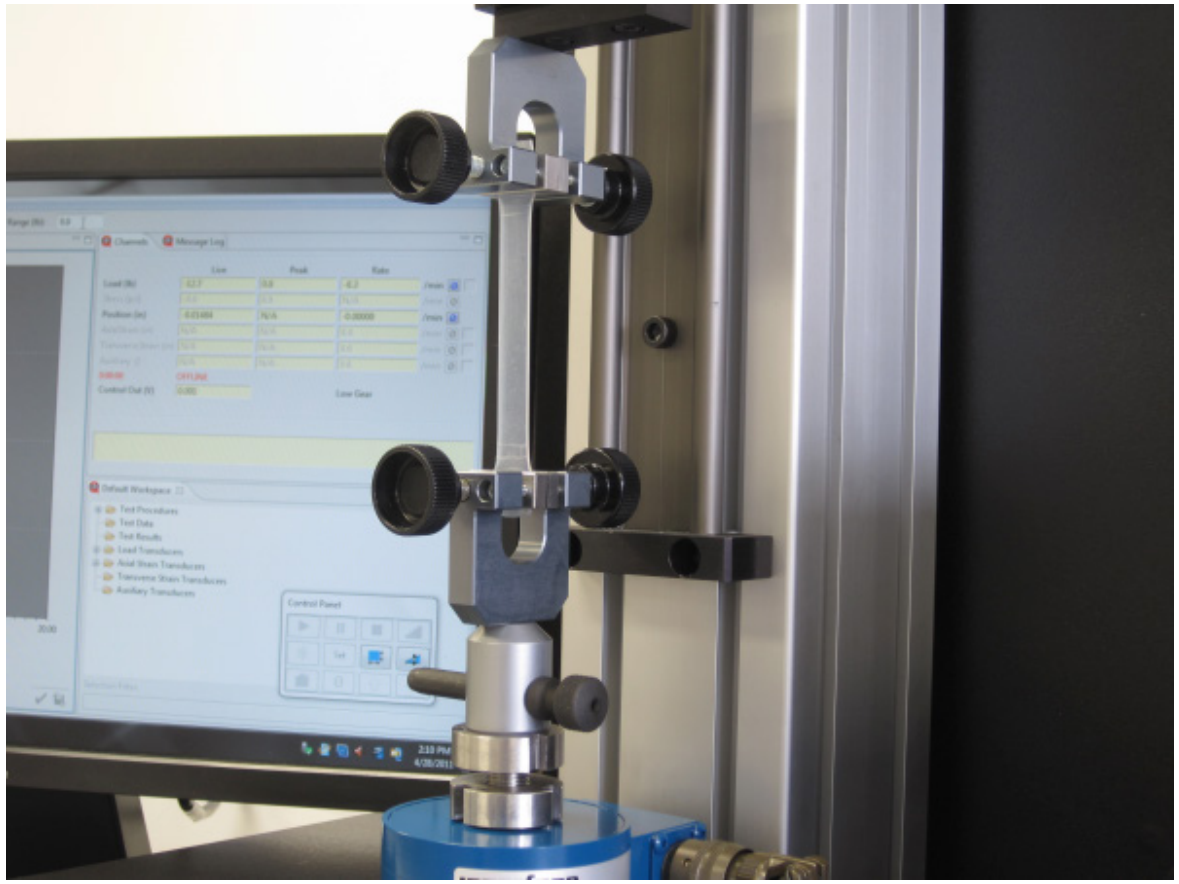
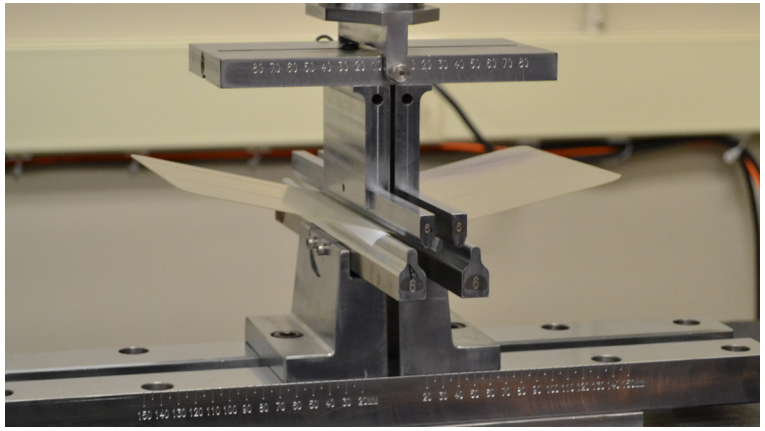
EXPERIMENTAL INVESTIGATION

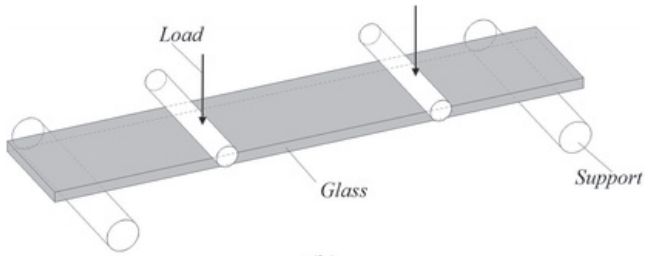
DUCTILE MATERIALS

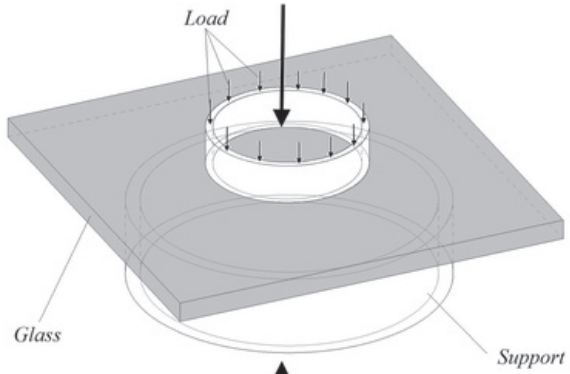


Tensile load
with pull-out test

BRITTLE MATERIALS



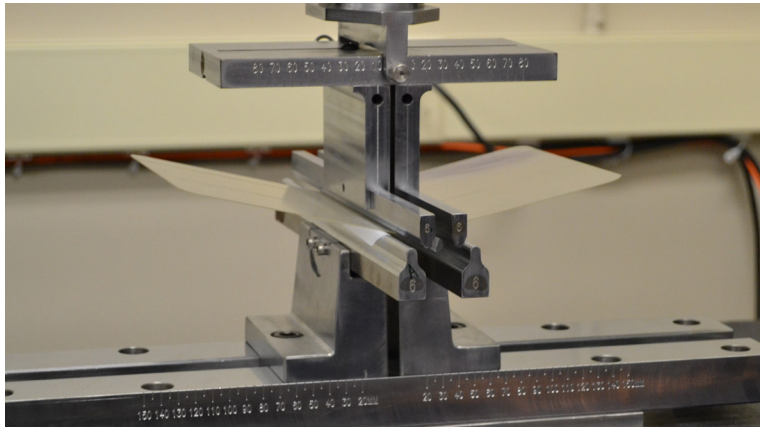


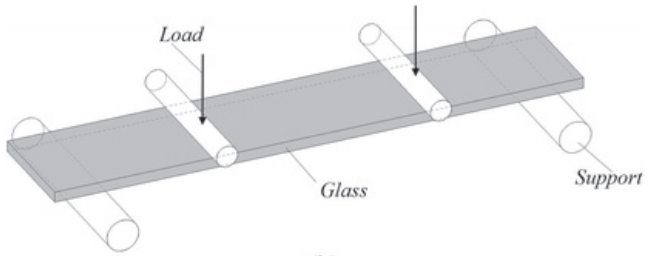


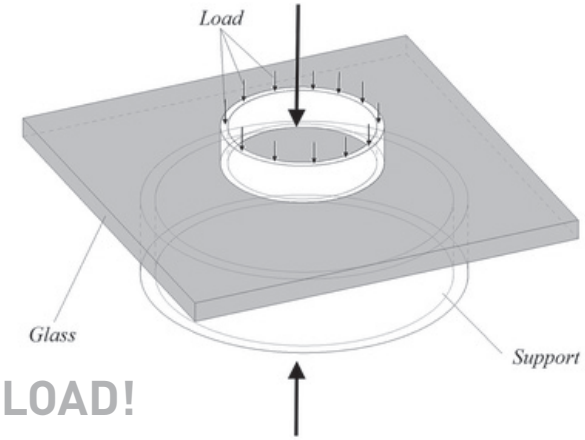
1. **Flexural load** with 4-point bend test

2. **Flexural load** with Ring-on-ring test

BRITTLE MATERIALS







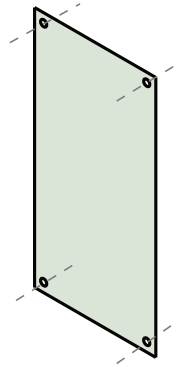
WE WANT TENSILE LOAD!

BRITTLE MATERIALS

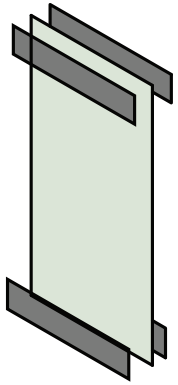
→ **DESIGN A NON-STANDARD TEST METHOD**
THAT FITS INTO THE PULL-OUT MACHINE

WE WANT TENSILE LOAD!

2D TENSIONING TO DETERMINE *STRENGTH*



1. Holes



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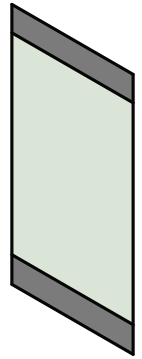
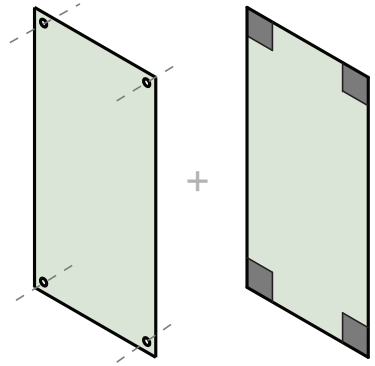
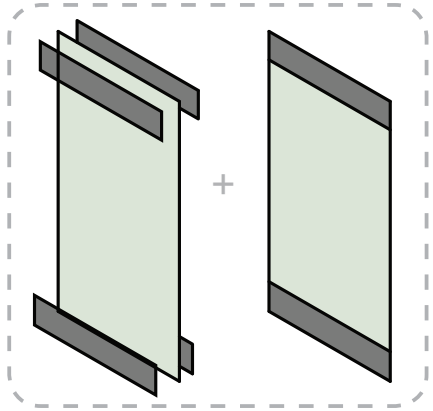


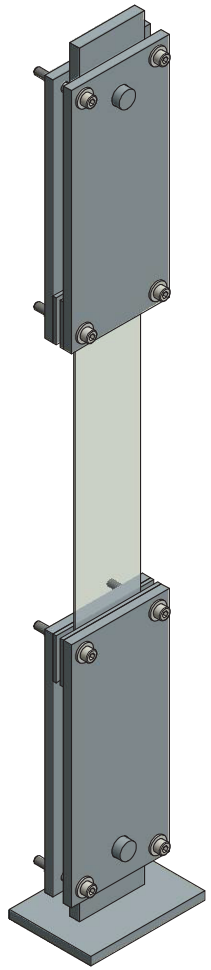
3. Adhesive

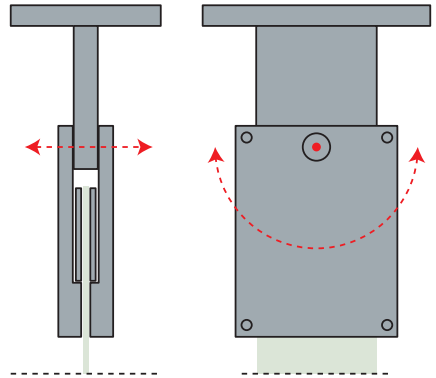


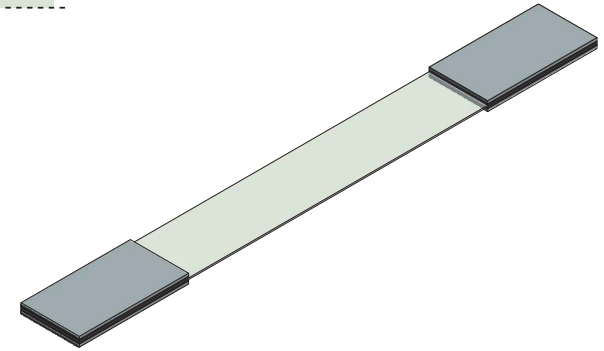


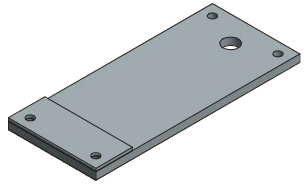
Clamping & gluing for design test set-up

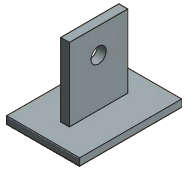
DESIGN TEST SET-UP



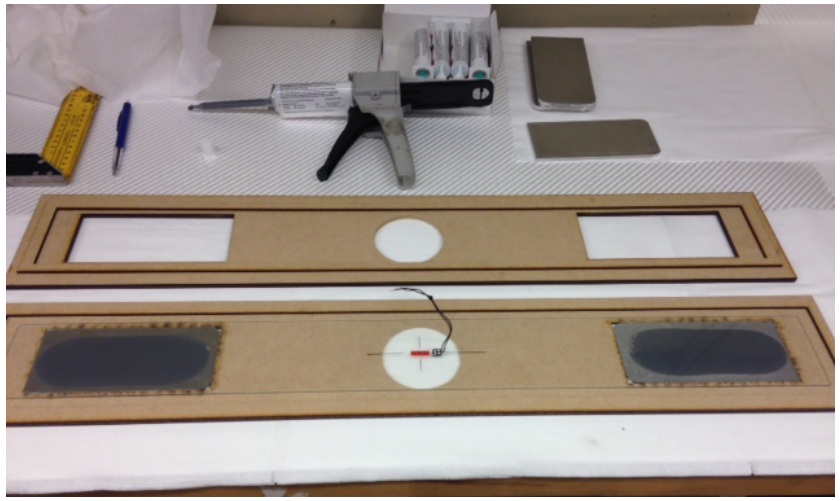


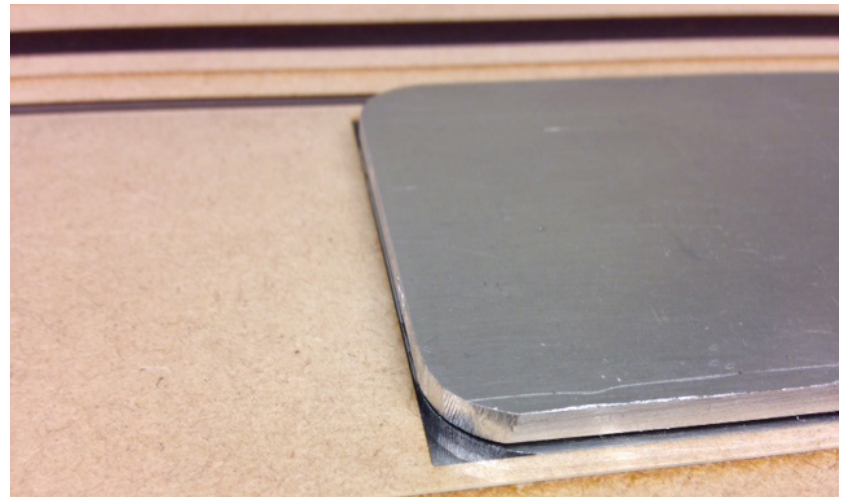


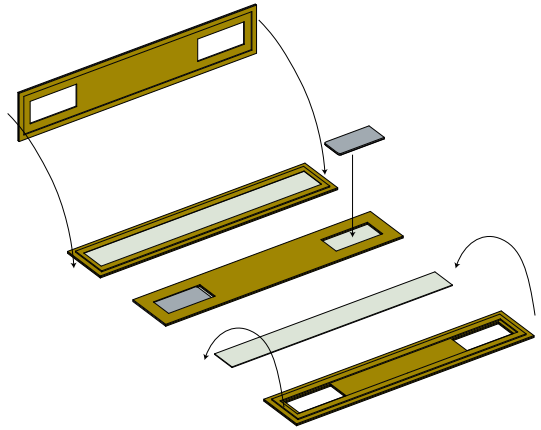


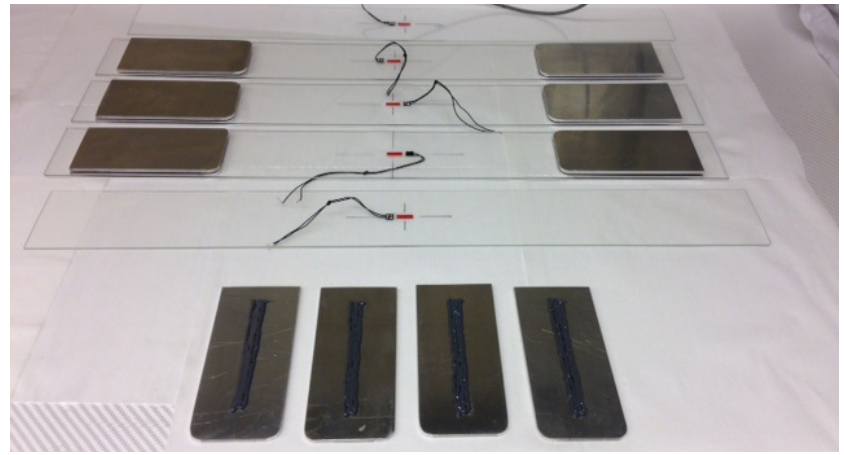


PREPERATION SPECIMENS

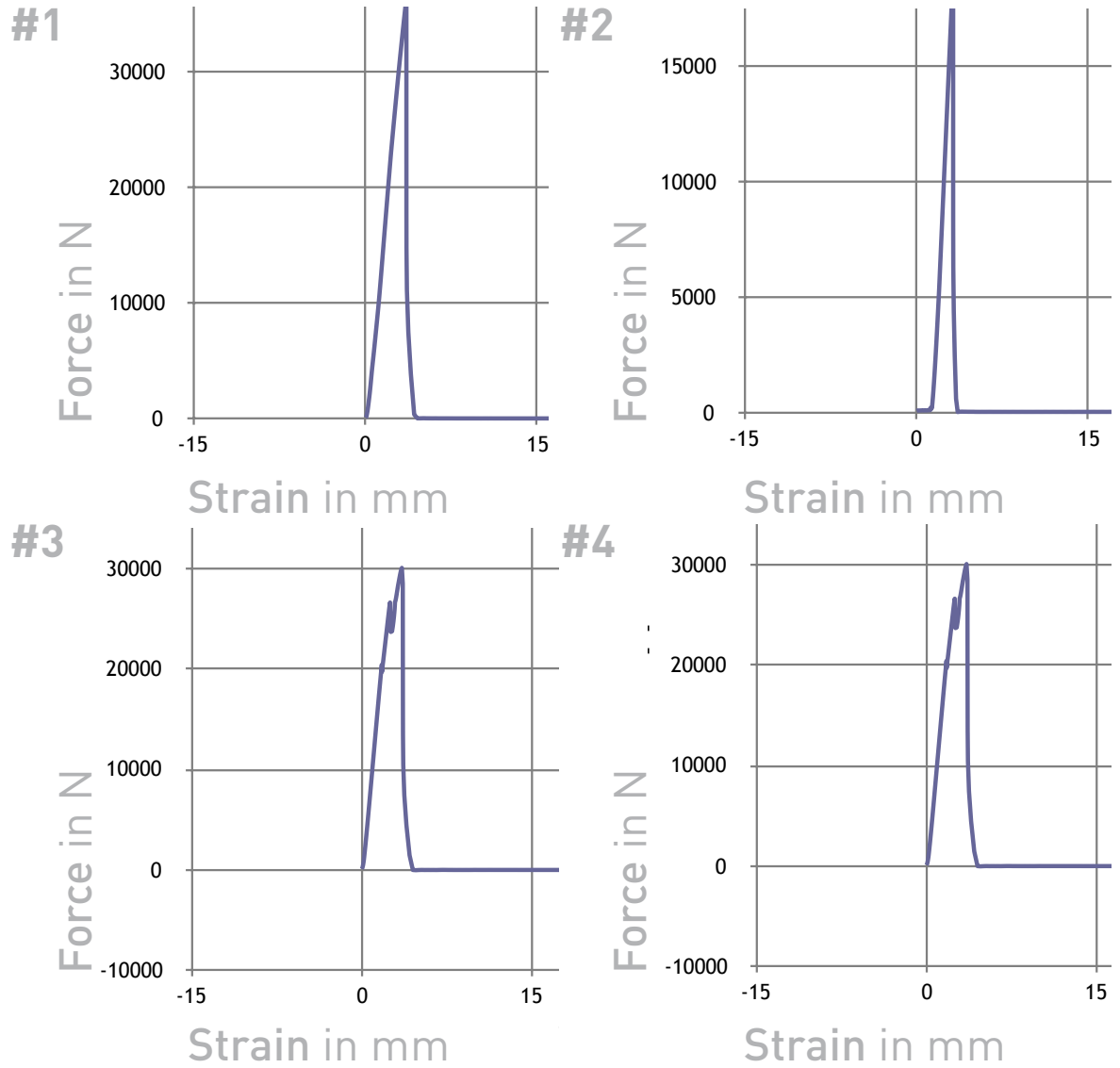








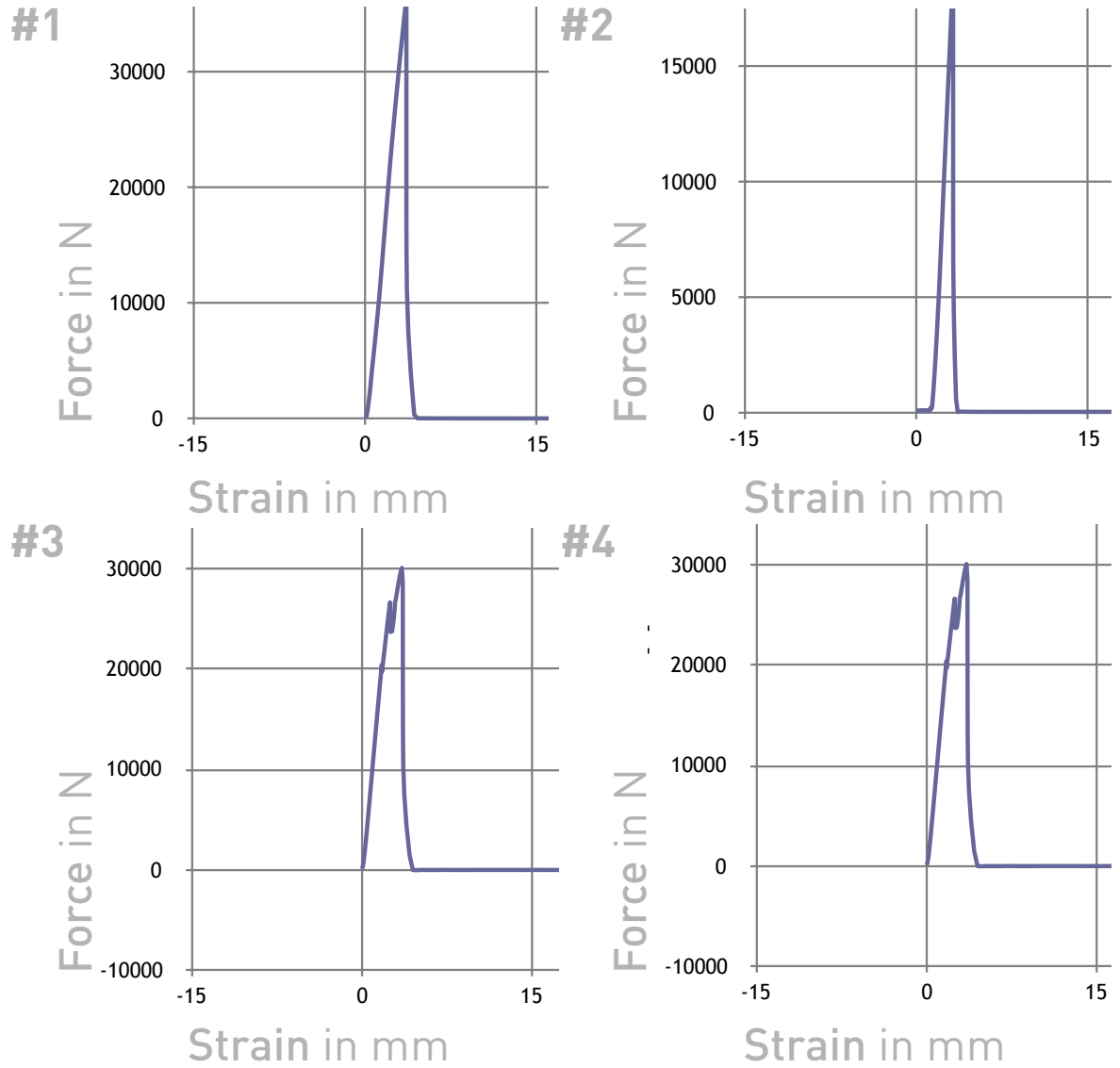
RESULTS SPECIMENS



RESULTS SPECIMENS

→ **3 of 4 above 30000N**

circa 3000 kg



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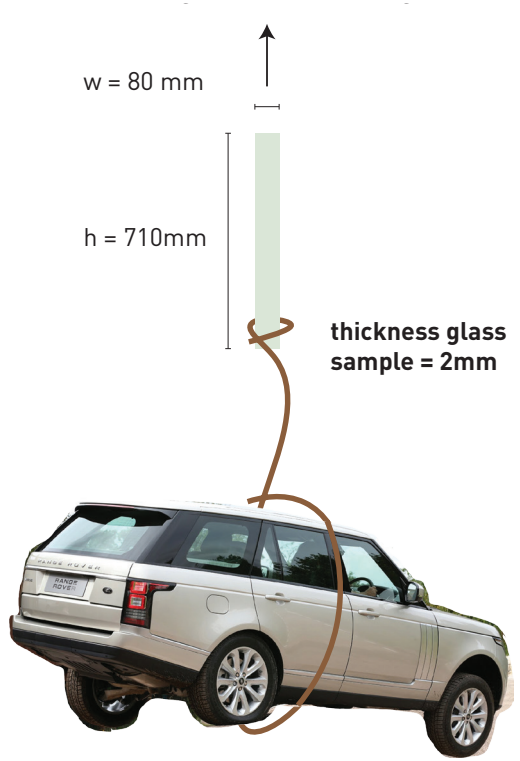
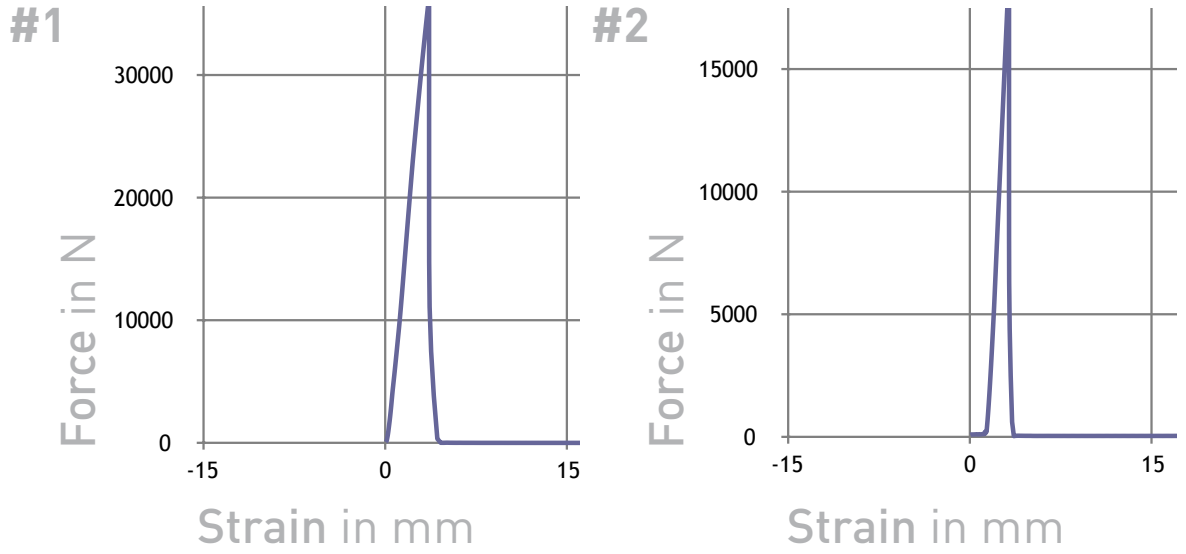
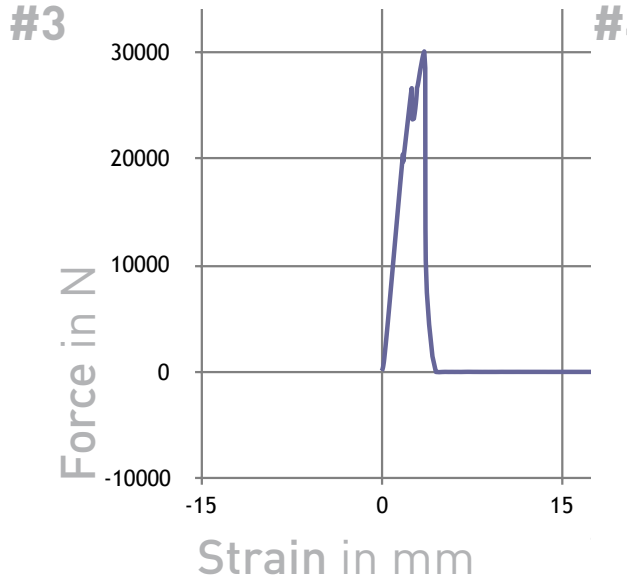
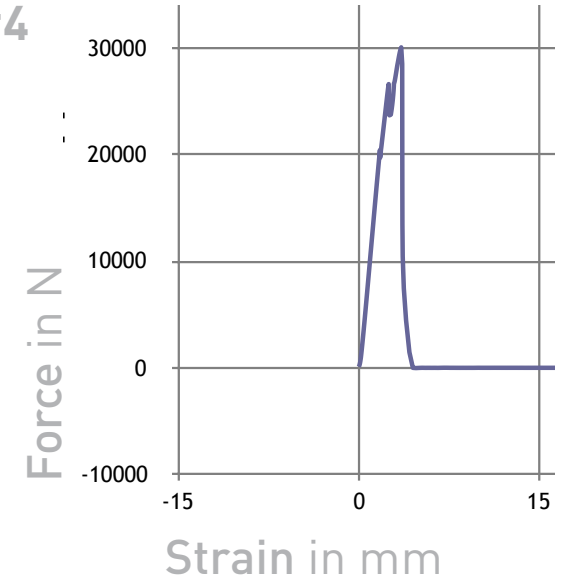






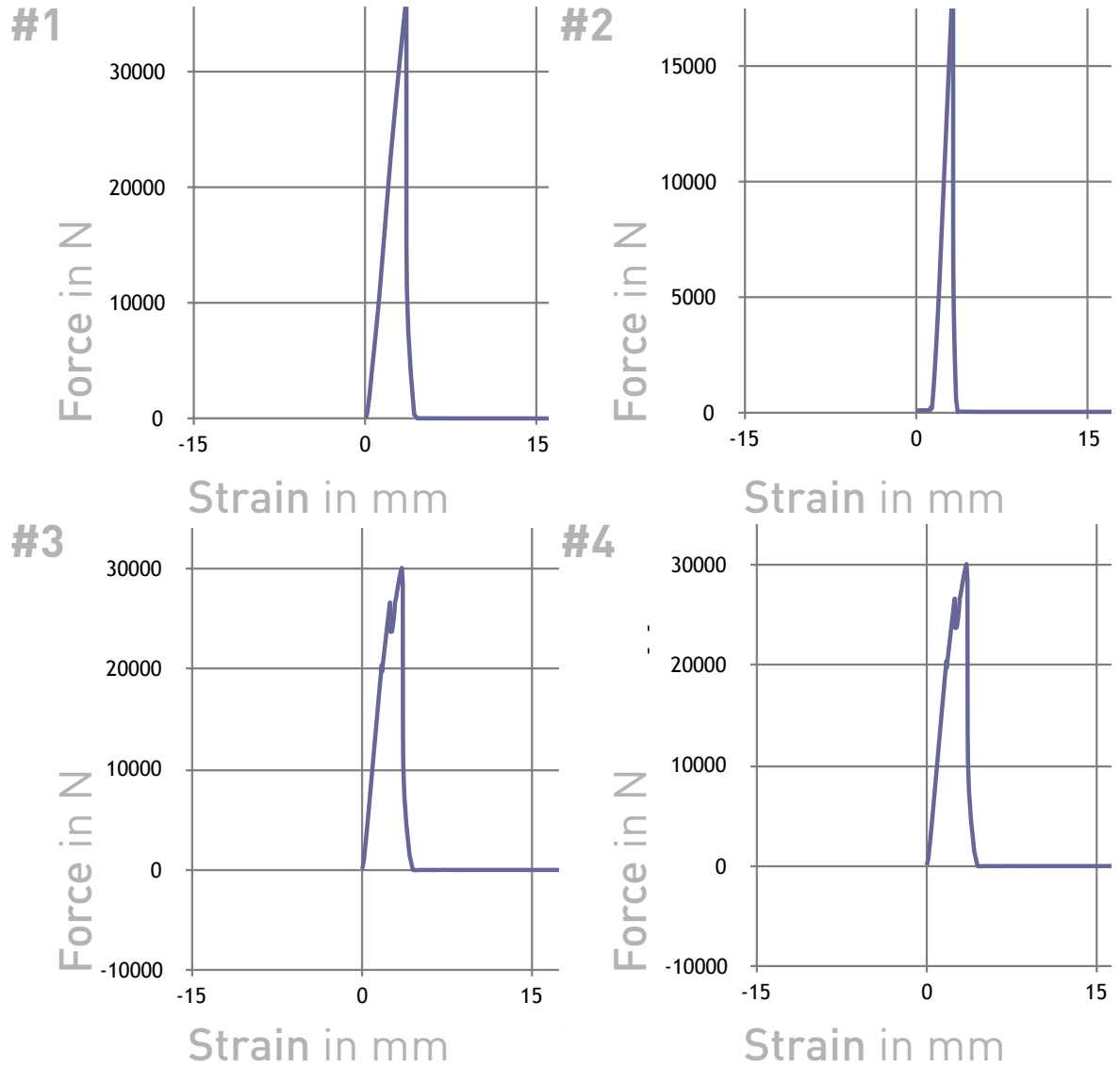


RESULTS SPECIMENS

→ **3 of 4 above 30000N**

circa 3000 kg

→ **2 of 4 force/strain functions are not linear**



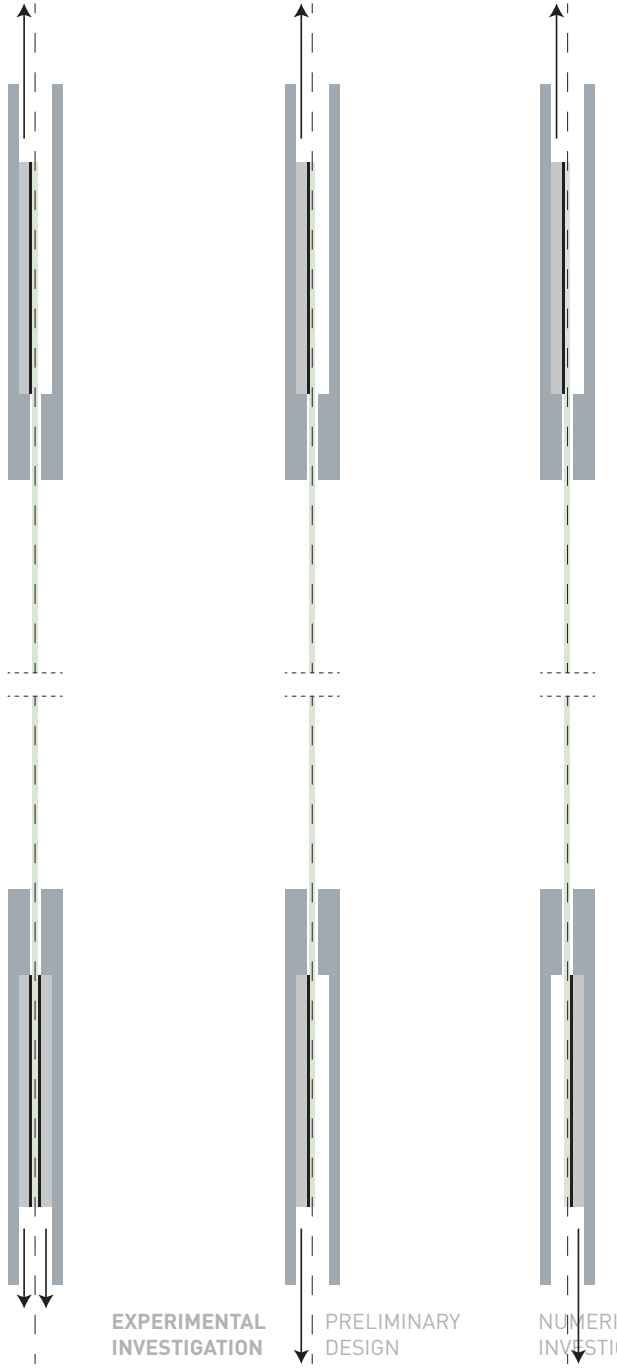
RESULTS SPECIMENS

→ **3 of 4 above 30000N**

circa 3000 kg

→ **2 of 4 force/strain function is not linear**

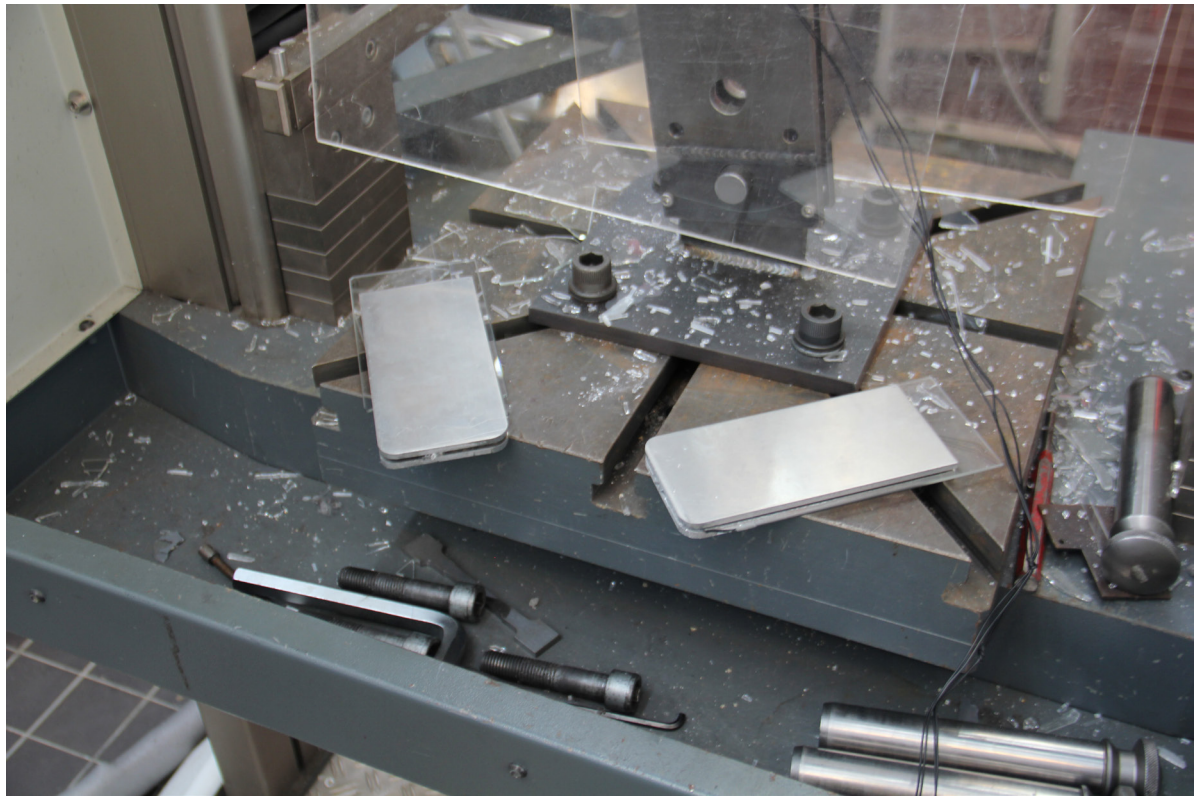
because of failure adhesive between glass and alumium plate



TEST RESULT SPECIMEN #1

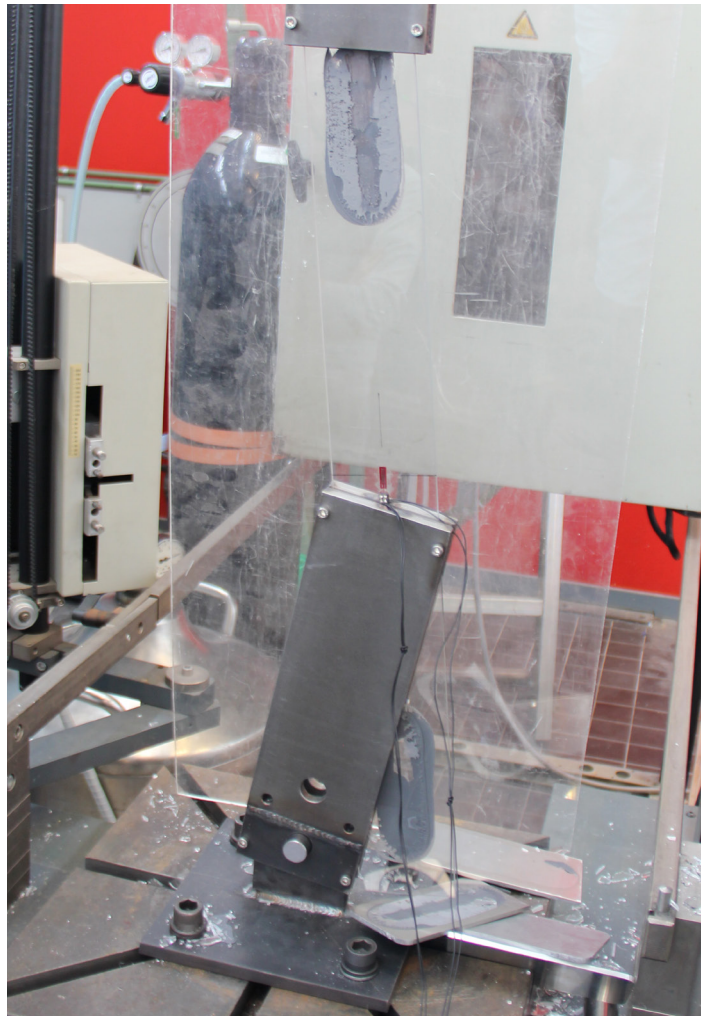
Failure at
36 286 N
3.570 mm

TEST RESULT SPECIMEN #2



Failure at
19 038 N
3.184 mm

TEST RESULT SPECIMEN #3



Failure at
30 164 N
3.576 mm

TEST RESULT SPECIMEN #4

Failure at
32 767 N
4.923 mm

TENSILE STRENGTH

250 MPa

TENSILE STRENGTH

250 MPa

1/3 of the earlier mentioned bending tensile strength of 750MPa...

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Same yield strength as structural A36 steel!

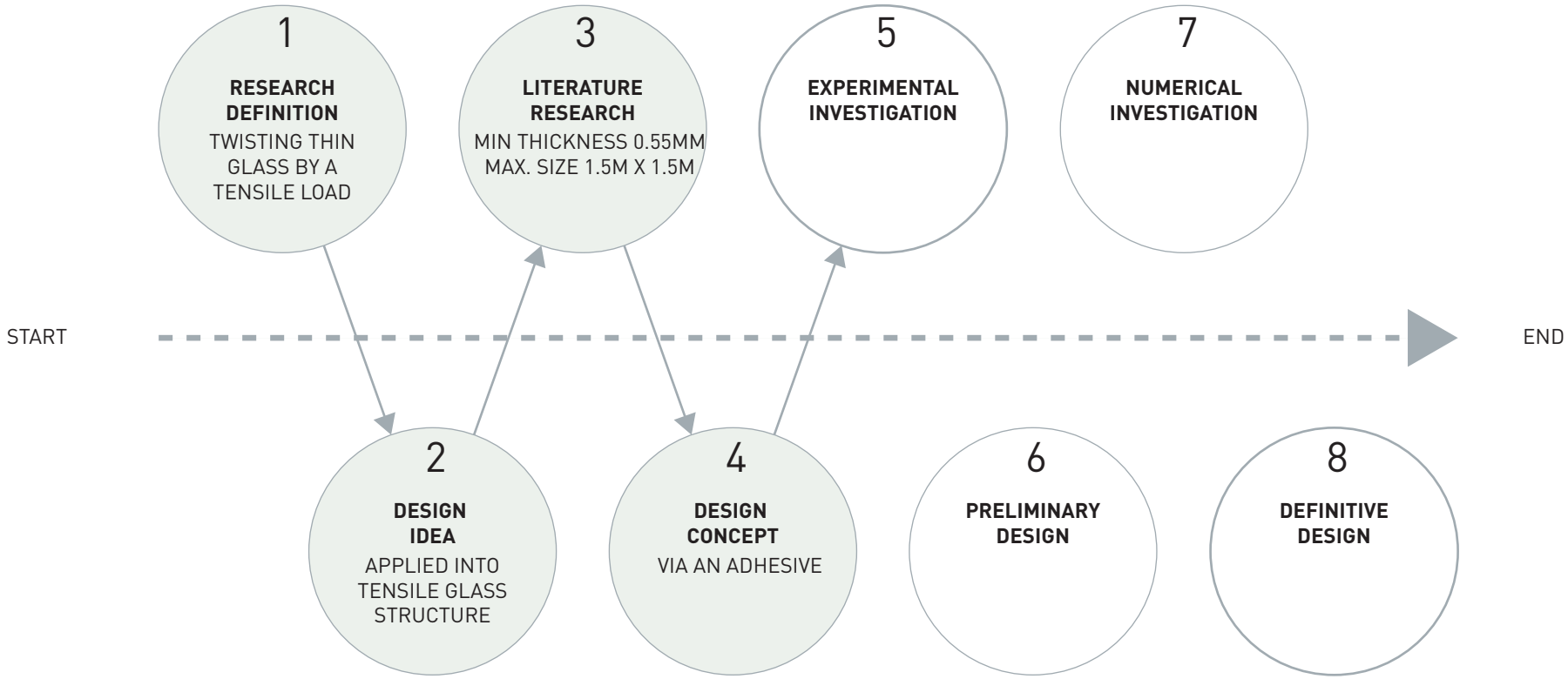
TENSILE STRENGTH

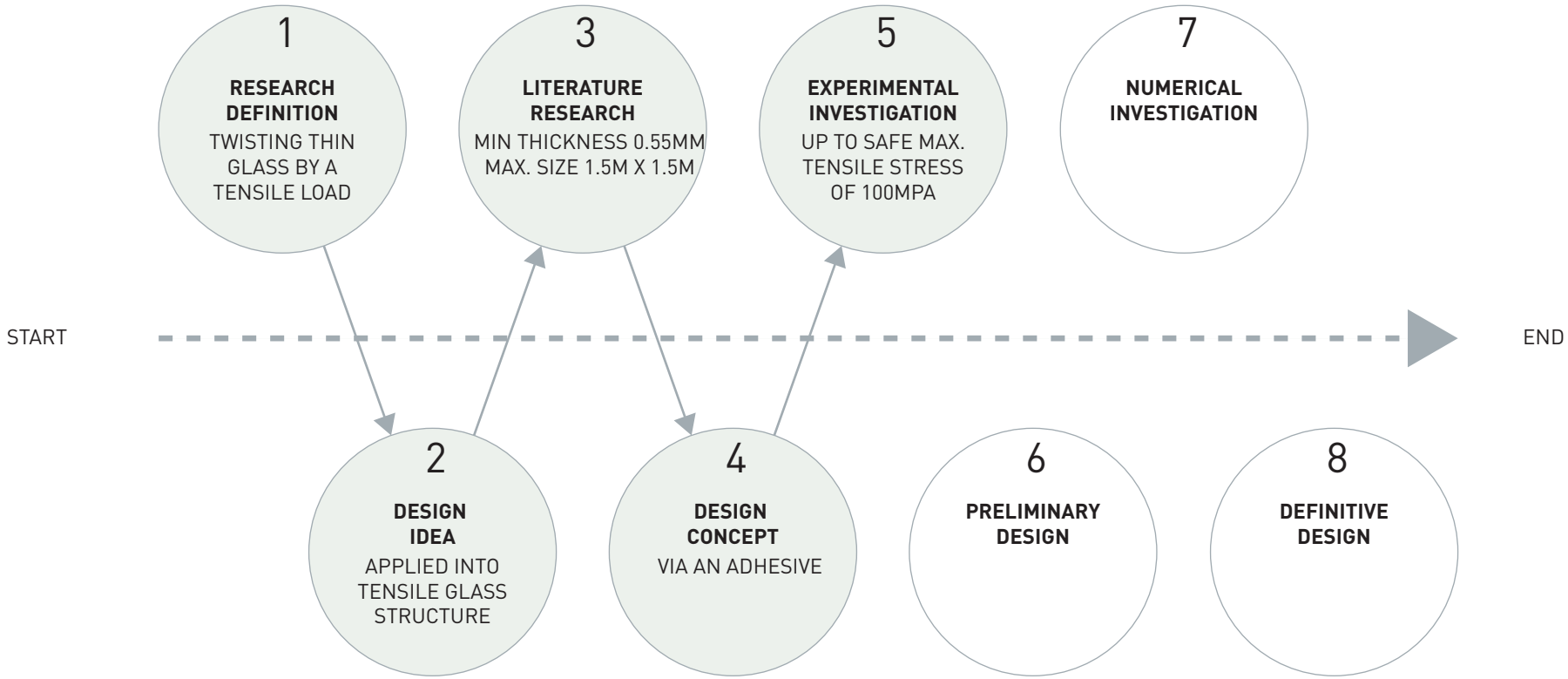
250 MPa

1/3 of the earlier mentioned bending tensile strength of 750MPa...

Same yield strength as structural A36 steel!

...of course, there has to be a design safety factor taken into account


1
RESEARCH DEFINITION
TWISTING THIN GLASS BY A TENSILE LOAD
3
LITERATURE RESEARCH
MIN THICKNESS 0.55MM
MAX. SIZE 1.5M X 1.5M
5
EXPERIMENTAL INVESTIGATION
7
NUMERICAL INVESTIGATION
START
END
2
DESIGN IDEA
APPLIED INTO TENSILE GLASS STRUCTURE
4
DESIGN CONCEPT
VIA AN ADHESIVE
6
PRELIMINARY DESIGN
8
DEFINITIVE DESIGN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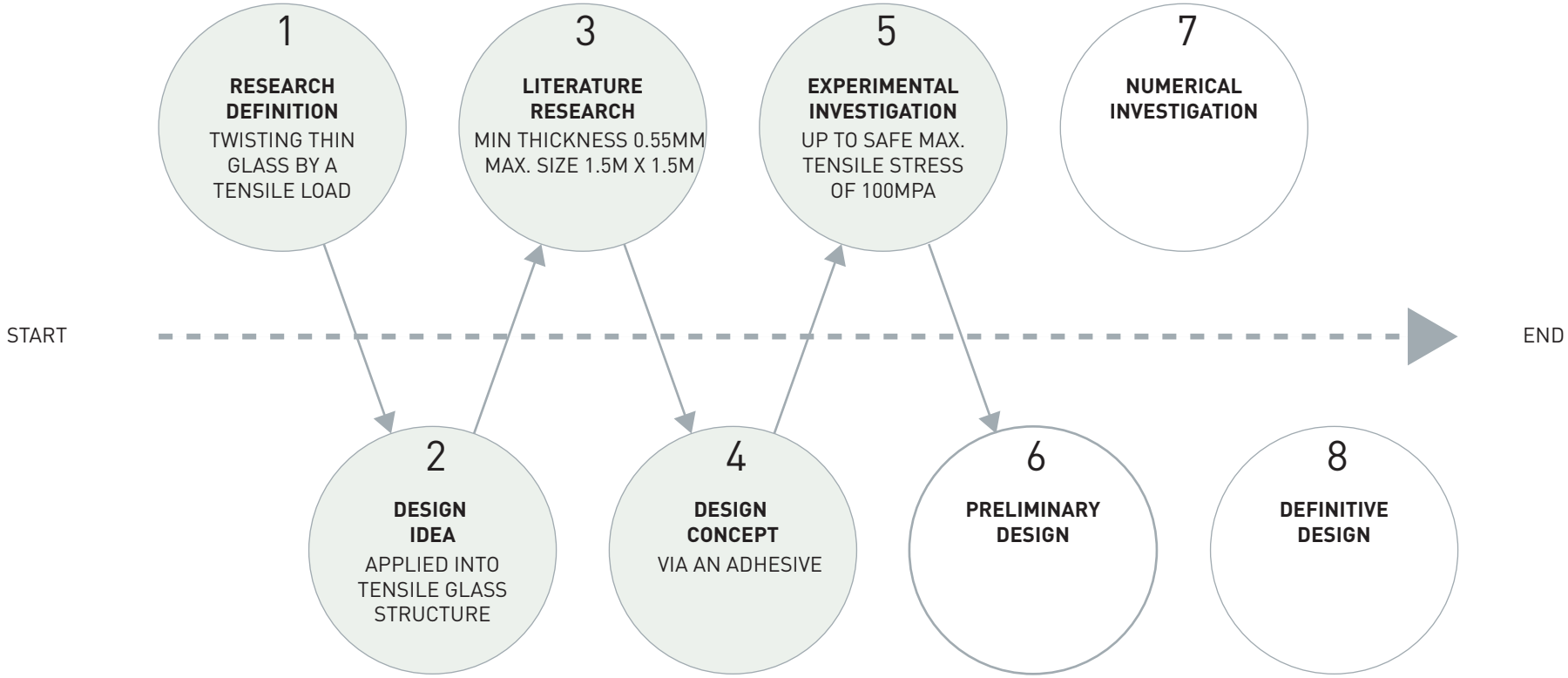
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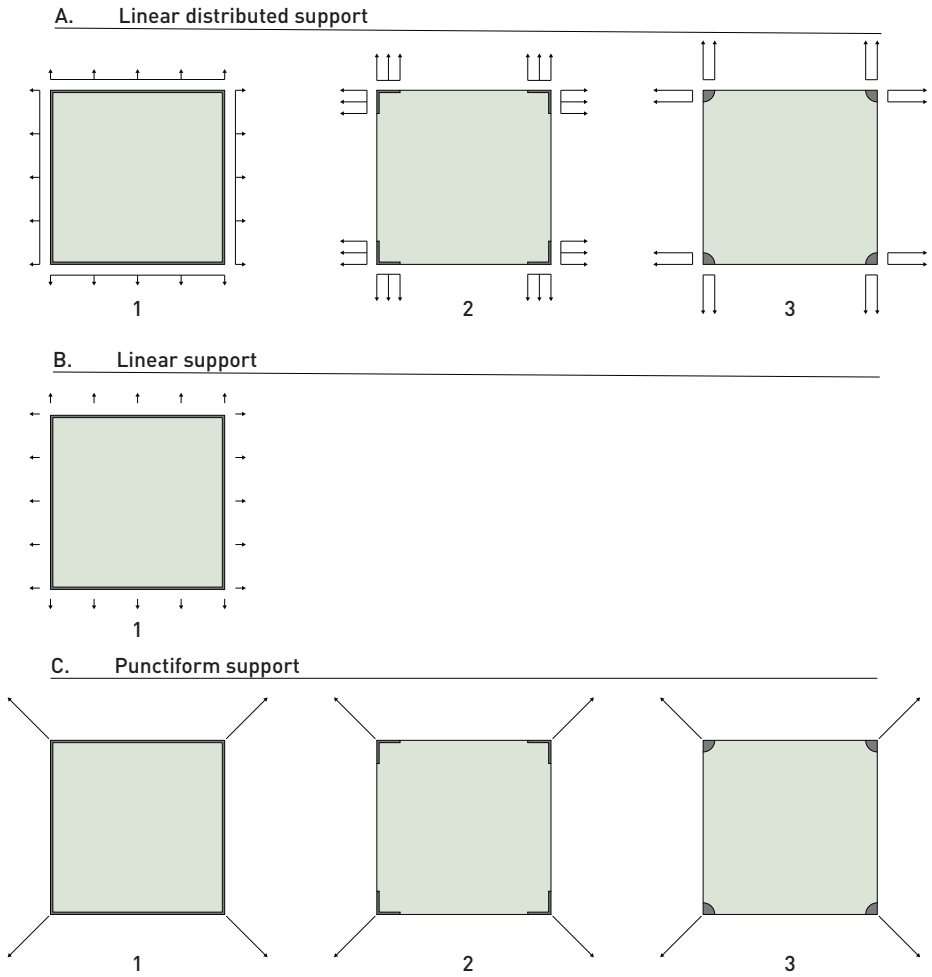
DEFINITIVE DESIGN

PRELIMANARY DESIGN

WHERE TO APPLY THE SUPPORT?



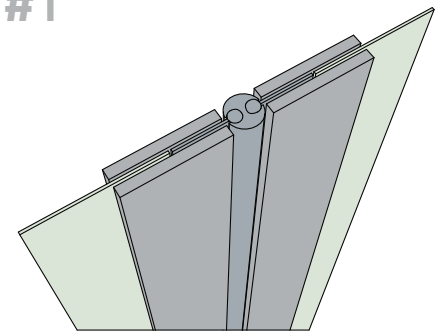
HOW DOES THE SUPPORT GOING TO LOOK LIKE?

STRENGTH	**W**EAKNESS
OPPORTUNITY	**T**HREAT

Reviewed aspects:

- Easiness of fabrication & assembling
- Structural behaviour
- Lightweightness

#1



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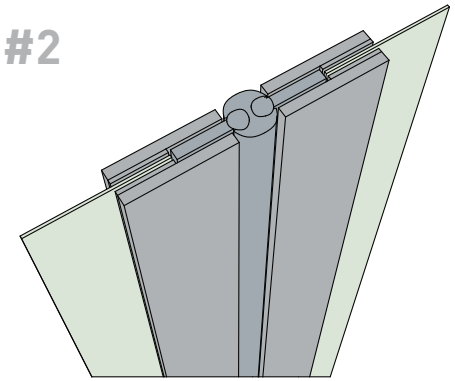

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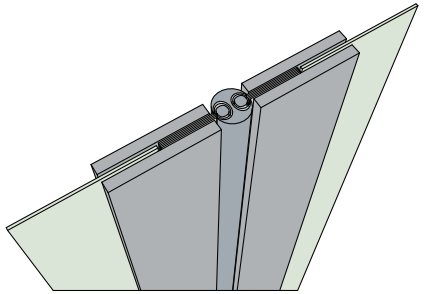

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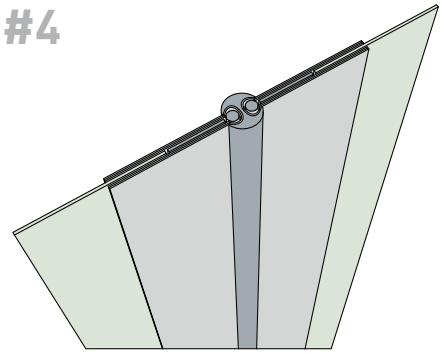

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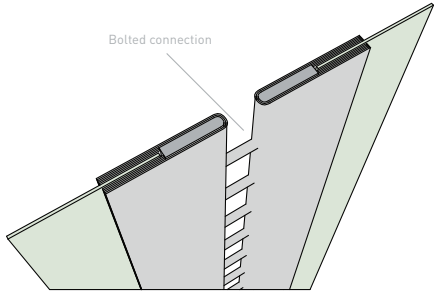

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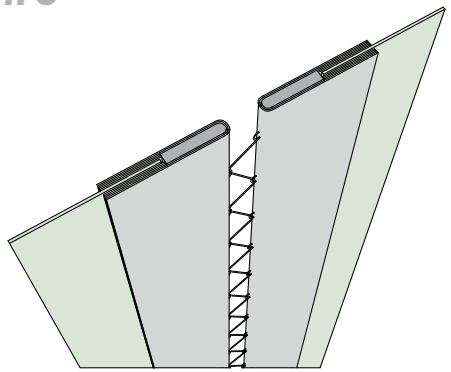

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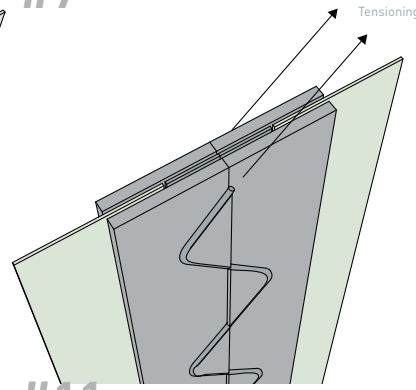

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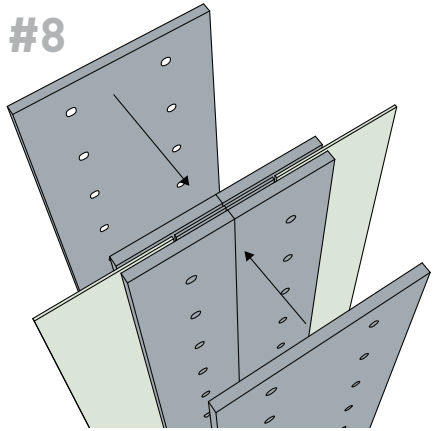

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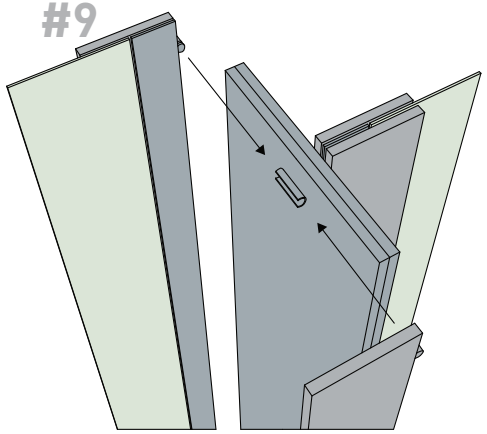

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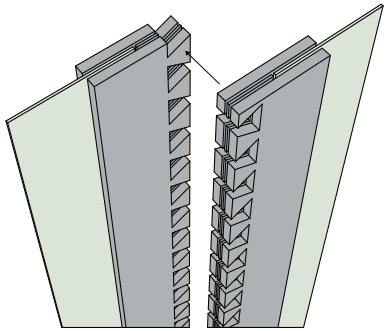

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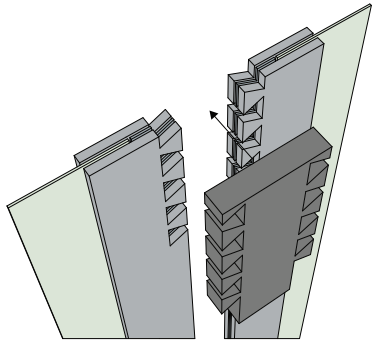
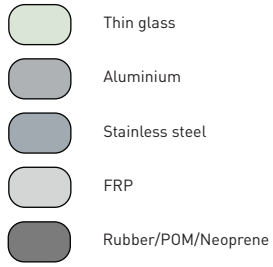
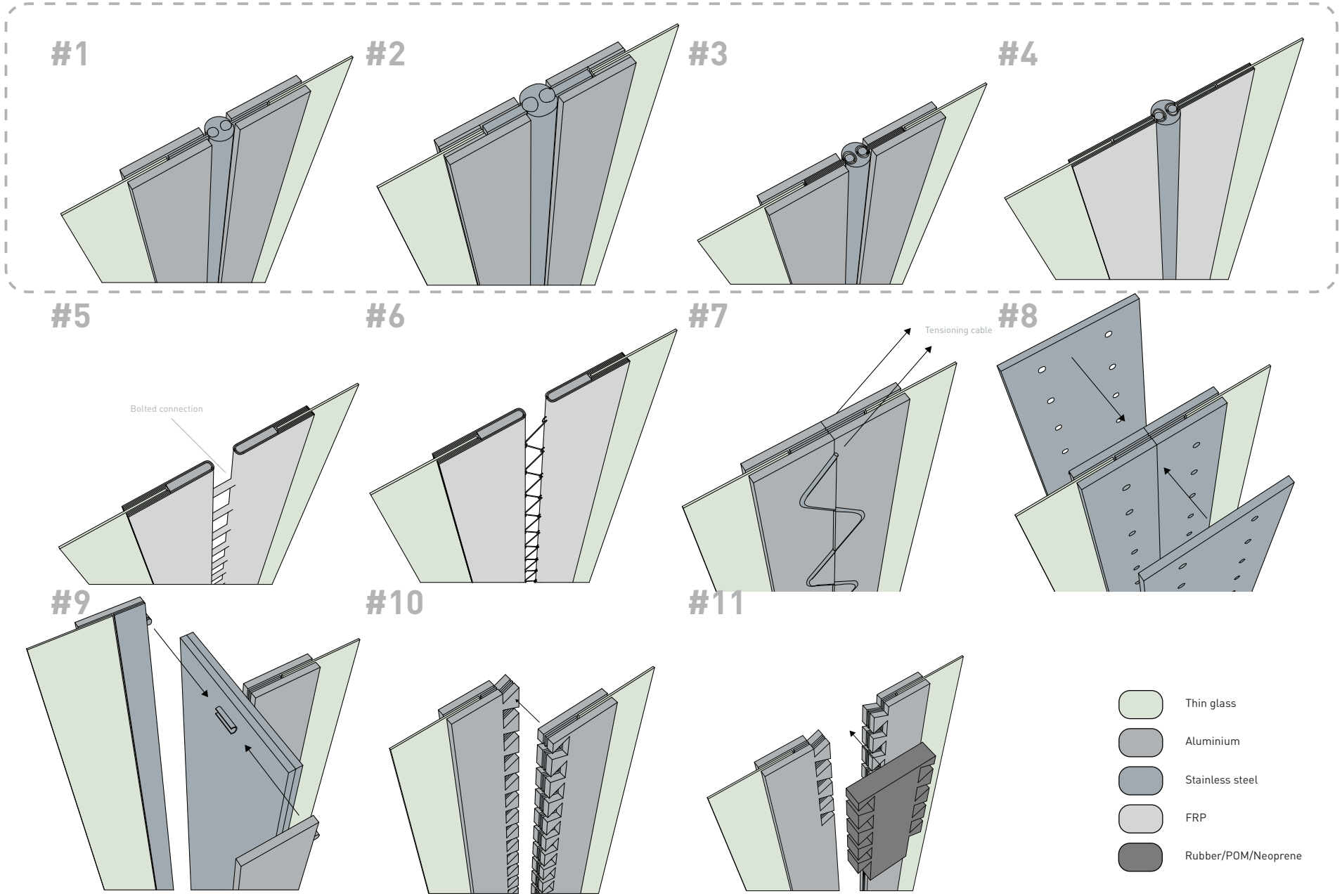
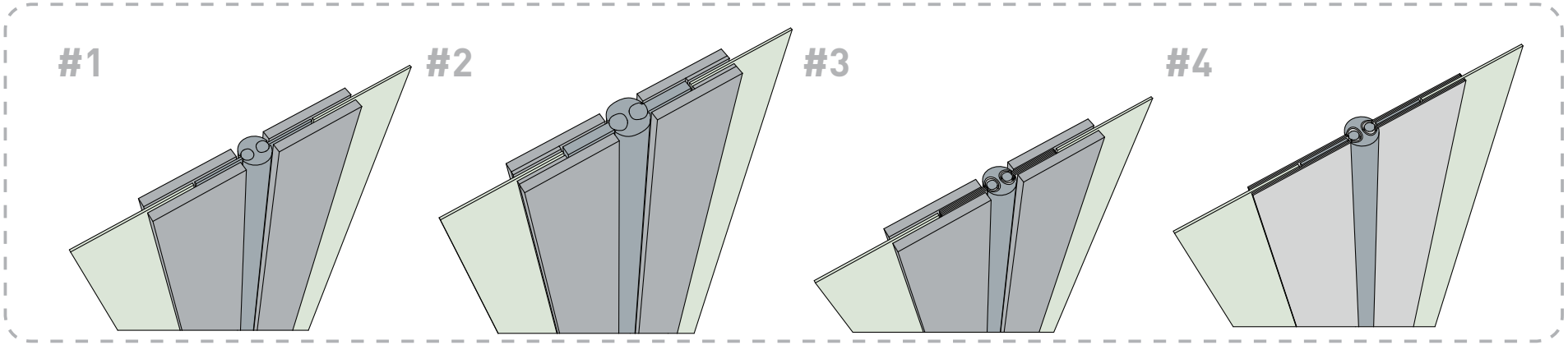




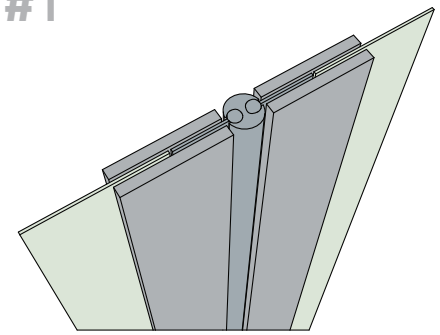

#1
#2
#3
#4
#5
Bolted connection
#6
#7
Tensioning cable
#8
#9
#10
#11
Thin glass
Aluminium
Stainless steel
FRP
Rubber/POM/Neoprene



CATEGORY **EXTRUDED PROFILE**

CATEGORY **EXTRUDED PROFILE**

#1



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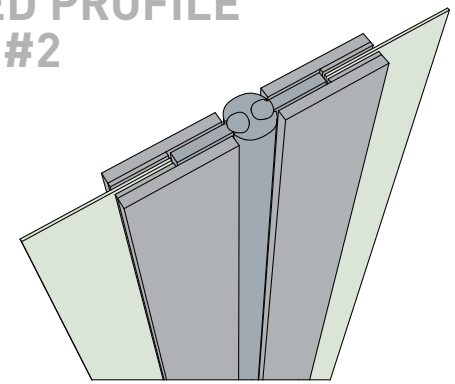

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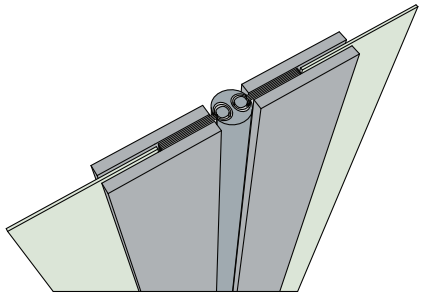

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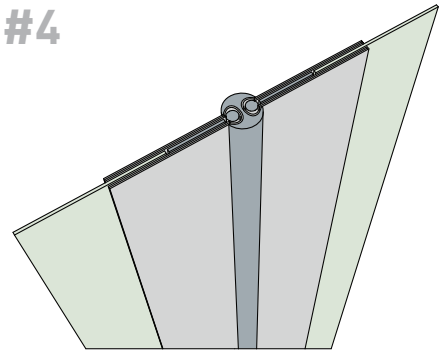

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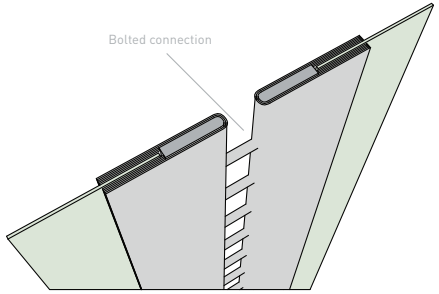

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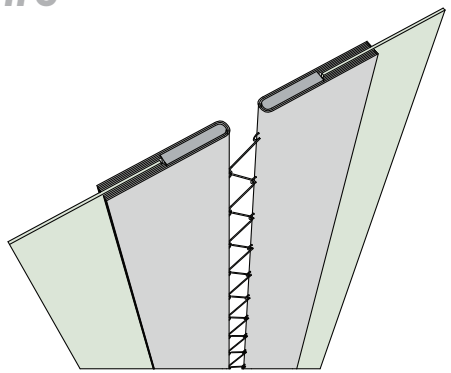

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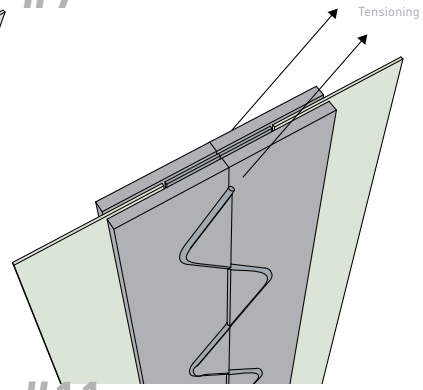

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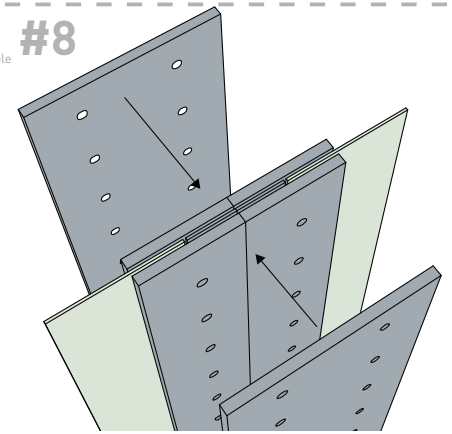

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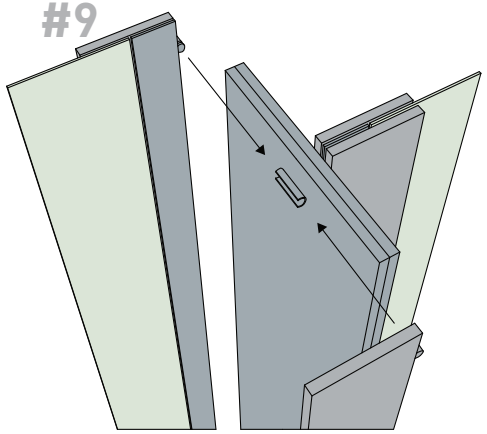

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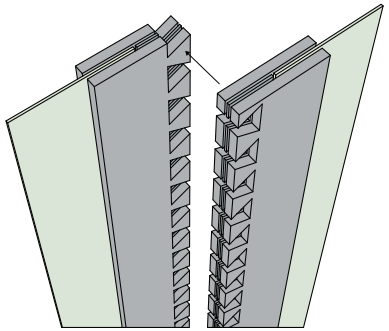

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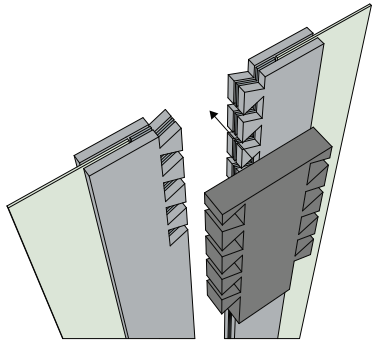
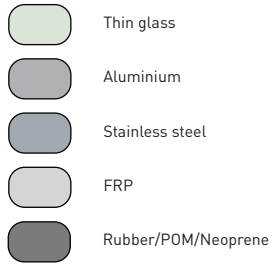
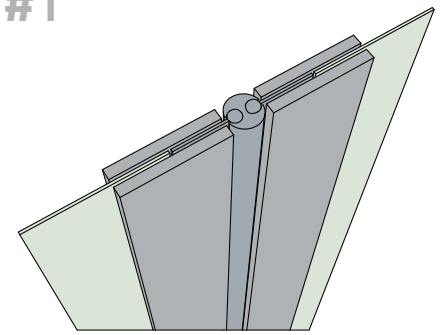




CATEGORY **EXTRUDED PROFILE**

#1



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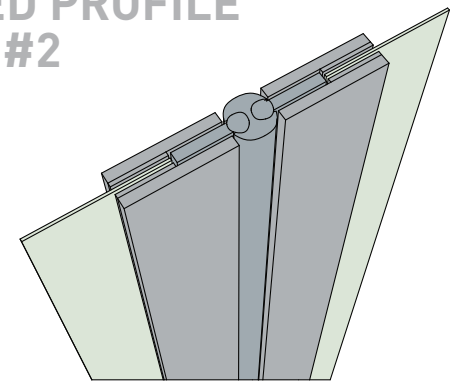

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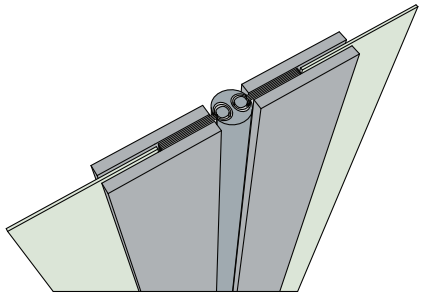

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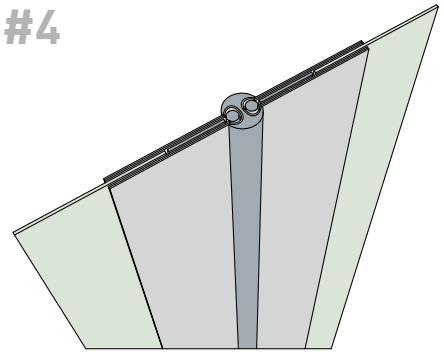

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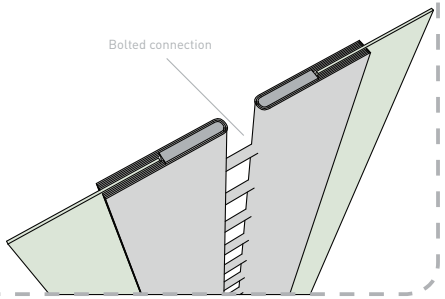

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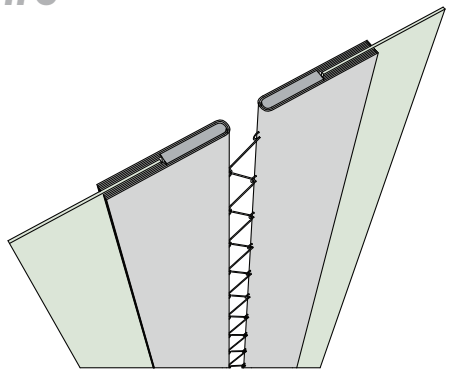

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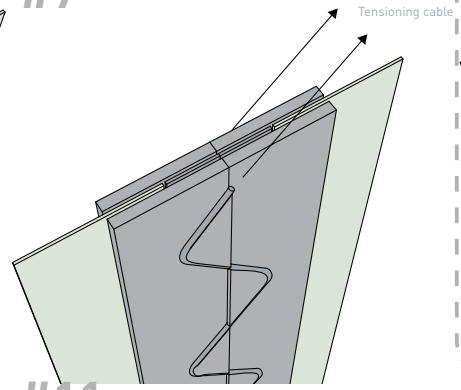

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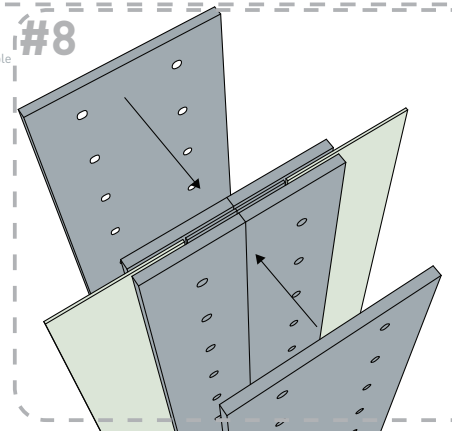

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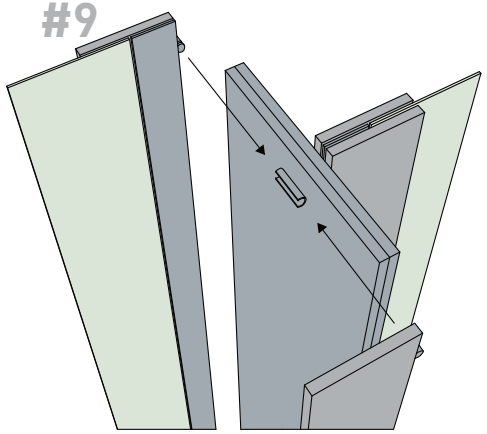

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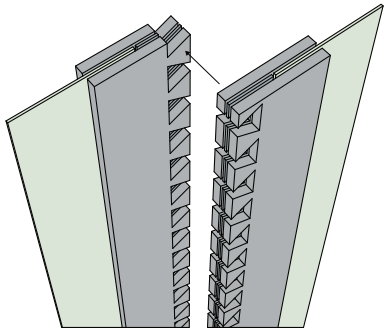

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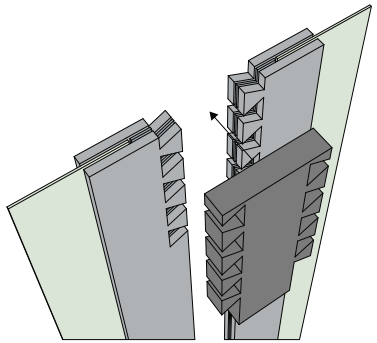
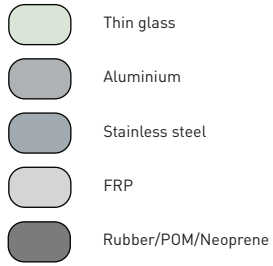
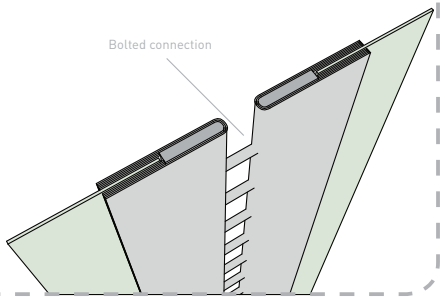




CATEGORY **BOLTED CONNECTION**

#5



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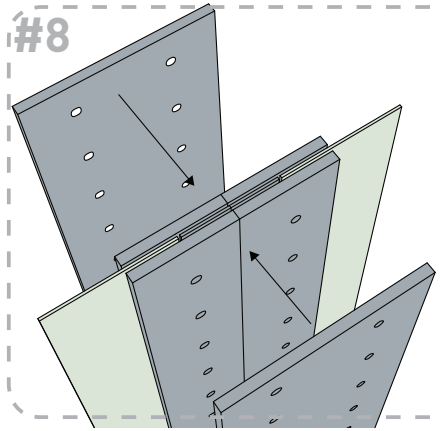
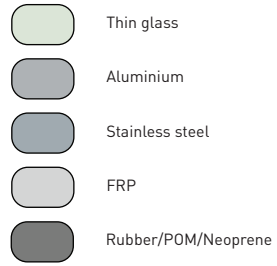
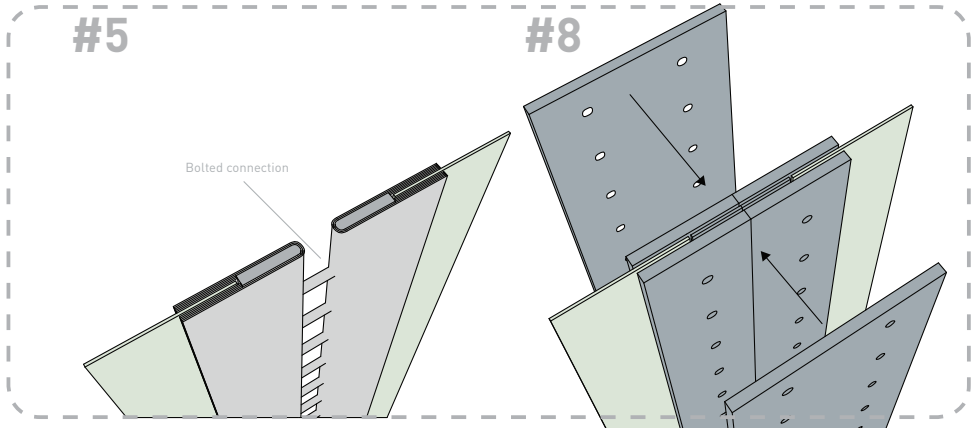




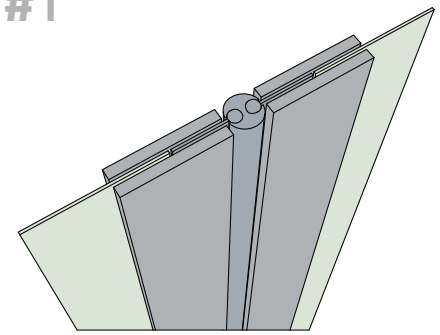
CATEGORY **BOLTED CONNECTION**



Thin glass
Aluminium
Stainless steel
FRP
Rubber/POM/Neoprene

CATEGORY **EXTRUDED PROFILE**

#1



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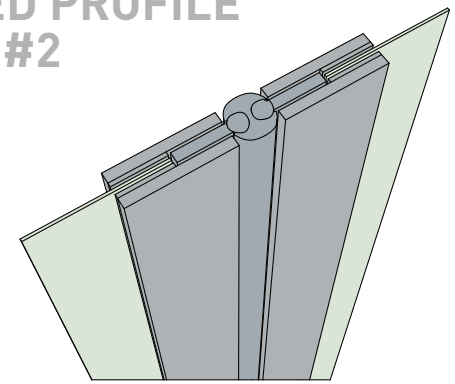

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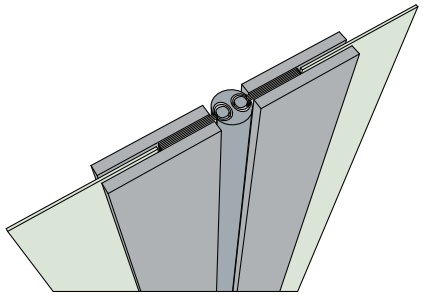

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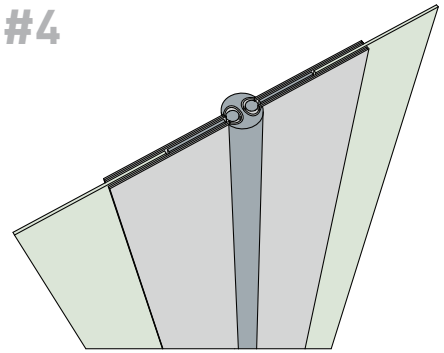

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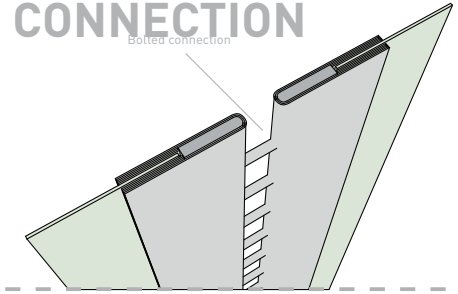
CATEGORY **BOLTED CONNECTION**



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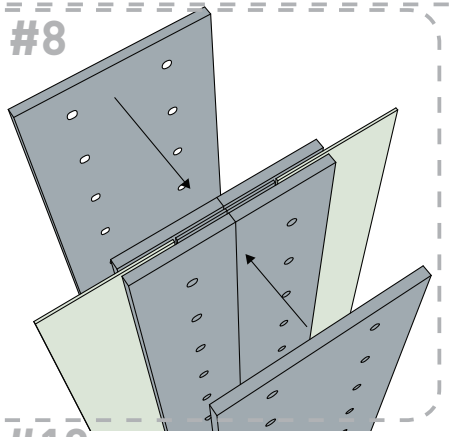

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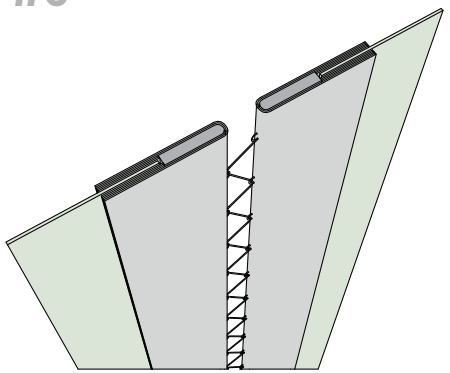

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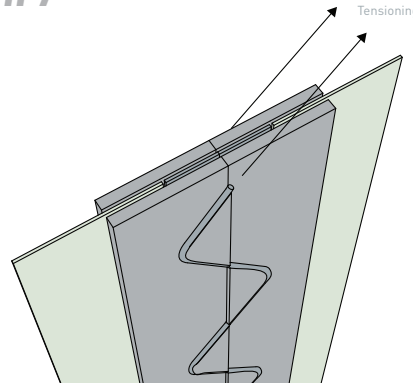

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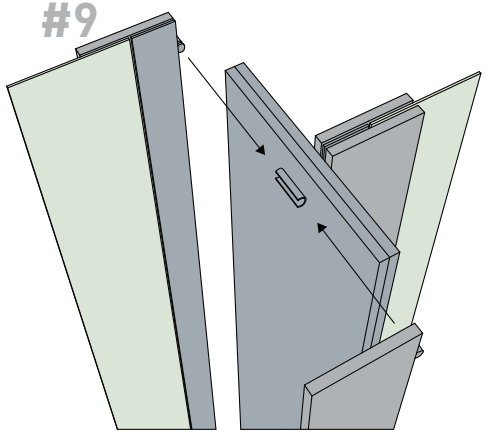

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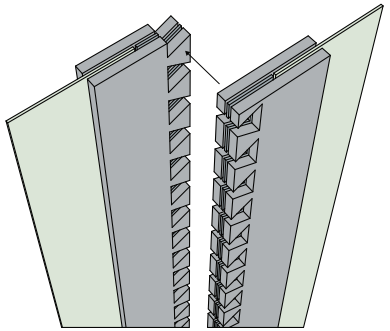

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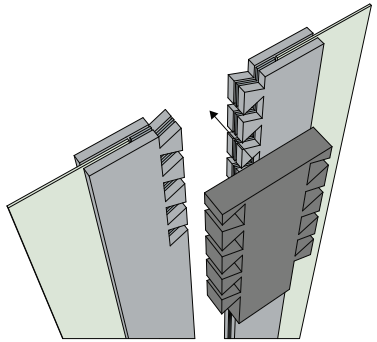
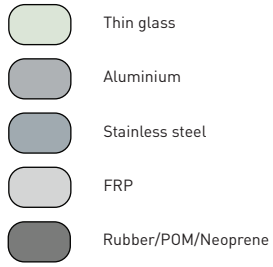
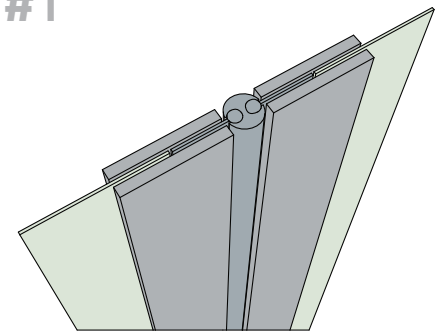




CATEGORY **EXTRUDED PROFILE**

#1



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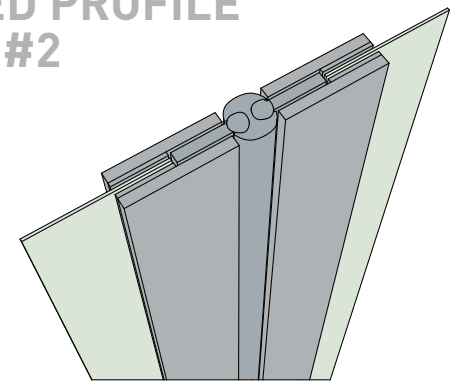

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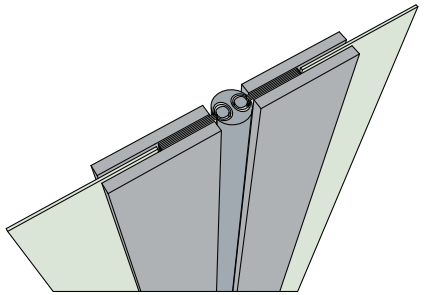

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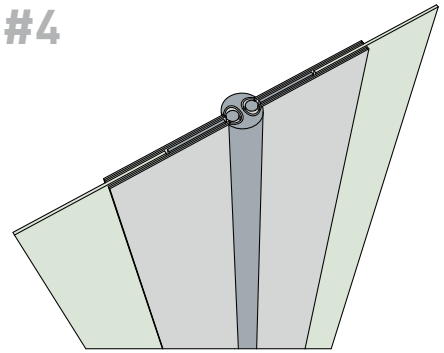
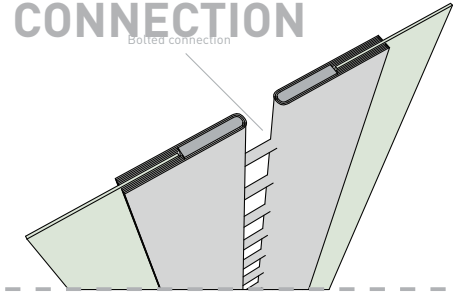


#5

CATEGORY **BOLTED CONNECTION**



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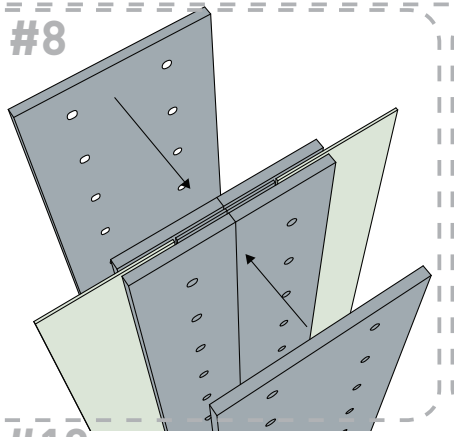

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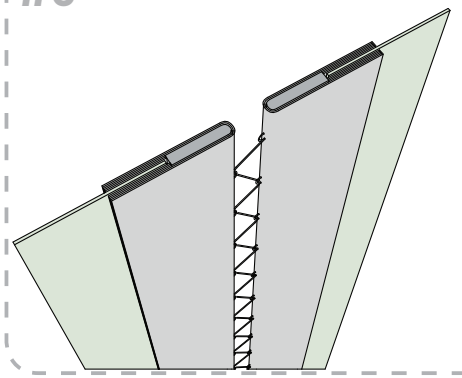

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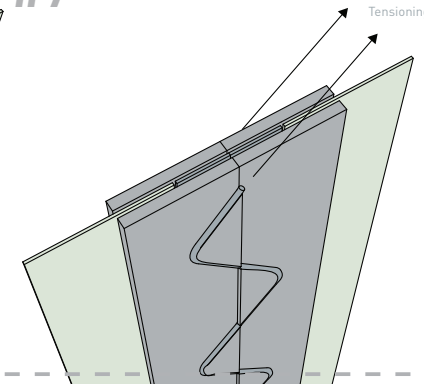

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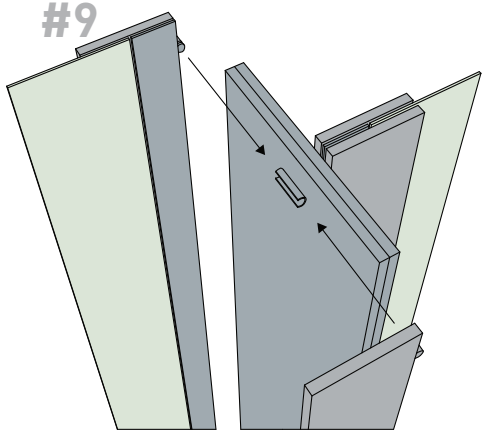

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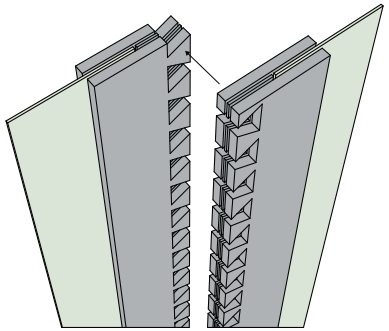

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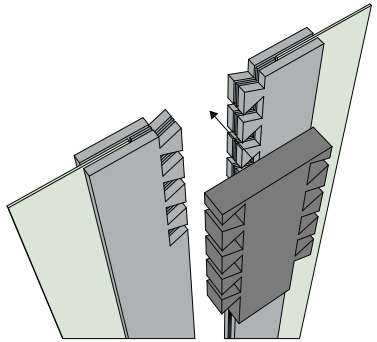
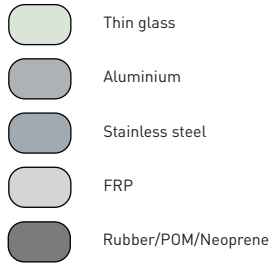
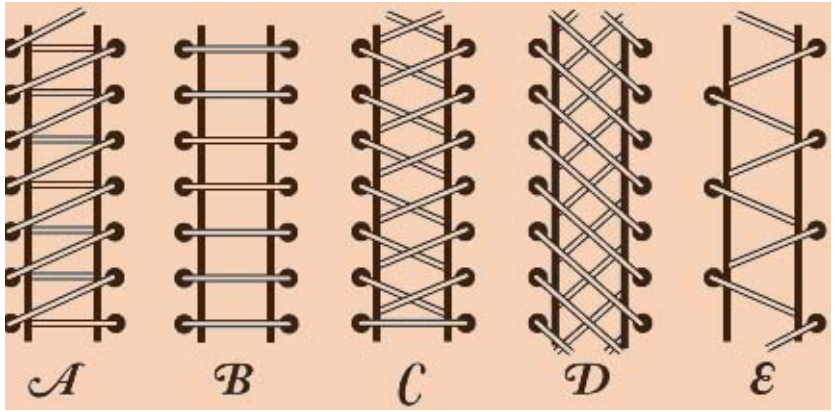
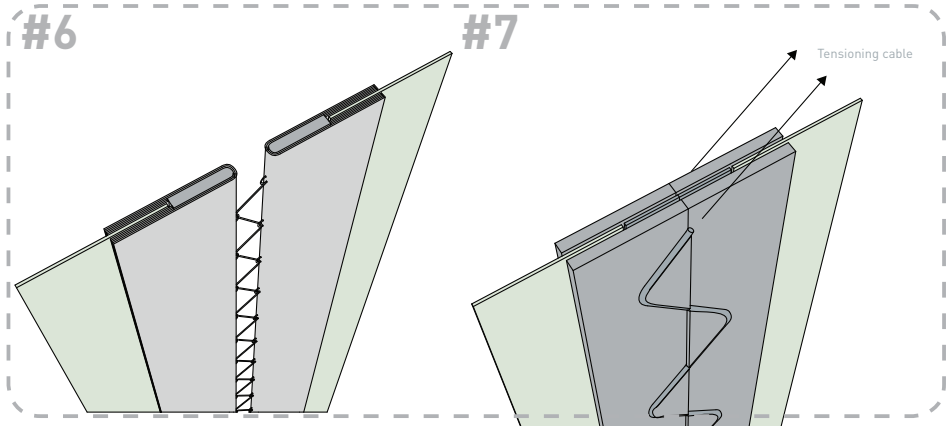
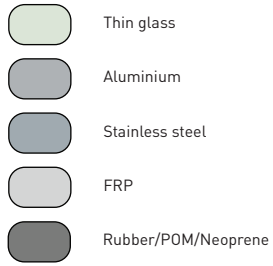




CATEGORY **LACING**

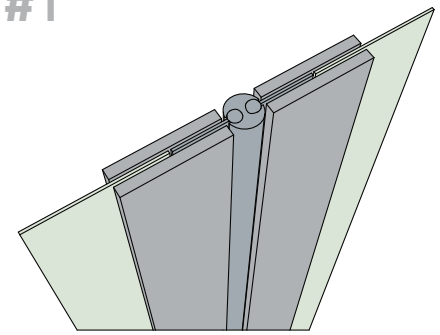






CATEGORY **EXTRUDED PROFILE**

#1



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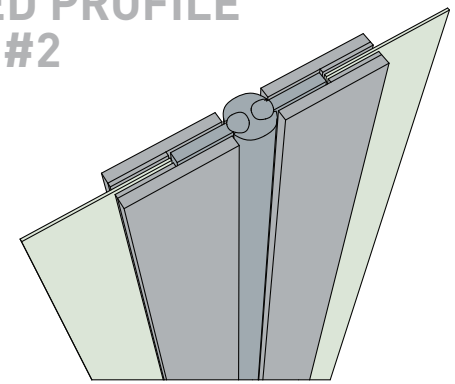

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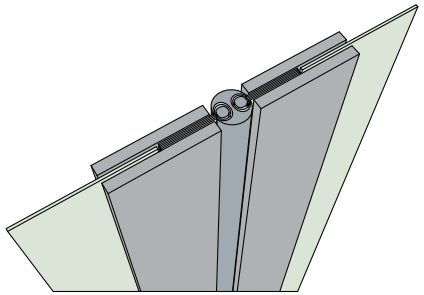

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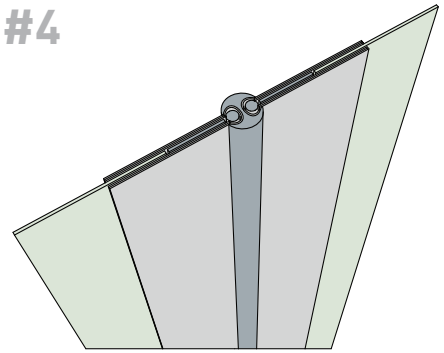
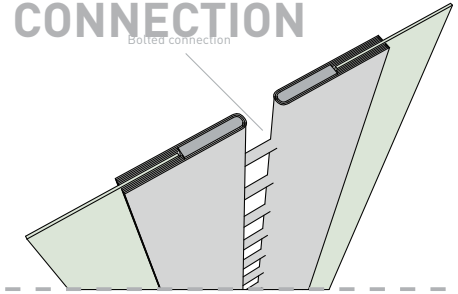


#5

CATEGORY **BOLTED CONNECTION**



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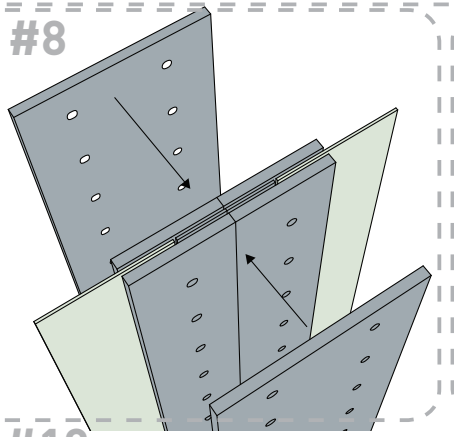
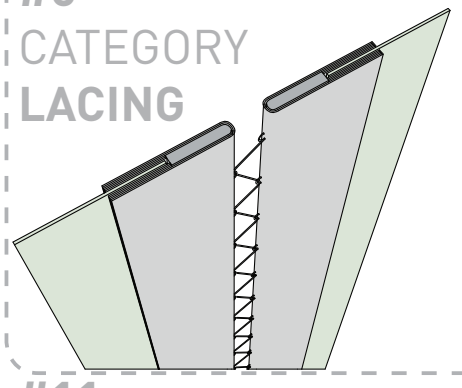


#6

CATEGORY **LACING**



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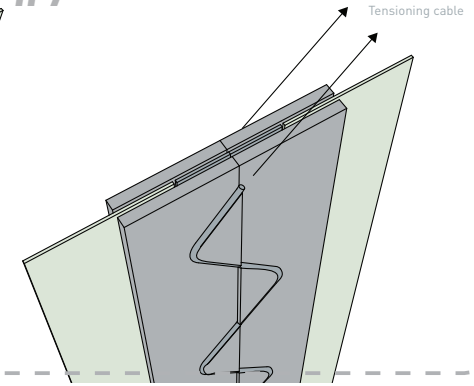

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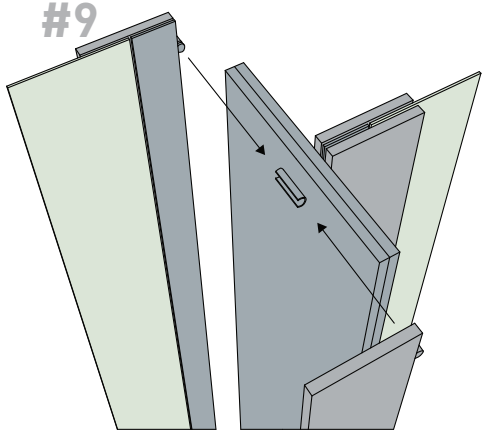

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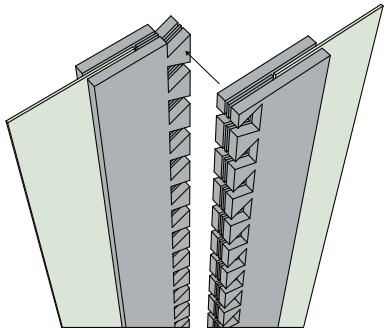

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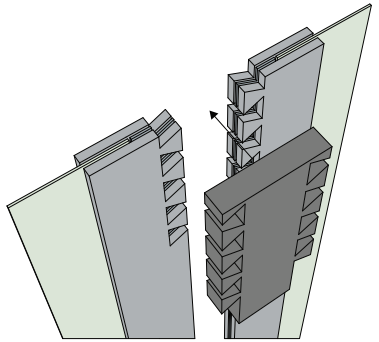
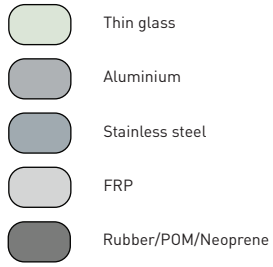
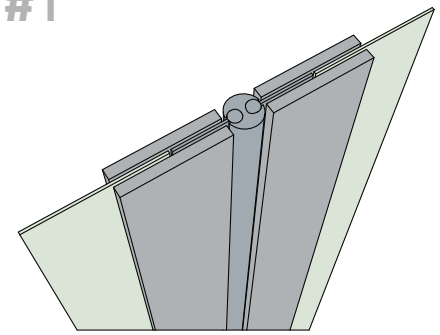


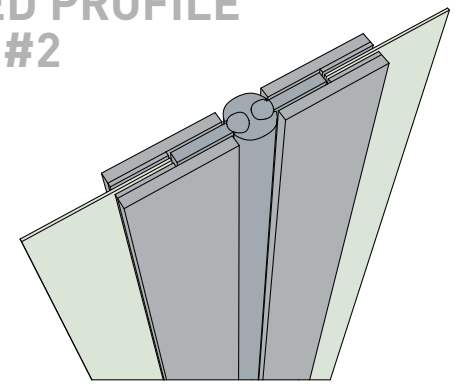


CATEGORY **EXTRUDED PROFILE**

#1



#2



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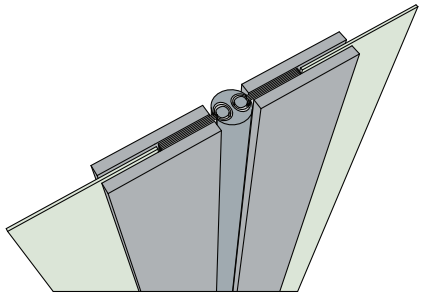

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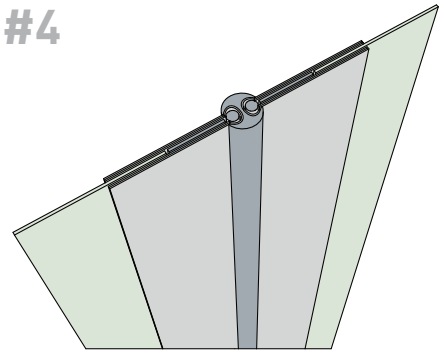
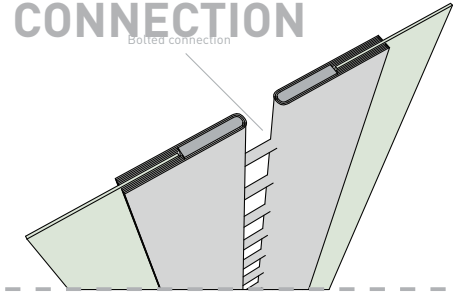


#5

CATEGORY **BOLTED CONNECTION**



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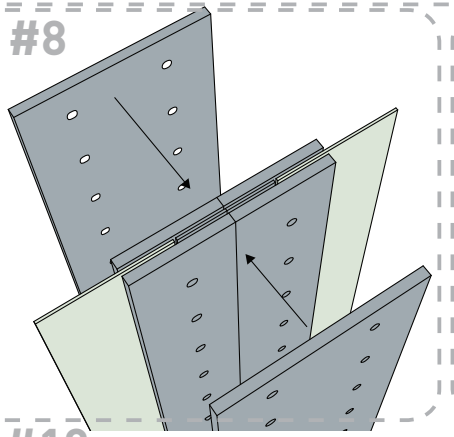
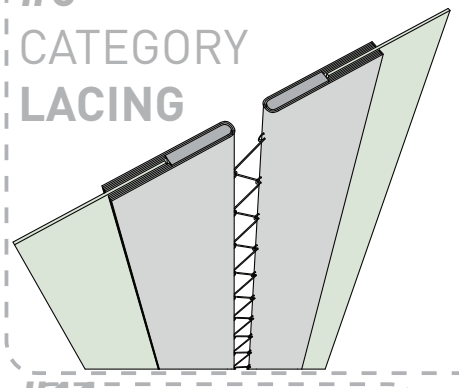


#6

CATEGORY **LACING**



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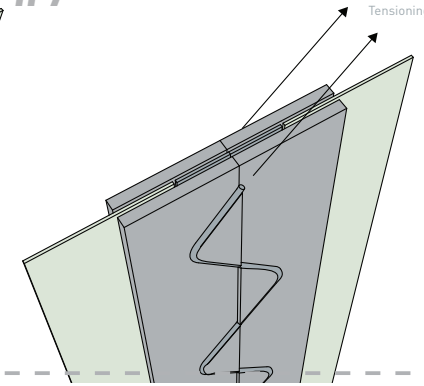

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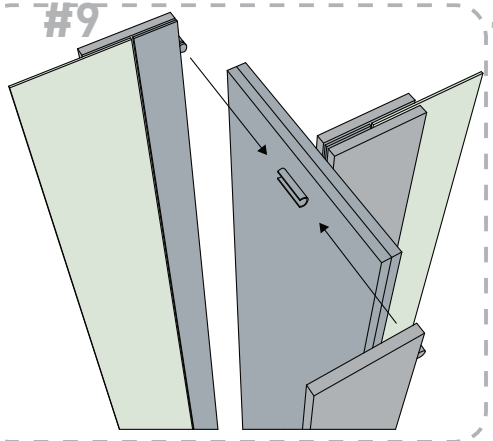

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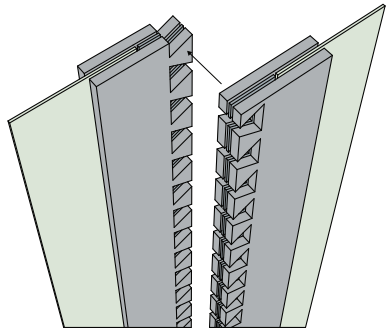

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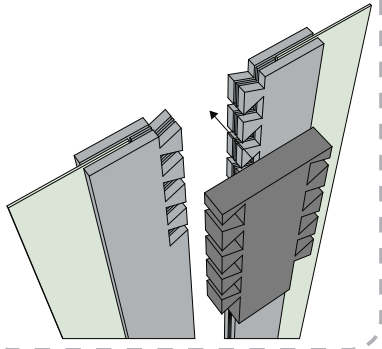
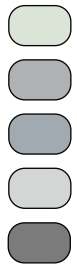
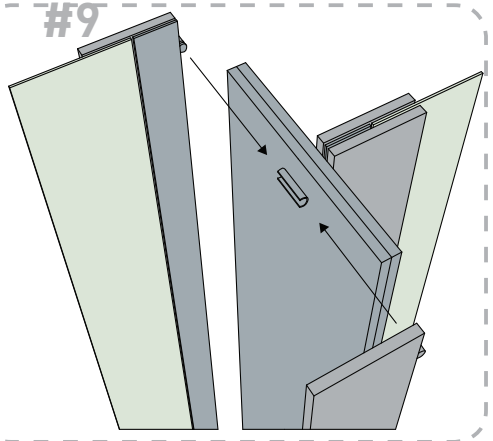




CATEGORY **SUBSTRUCTURE**

#9



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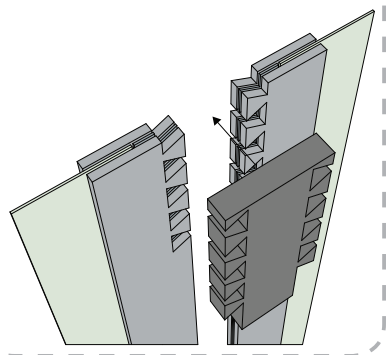
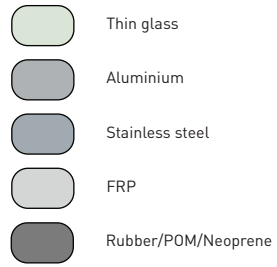
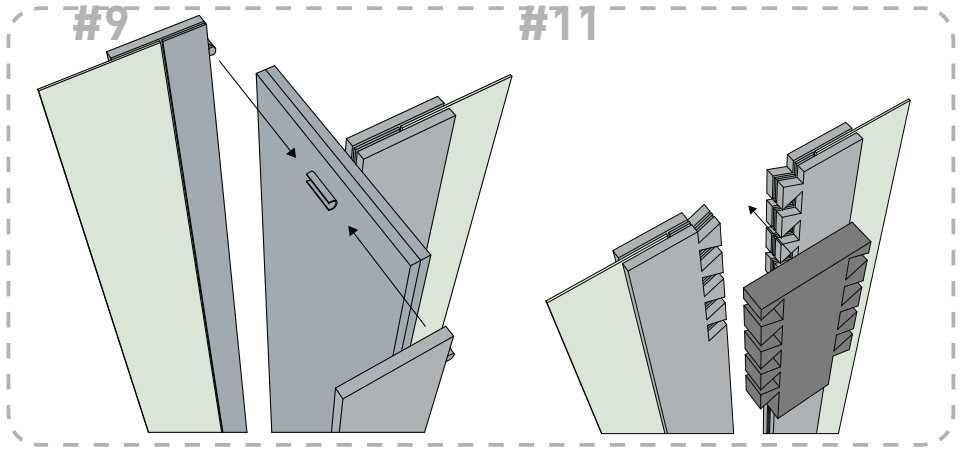




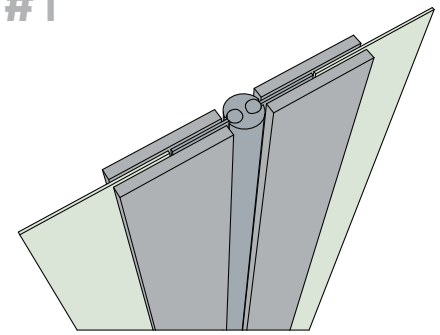
CATEGORY **SUBSTRUCTURE**



Thin glass
Aluminium
Stainless steel
FRP
Rubber/POM/Neoprene

CATEGORY **EXTRUDED PROFILE**

#1



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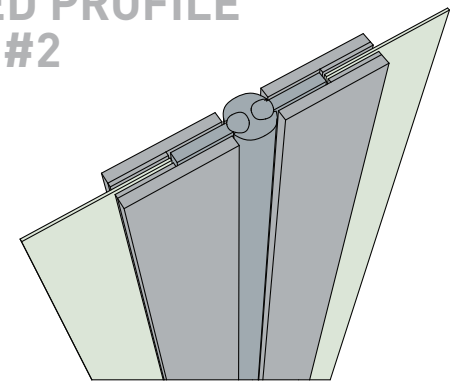

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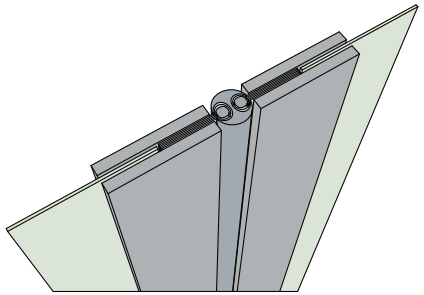
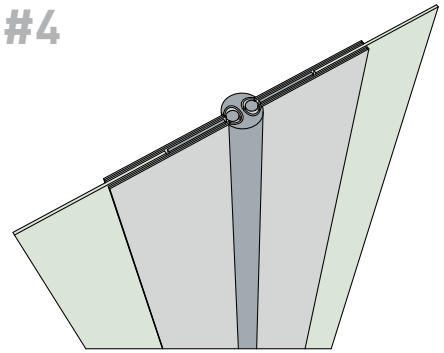
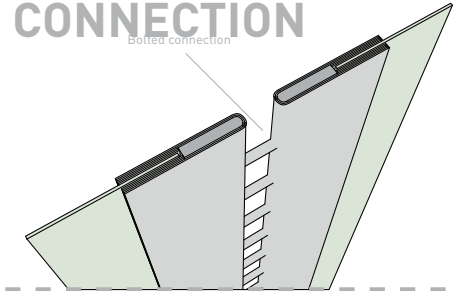


#4



#5

CATEGORY **BOLTED CONNECTION**



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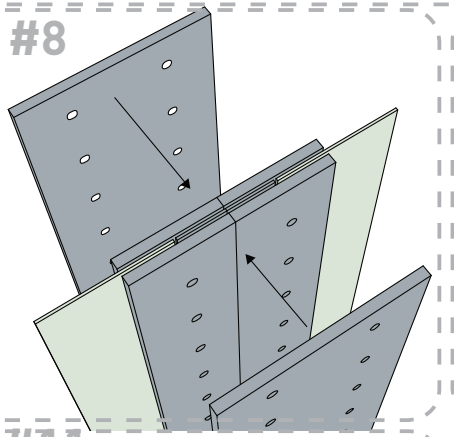
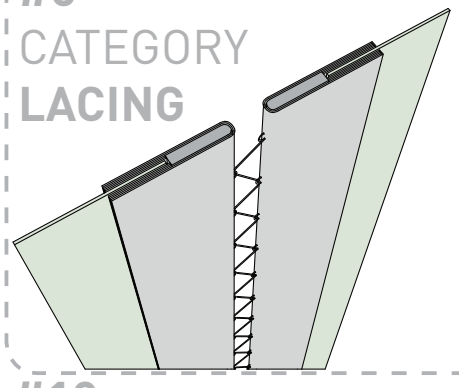


#6

CATEGORY **LACING**



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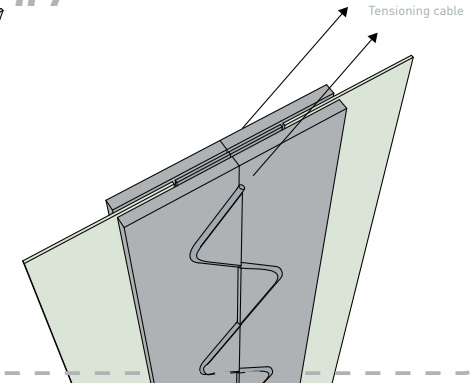

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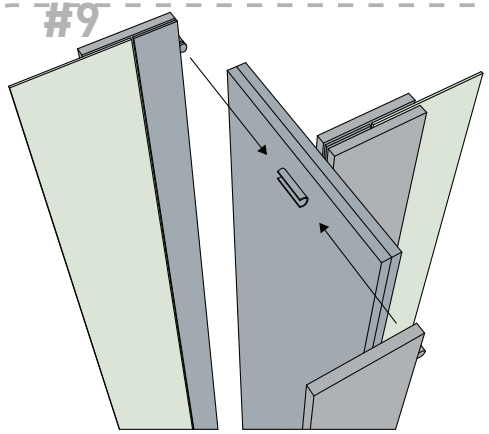
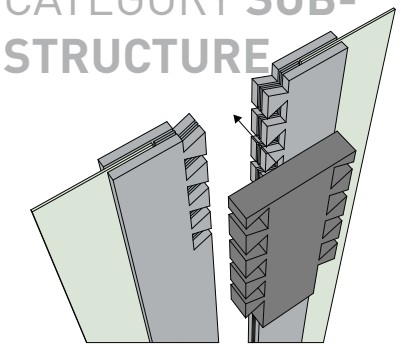


#11

CATEGORY **SUB-STRUCTURE**



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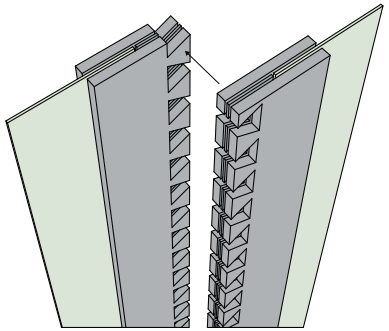
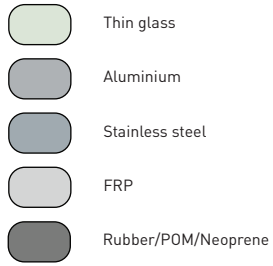
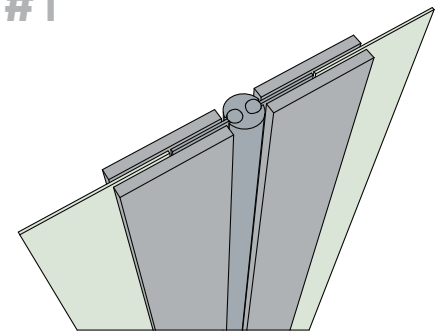




CATEGORY **EXTRUDED PROFILE**

#1



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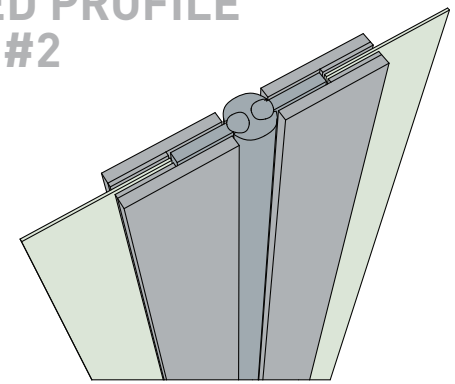

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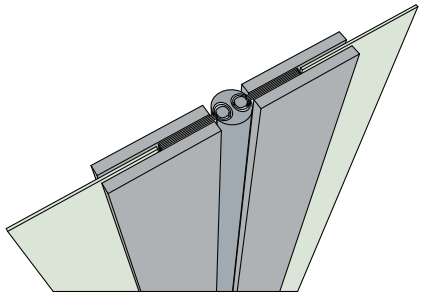

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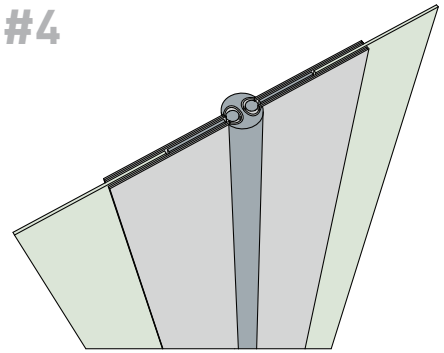
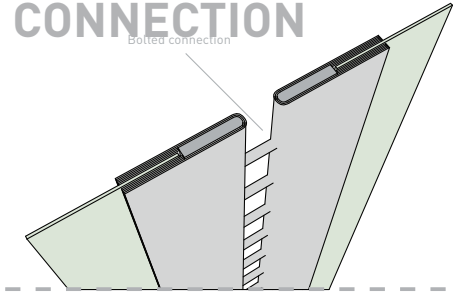


#5

CATEGORY **BOLTED CONNECTION**



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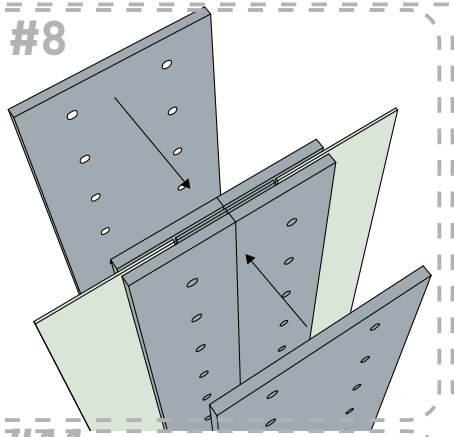
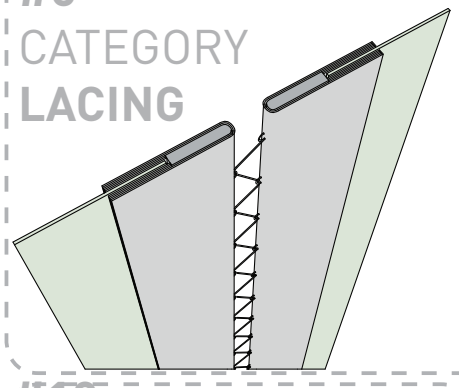


#6

CATEGORY **LACING**



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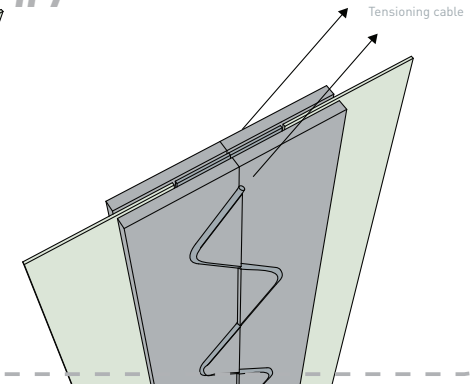

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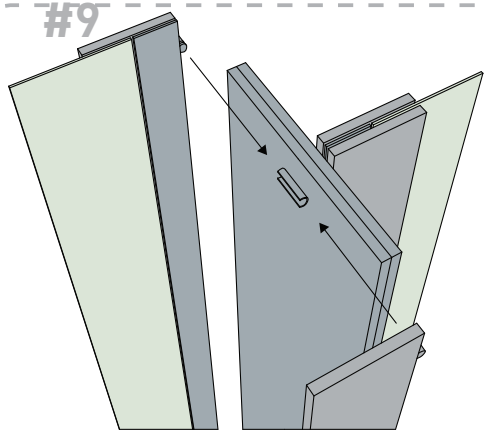
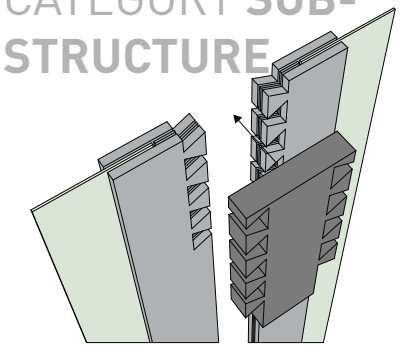


#11

CATEGORY **SUB-STRUCTURE**



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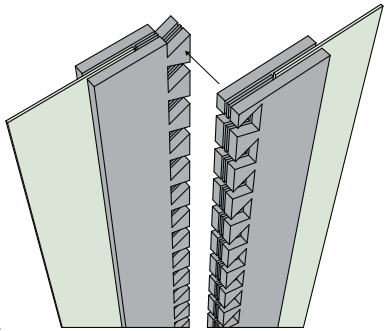
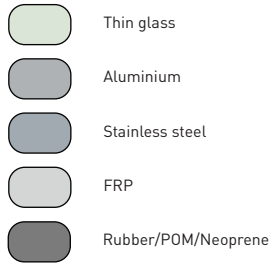
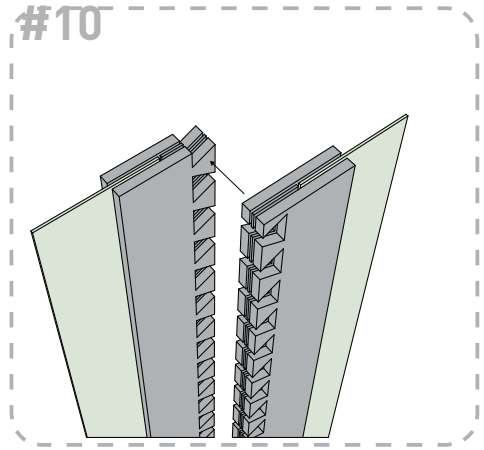
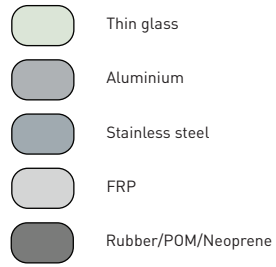




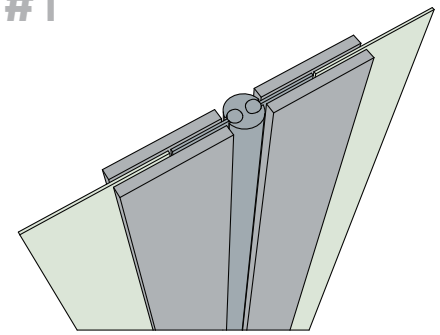
CATEGORY **CLEAN CONNECTION**



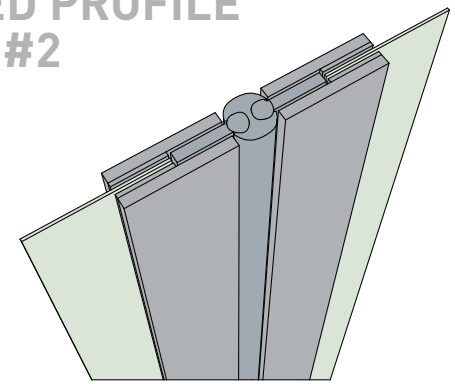


CATEGORY **EXTRUDED PROFILE**

#1



#2



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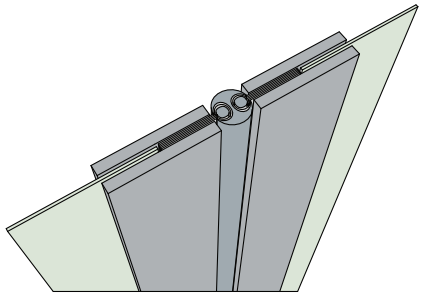

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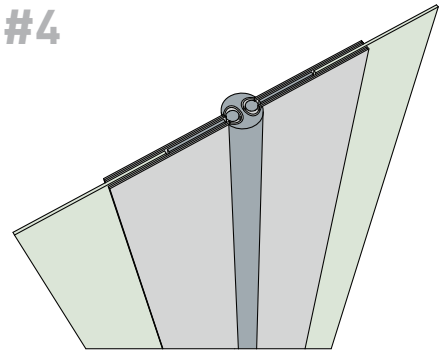
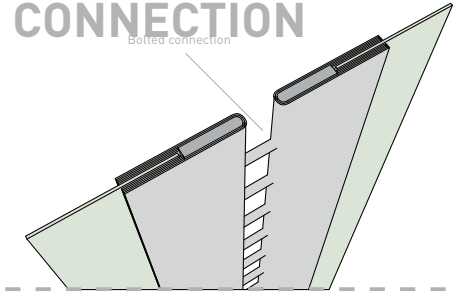
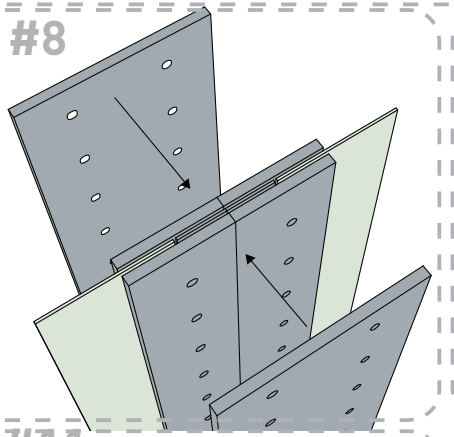


#5

CATEGORY **BOLTED CONNECTION**

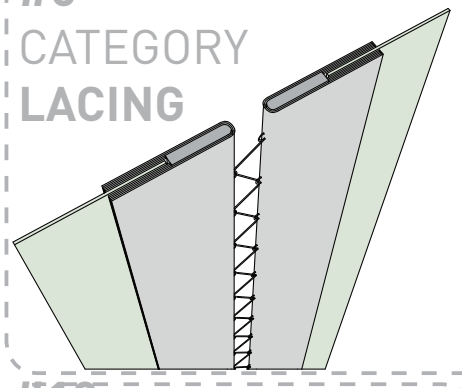


#8



#6

CATEGORY **LACING**



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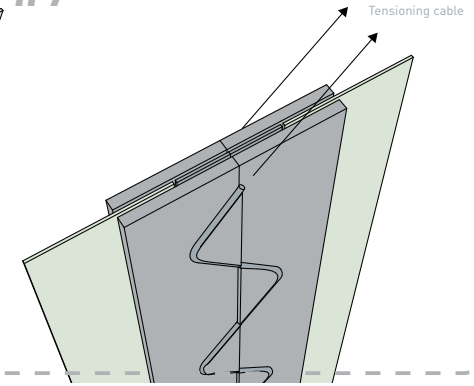

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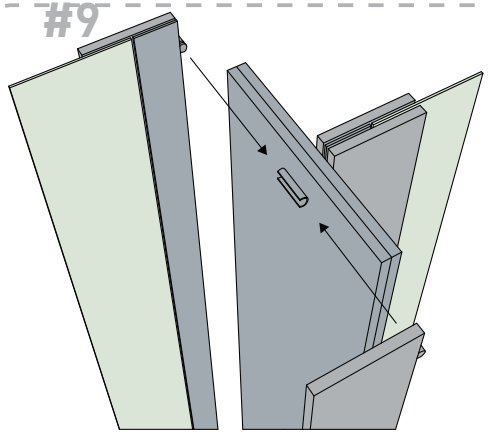
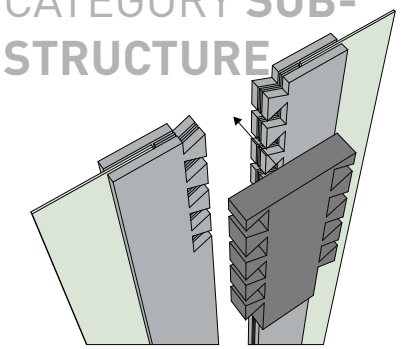


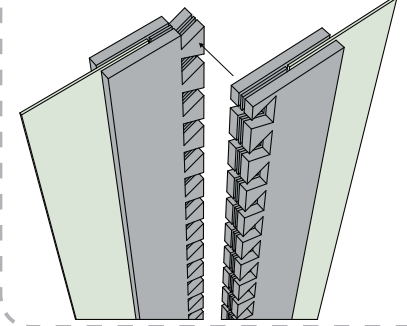
#11

CATEGORY **SUB-STRUCTURE**



#10

CATEGORY **CLEAN CONNECTION**



Thin glass

Aluminium

Stainless steel

FRP

Rubber/POM/Neoprene

CATEGORY **EXTRUDED PROFILE**

I

CATEGORY **BOLTED CONNECTION**

II

CATEGORY **LACING**

III

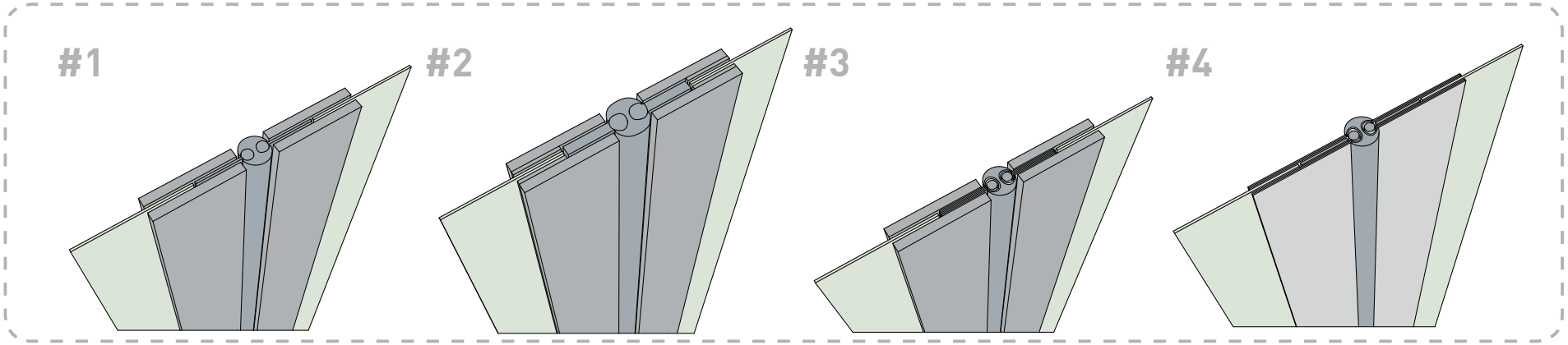
CATEGORY **SUB-STRUCTURE**

IV

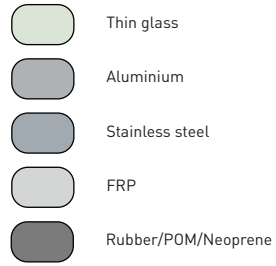
CATEGORY **CLEAN CONNECTION**

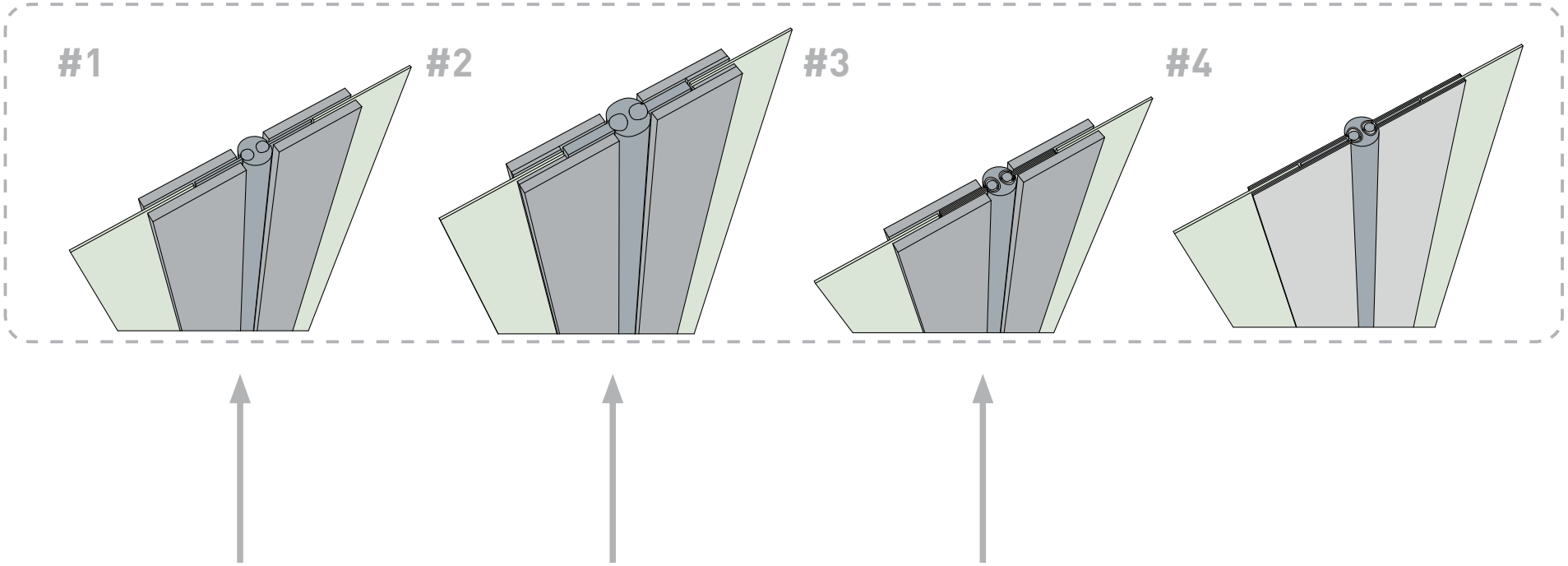
V

- Thin glass
- Aluminium
- Stainless steel
- FRP
- Rubber/POM/Neoprene



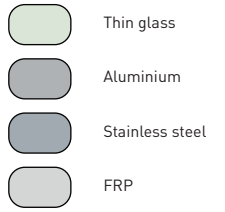
CATEGORY I **EXTRUDED PROFILE**

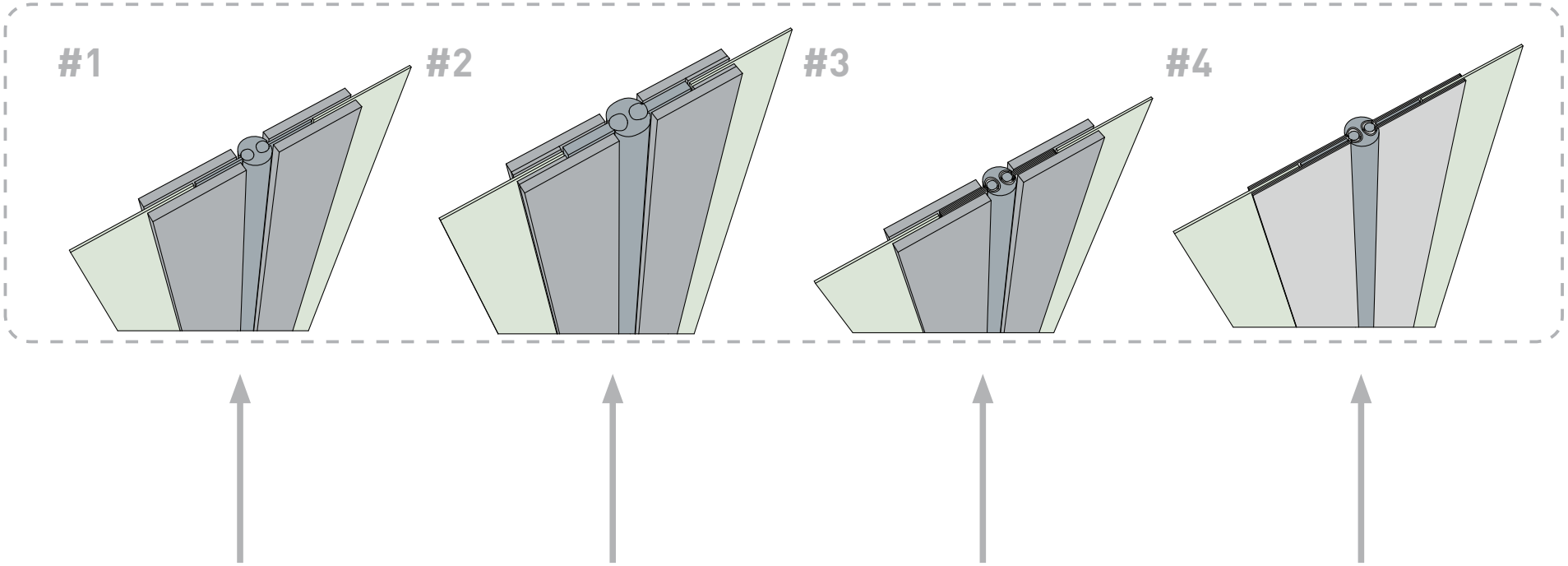




- TOO HEAVY

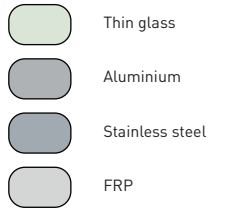
CATEGORY I **EXTRUDED PROFILE**

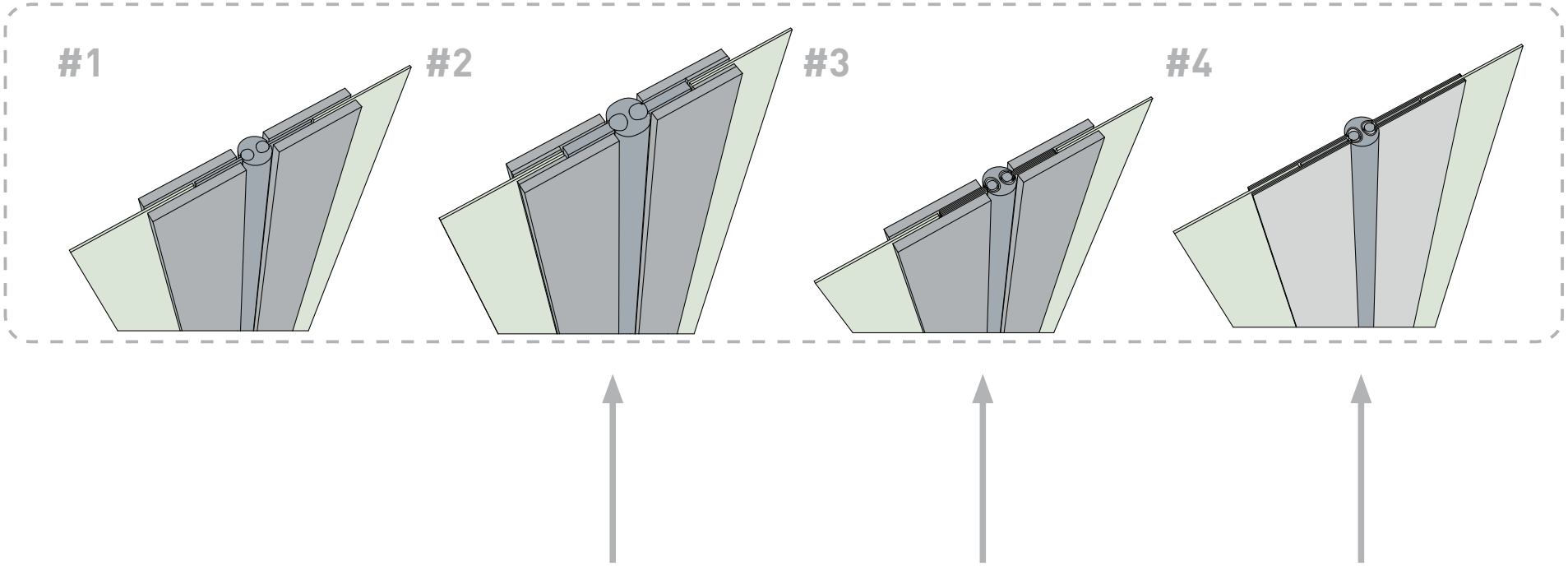




- HIGH INTERNAL STRESSES IN EXTRUDED PROFILE

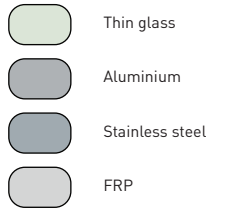
CATEGORY I **EXTRUDED PROFILE**

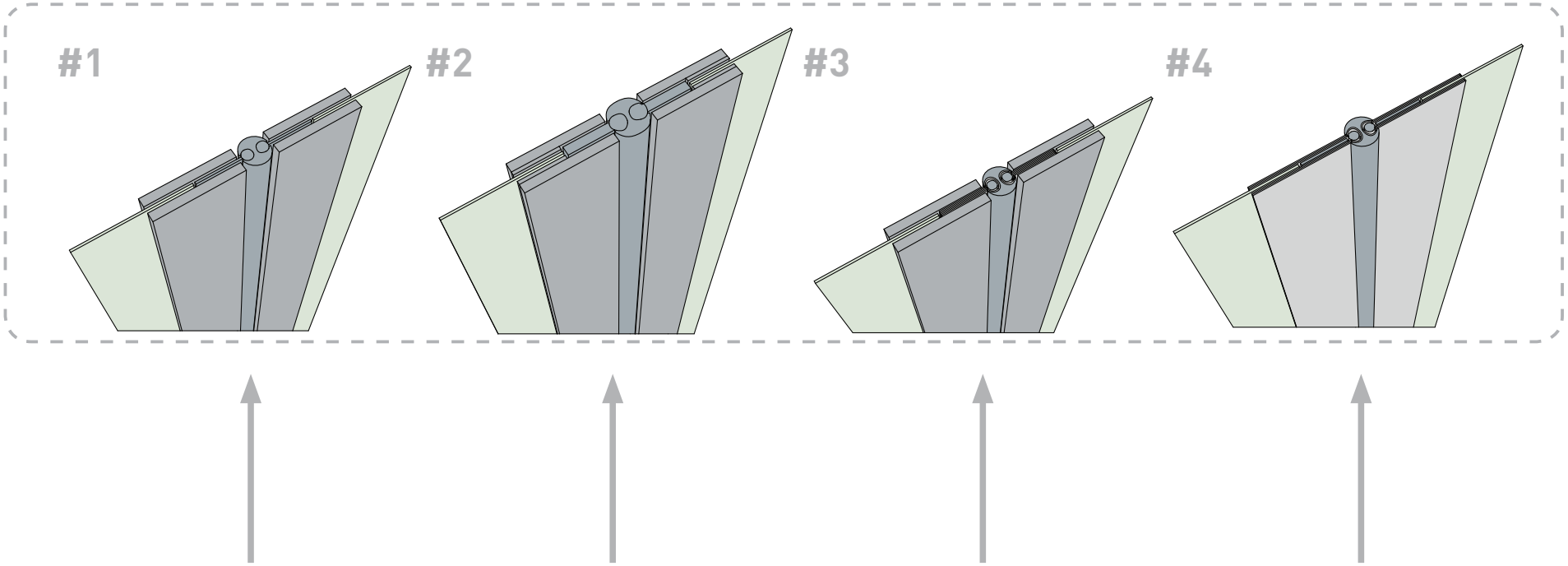




- DIFFICULT TO FABRICATE

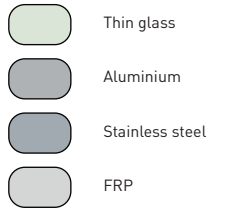
CATEGORY I **EXTRUDED PROFILE**

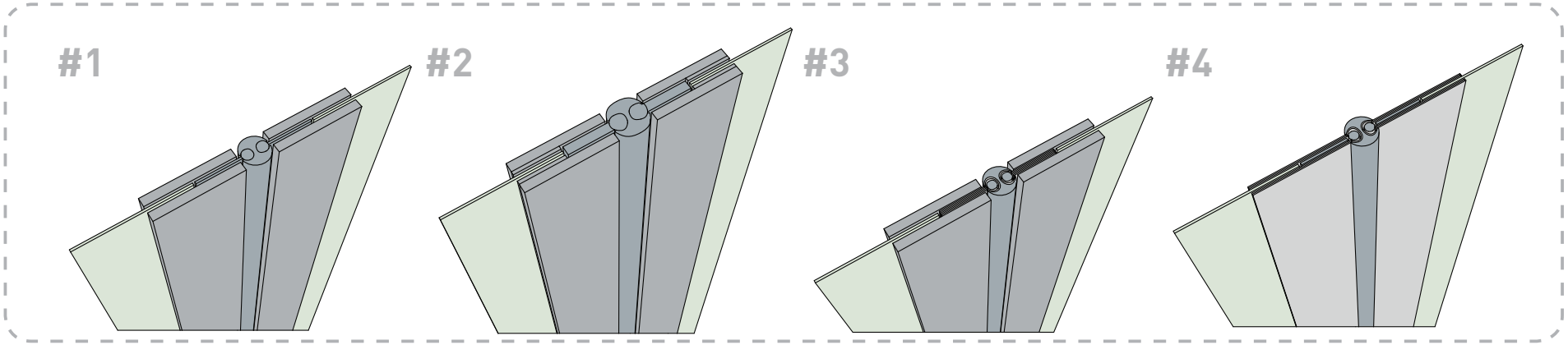




- DIFFICULT TO ASSEMBLY

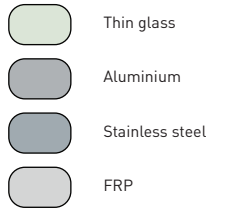
CATEGORY I **EXTRUDED PROFILE**



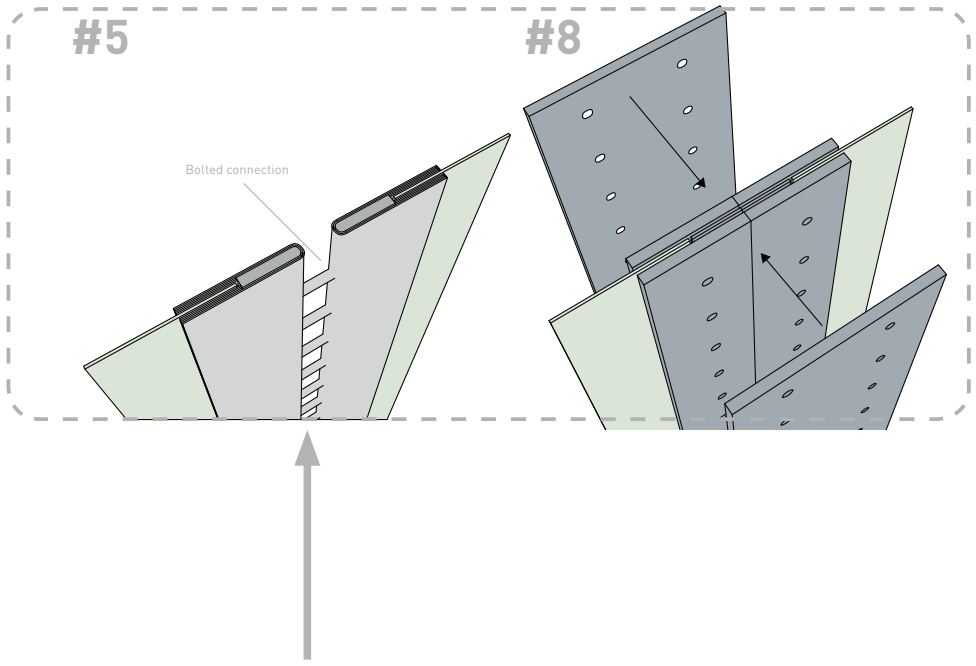


+ TENSILE STRESSES CAN BE CONTROLED BY COMPOSITE MATERIAL

CATEGORY I **EXTRUDED PROFILE**



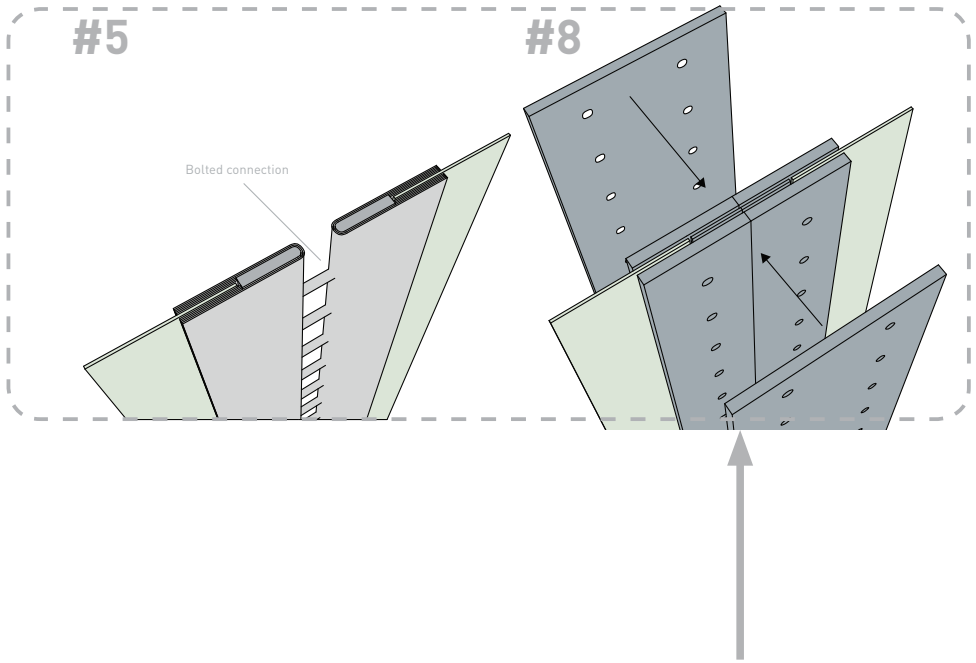
CATEGORY II **BOLTED CONNECTION**



- DISTANCE BETWEEN PANELS

Thin glass
Aluminium
Stainless steel
FRP

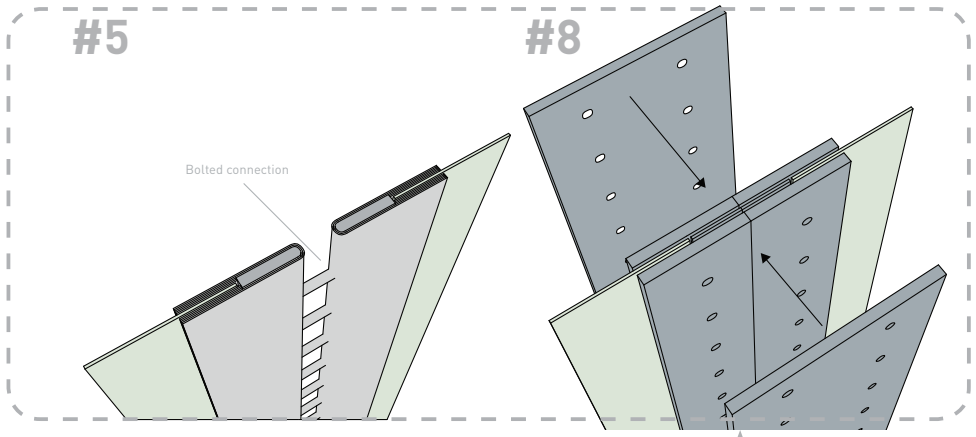
CATEGORY II **BOLTED CONNECTION**



+ REDUCED DISTANCE BETWEEN PANELS

Thin glass
Aluminium
Stainless steel
FRP

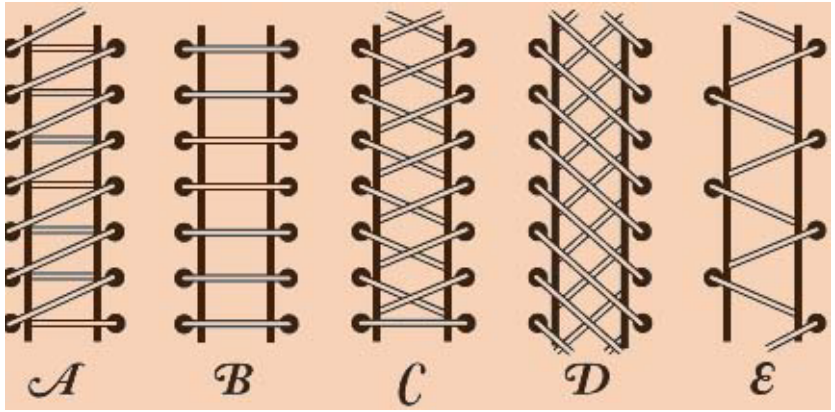
CATEGORY II **BOLTED CONNECTION**

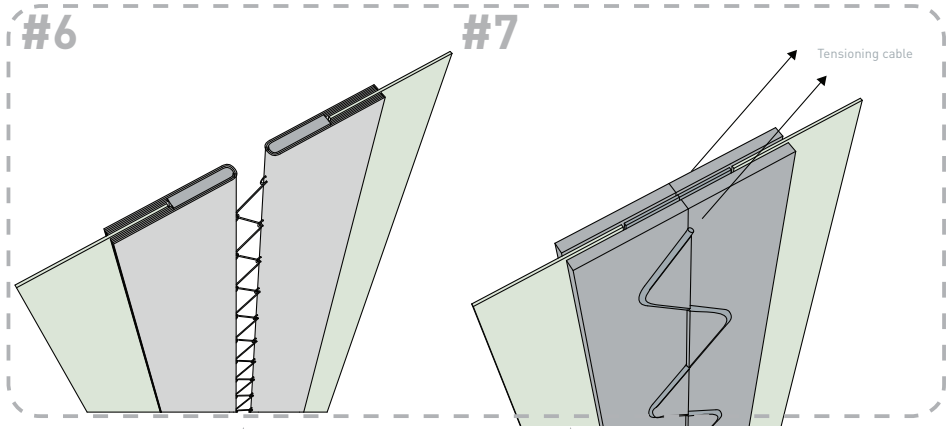


- LOTS OF BOLTS

Thin glass
Aluminium
Stainless steel
FRP

CATEGORY III **LACING**



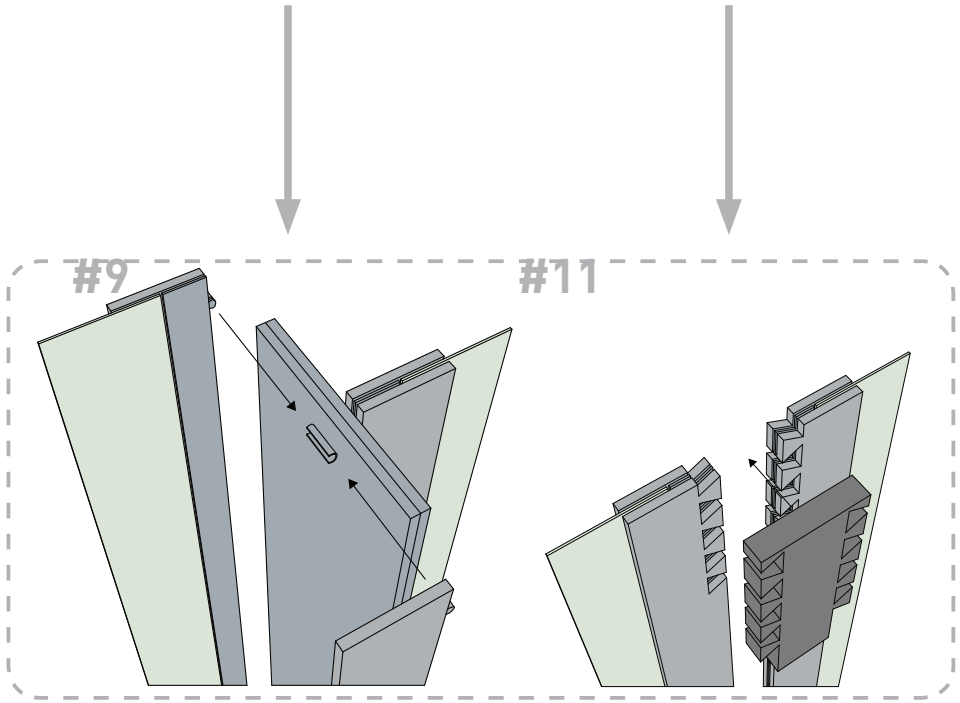


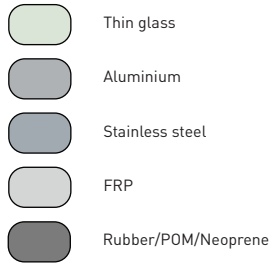
- DIFFICULT TO MOUNT

Thin glass
Aluminium
Stainless steel
FRP

CATEGORY IV **SUBSTRUCTURE**

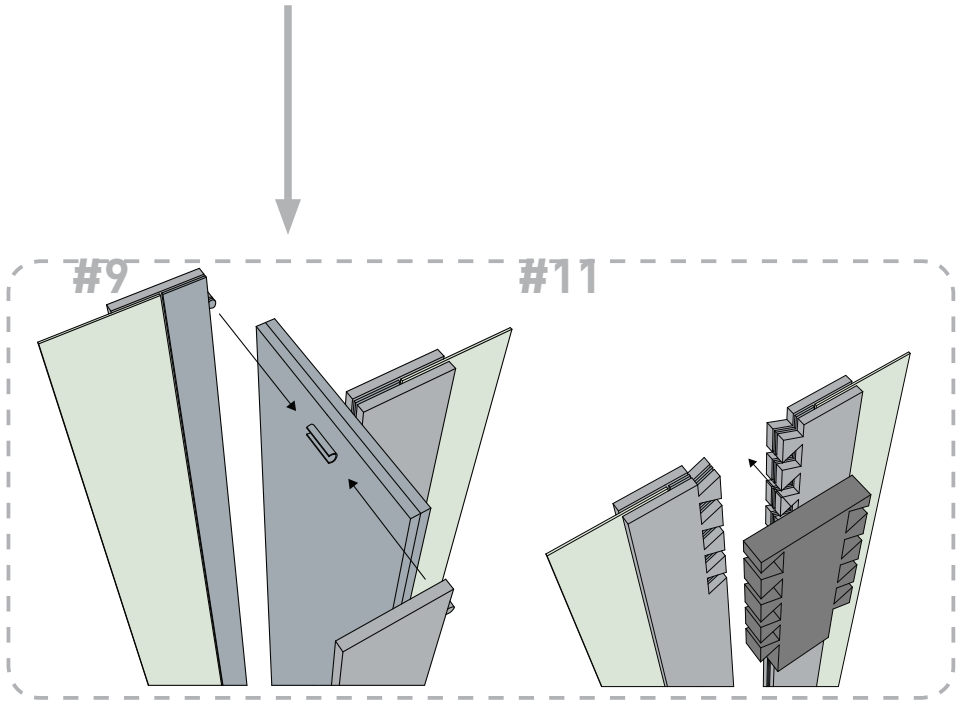
- LOTS OF SUBSTRUCTURE → LOOSING TRANSPARENCY

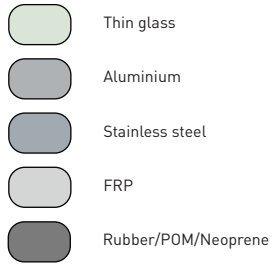




CATEGORY IV **SUBSTRUCTURE**

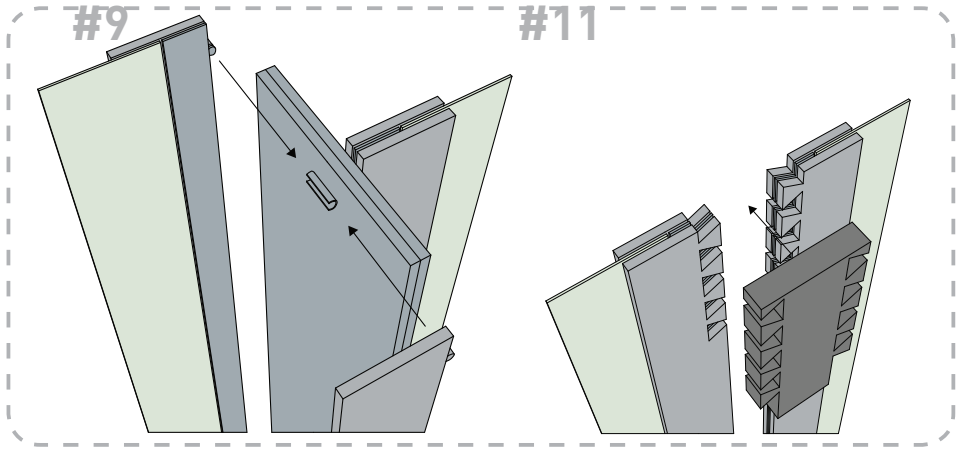
- NO CONTROL OF APPLIED TENSION

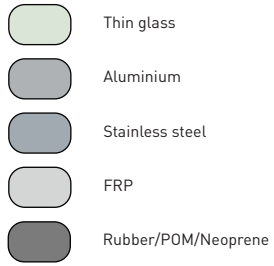




CATEGORY IV **SUBSTRUCTURE**

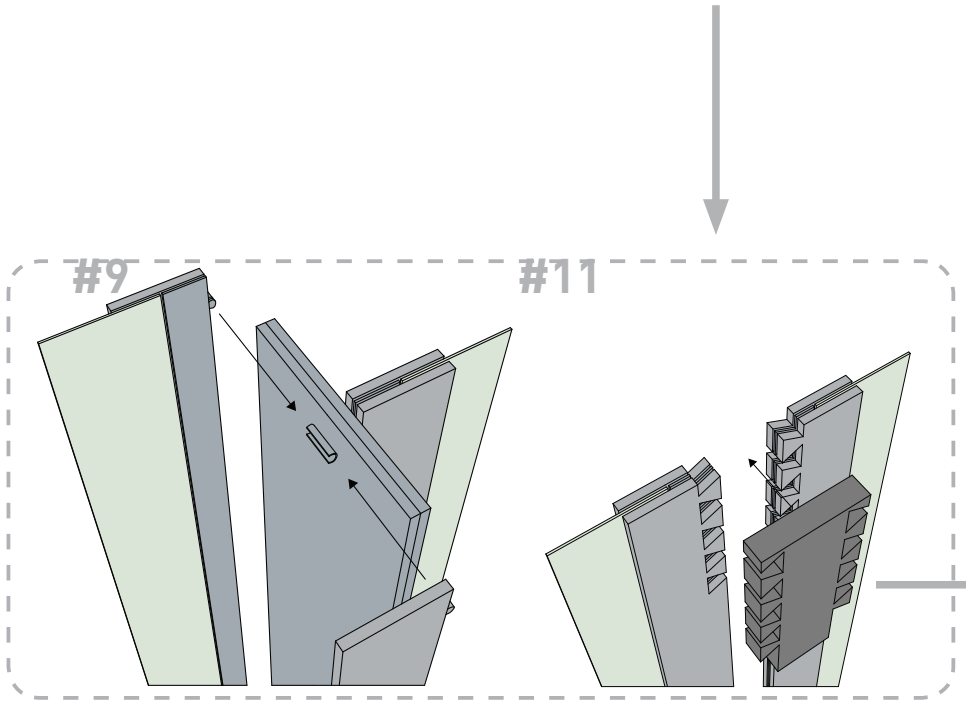
+/- ADDED SUBSTRUCTURE OF RUBBER CAN BE STRAINED BUT HAS NO CAPABILITY OF TRANSFERRING TENSION

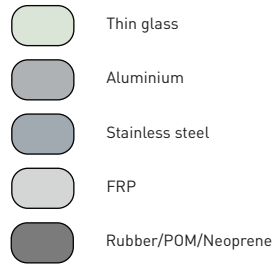




CATEGORY IV **SUBSTRUCTURE**

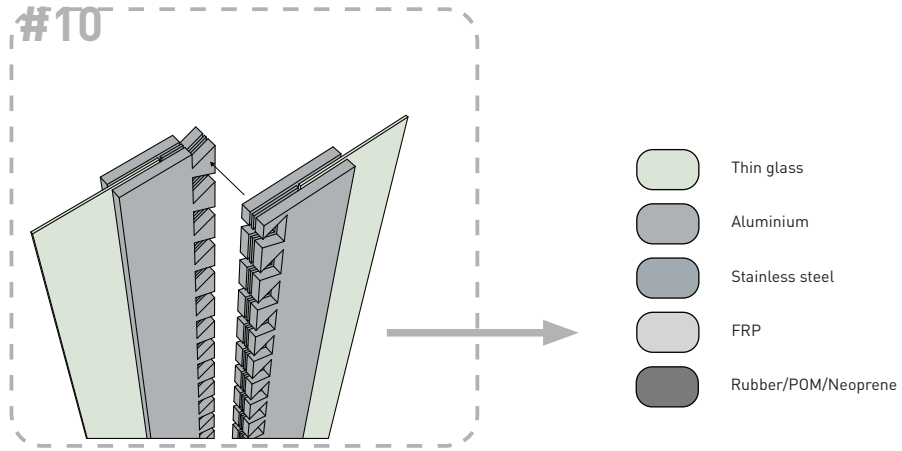
+ ADDING FIBRES WOULD GIVE THE POSSIBILITY OF TRANSFERRING TENSILE STRESSES





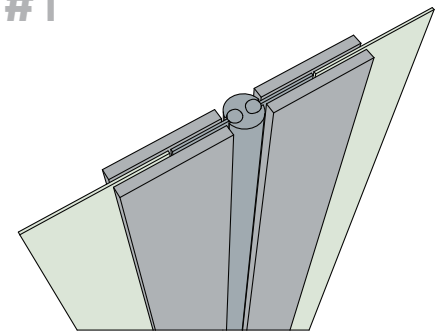
CATEGORY V **CLEAN CONNECTION**

+ BETTER TO MAKE IT FROM 1 MATERIAL WITHOUT THE USE OF EXTRA CONSTRUCTION MATERIAL



CATEGORY **EXTRUDED PROFILE**

#1



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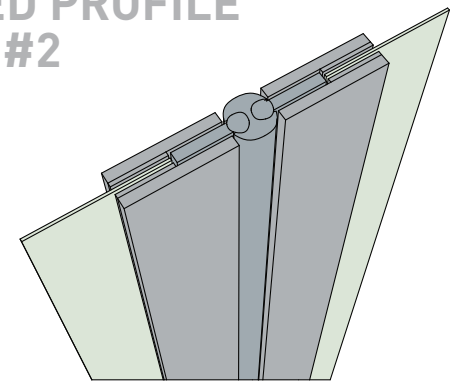

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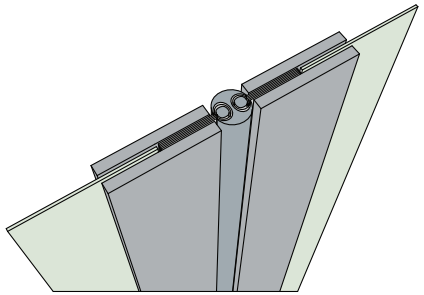

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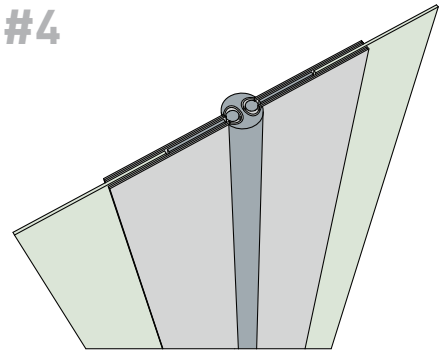
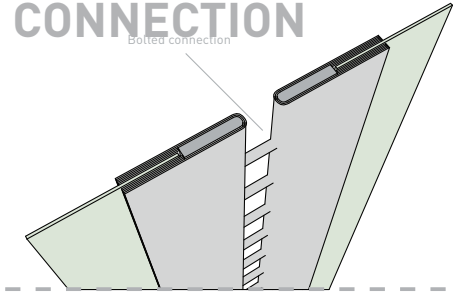


#5

CATEGORY **BOLTED CONNECTION**



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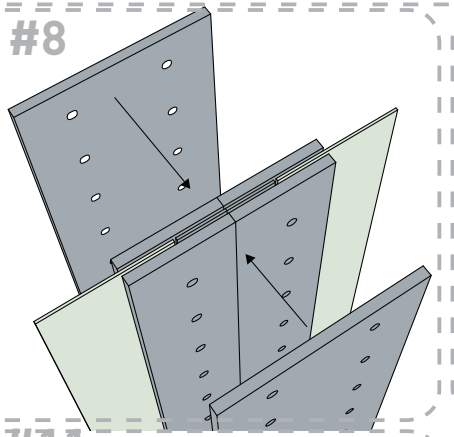
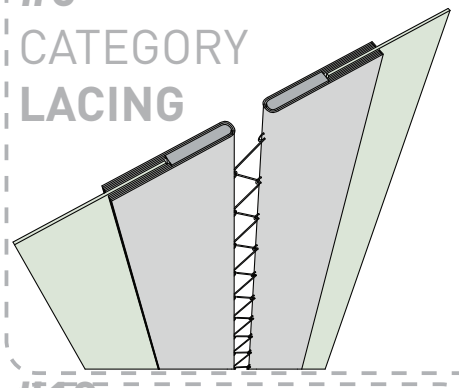


#6

CATEGORY **LACING**



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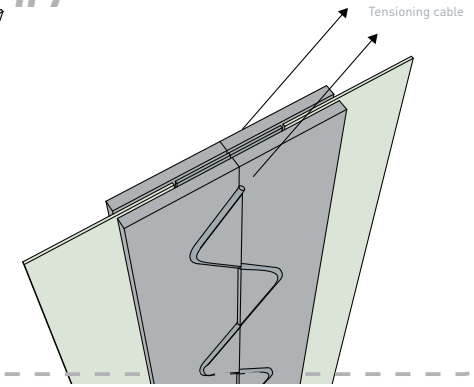

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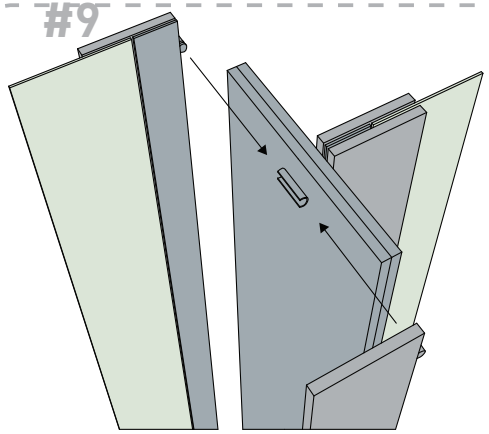
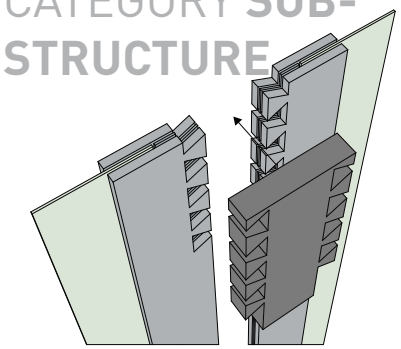


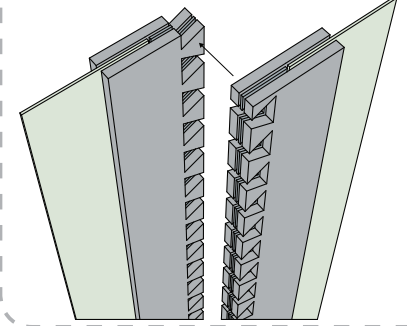
#11

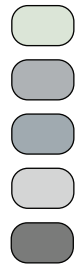
CATEGORY **SUB-STRUCTURE**



#10

CATEGORY **CLEAN CONNECTION**





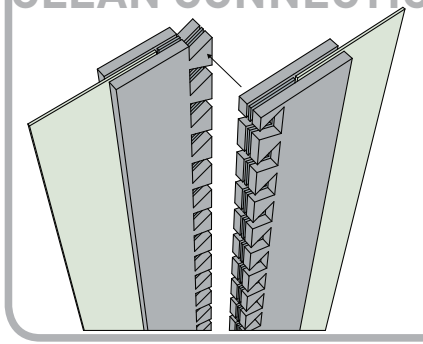
CATEGORY **EXTRUDED PROFILE**

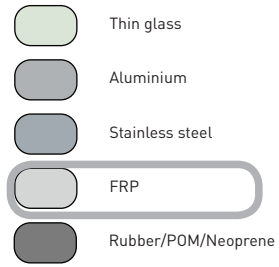
CATEGORY **BOLTED CONNECTION**

CATEGORY **LACING**

CATEGORY **SUB-STRUCTURE**

CATEGORY **CLEAN CONNECTION**

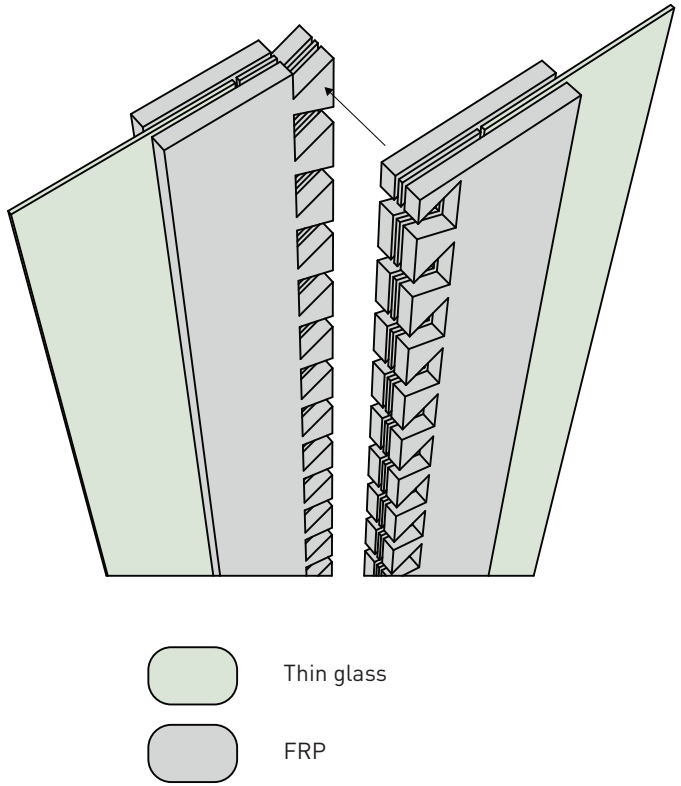


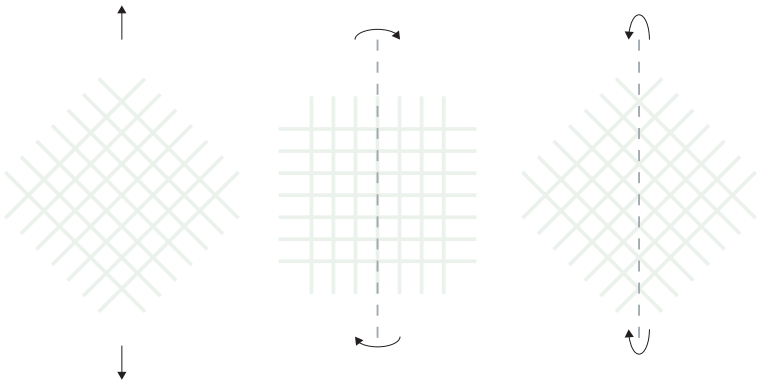


WITH A **COMPOSITE MATERIAL** NEEDED **STRAIN/TENSION** CAN BE CONTROLLED

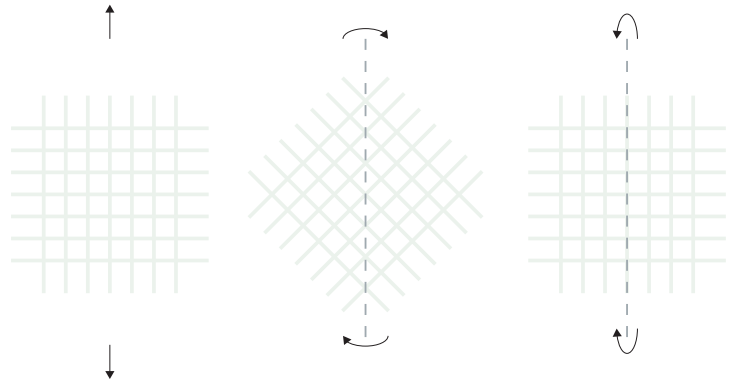
→ MORE LAYERS OF GFRP

→ DIFFERENT DIRECTION OF FIBRES



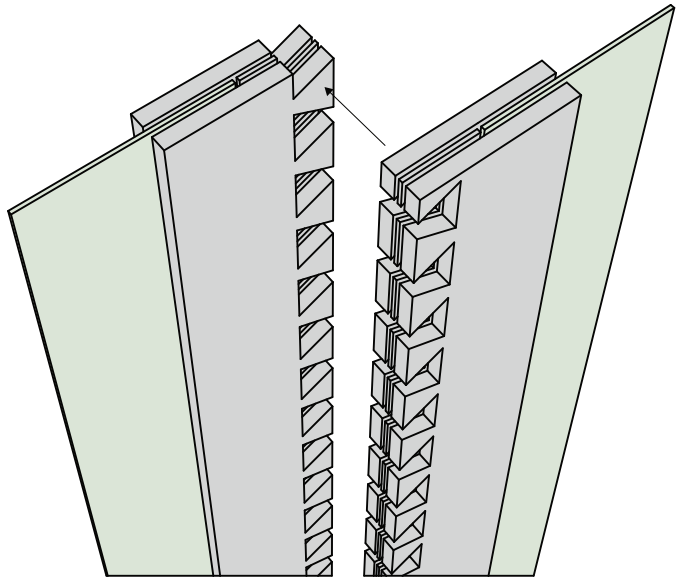


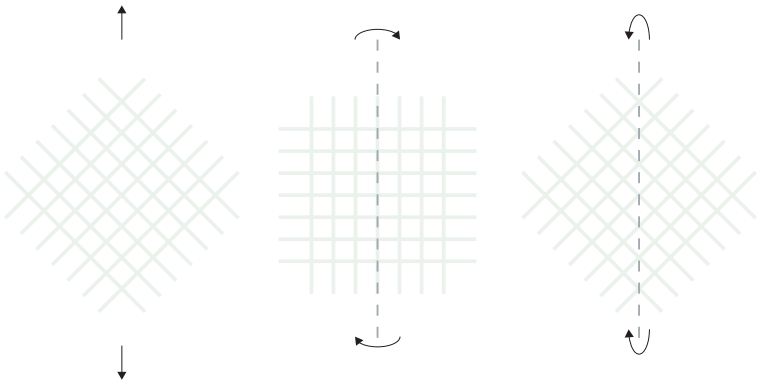
More strain in *low stiffness* direction



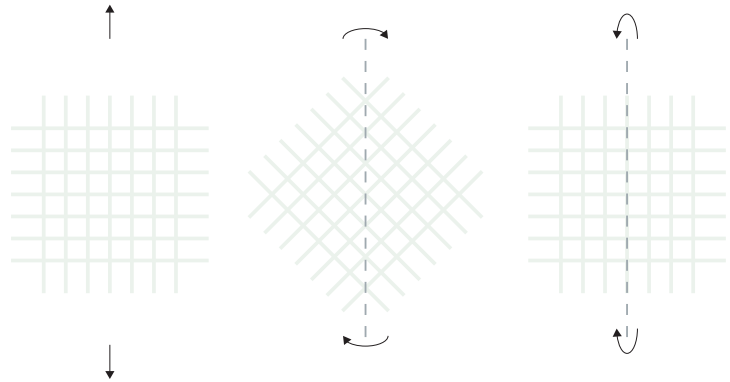
Lower strain in *higher stiffness* direction

WITH A **COMPOSITE MATERIAL** NEEDED **STRAIN/TENSION** CAN BE CONTROLLED



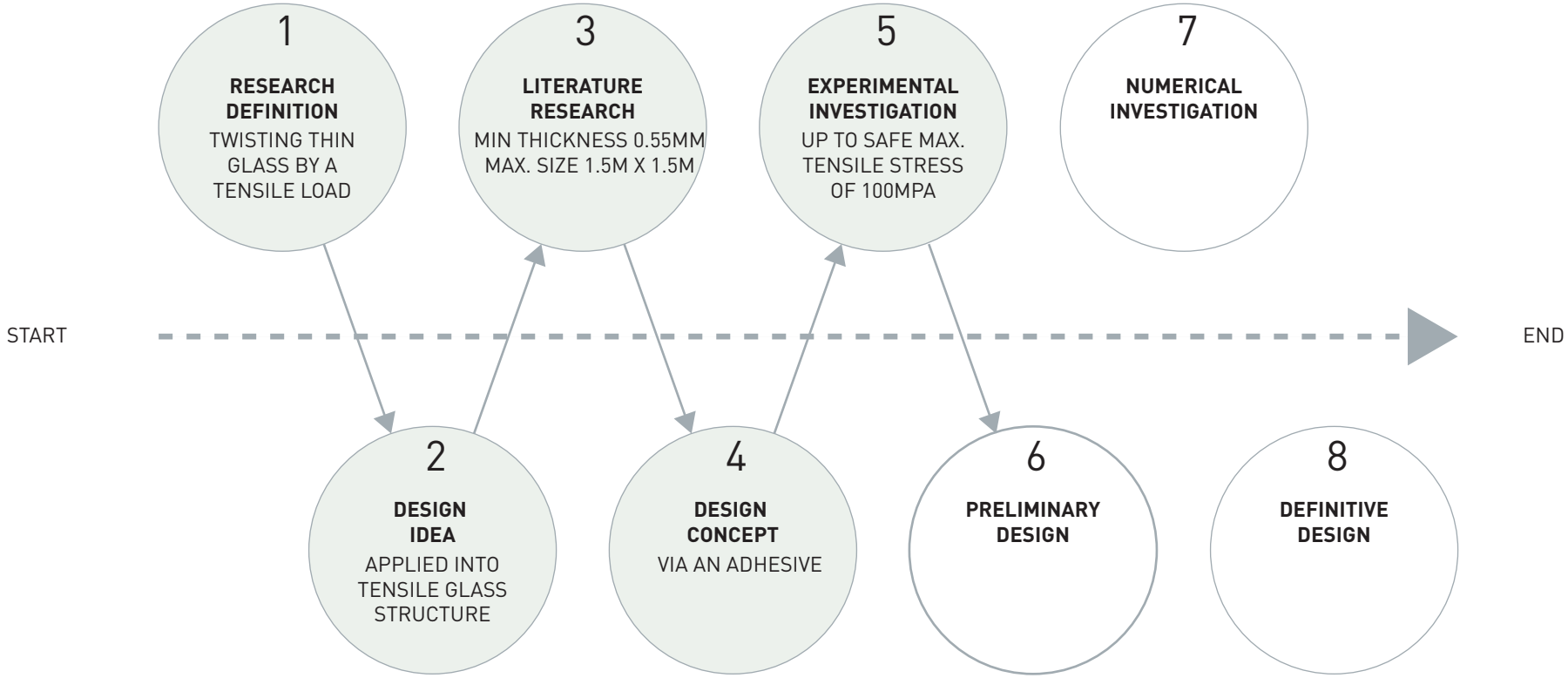


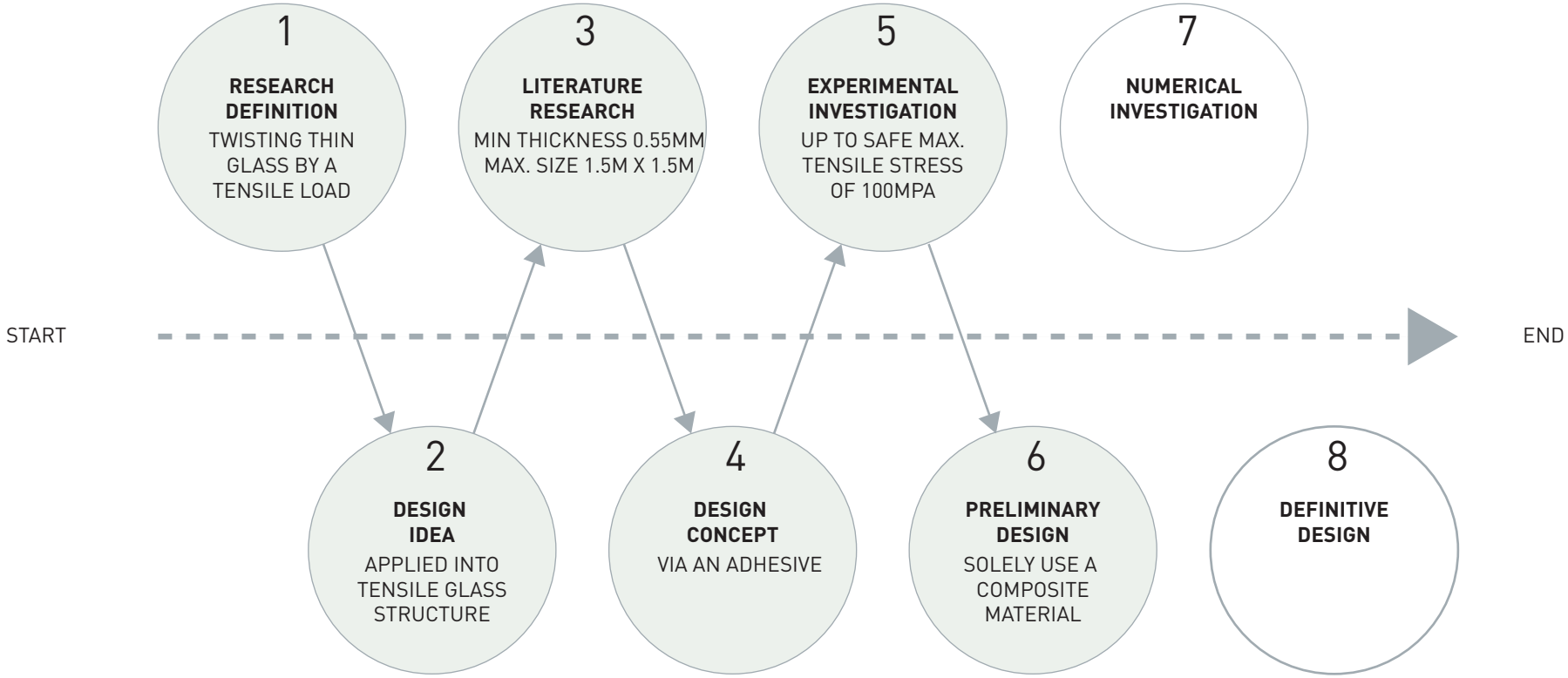
More strain in *low stiffness* direction



Lower strain in *higher stiffness* direction

→ **NUMERICAL SIMULATION**
WILL DETERMINE THE STIFFNESS


1
RESEARCH DEFINITION
TWISTING THIN GLASS BY A TENSILE LOAD
3
LITERATURE RESEARCH
MIN THICKNESS 0.55MM MAX. SIZE 1.5M X 1.5M
5
EXPERIMENTAL INVESTIGATION
UP TO SAFE MAX. TENSILE STRESS OF 100MPA
7
NUMERICAL INVESTIGATION
START
END
2
DESIGN IDEA
APPLIED INTO TENSILE GLASS STRUCTURE
4
DESIGN CONCEPT
VIA AN ADHESIVE
6
PRELIMINARY DESIGN
8
DEFINITIVE DESIGN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APPLIED INTO TENSILE GLASS STRUCTURE
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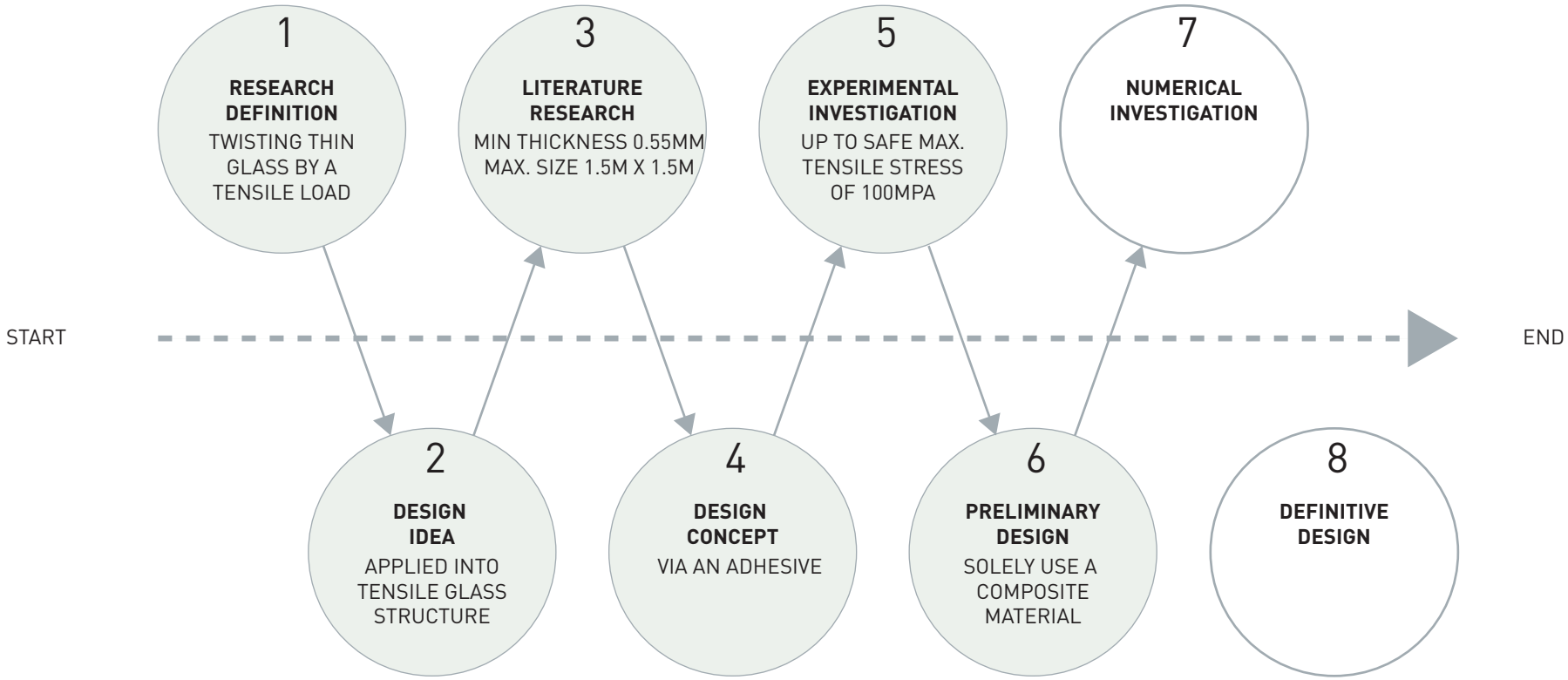
DESIGN CONCEPT
VIA AN ADHESIVE
6
PRELIMINARY DESIGN
SOLELY USE A COMPOSITE MATERIAL
8
DEFINITIVE DESIGN


1
RESEARCH DEFINITION
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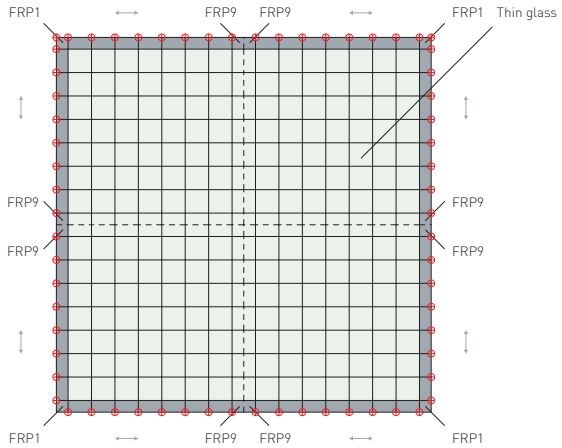
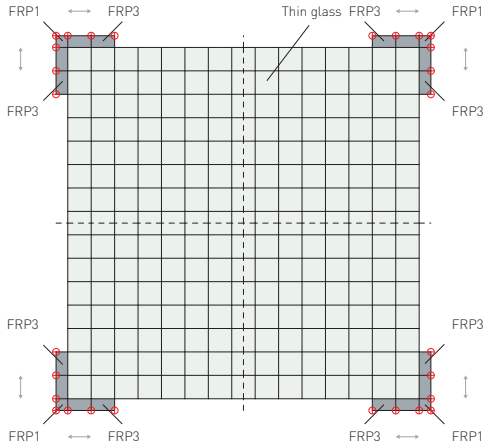
UP TO SAFE MAX. TENSILE STRESS OF 100MPA
6
PRELIMINARY DESIGN
SOLELY USE A COMPOSITE MATERIAL
7
NUMERICAL INVESTIGATION
8
DEFINITIVE DESIGN
START
END

NUMERICAL INVESTIGATION

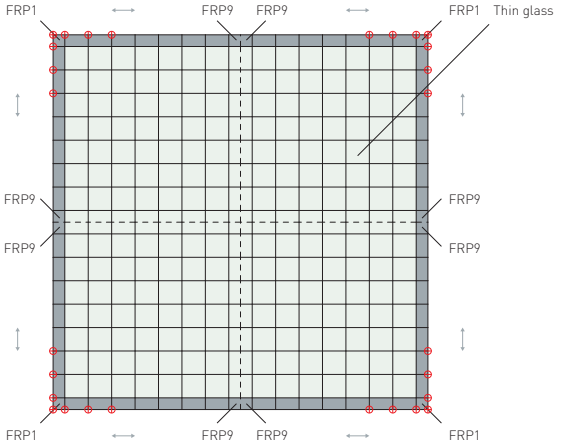
DYNAMIC EDGE STIFFNESS: **THREE MODELS**



I. Twisting from the middle

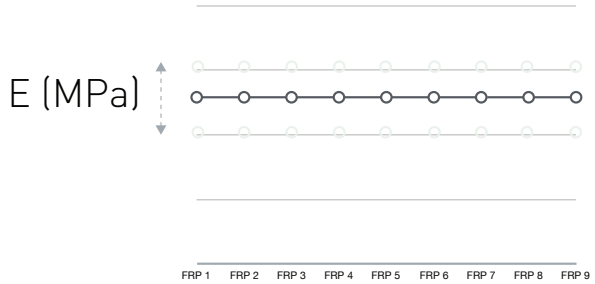


II. Twisting from the corners

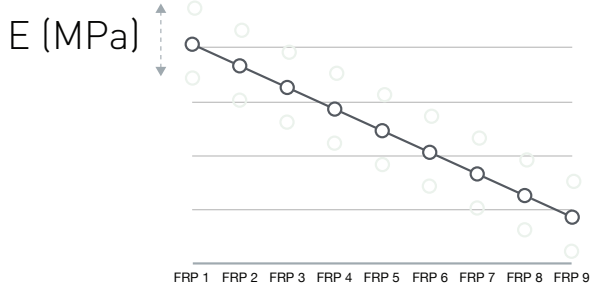


III. Twisting from the corners

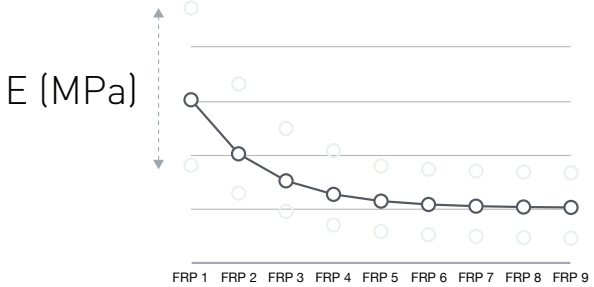
DYNAMIC EDGE STIFFNESS: **FIVE DIFFERENT GRADIENTS**



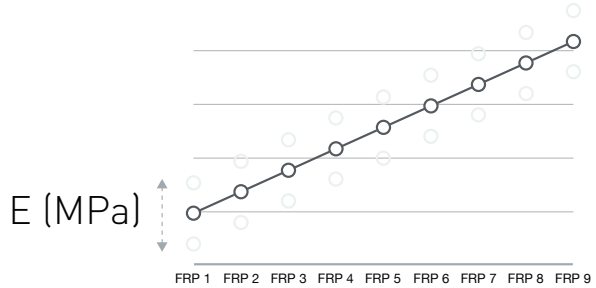
A. Constant stiffness



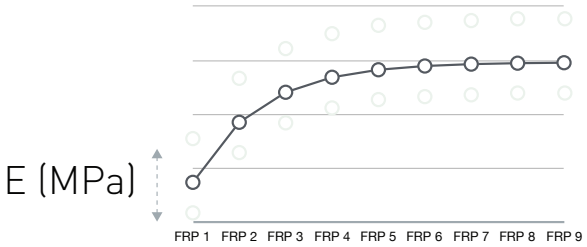
B. Linear decreased stiffness



D. Digressive decreased stiffness

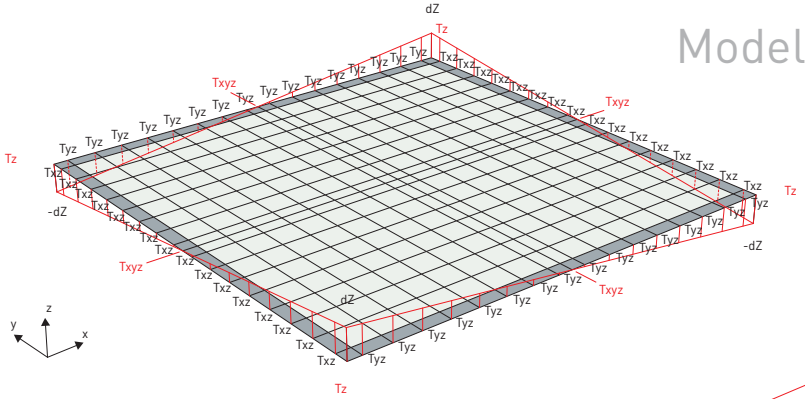


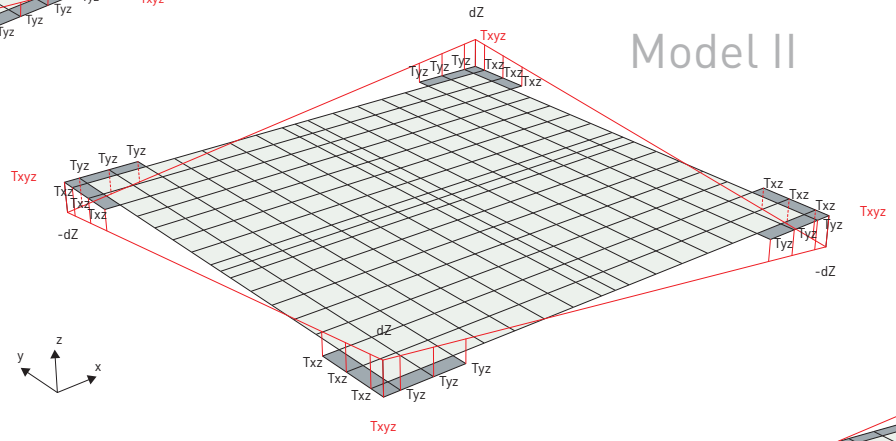
C. Linear increased stiffness

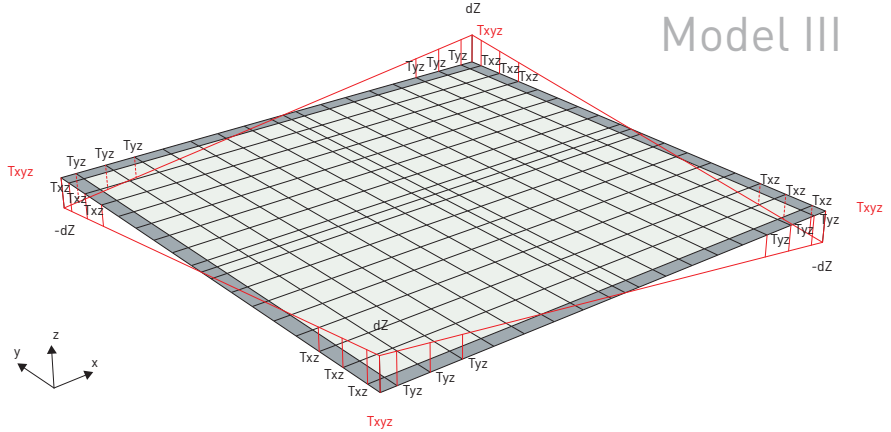


E. Digressive increased stiffness

APPLYING THE 5 DIFFERENT STIFFNESS GRADIENTS TO THE MODELS

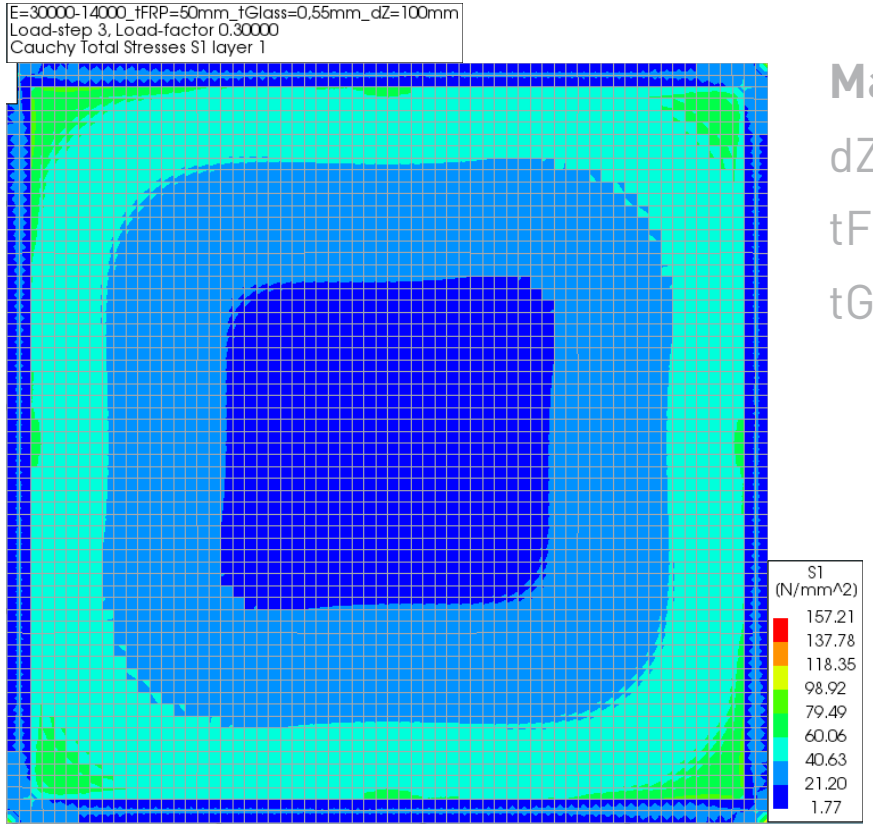






How far the thin glass plate can be twist within allowable generated stresses?

MODEL III TWISTING FROM & AT THE CORNERS

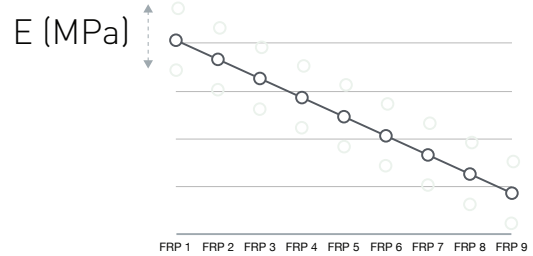


Maximum twist

dZ = 30mm

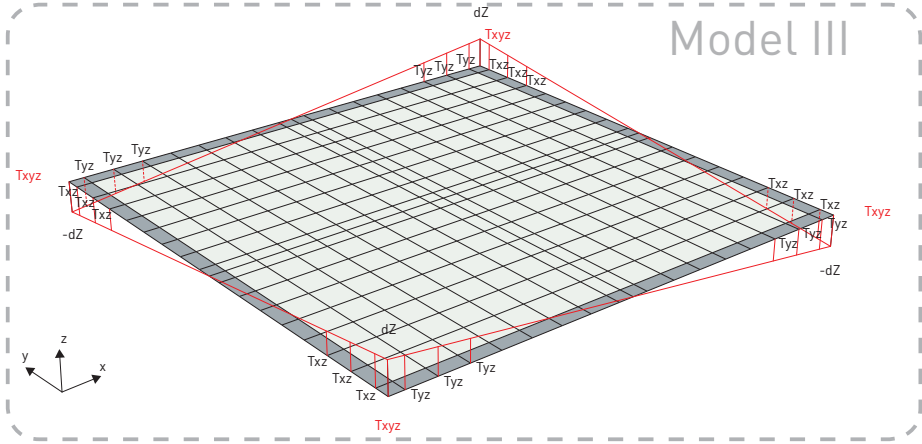
tFRP = 50mm

tGlass = 0.55mm

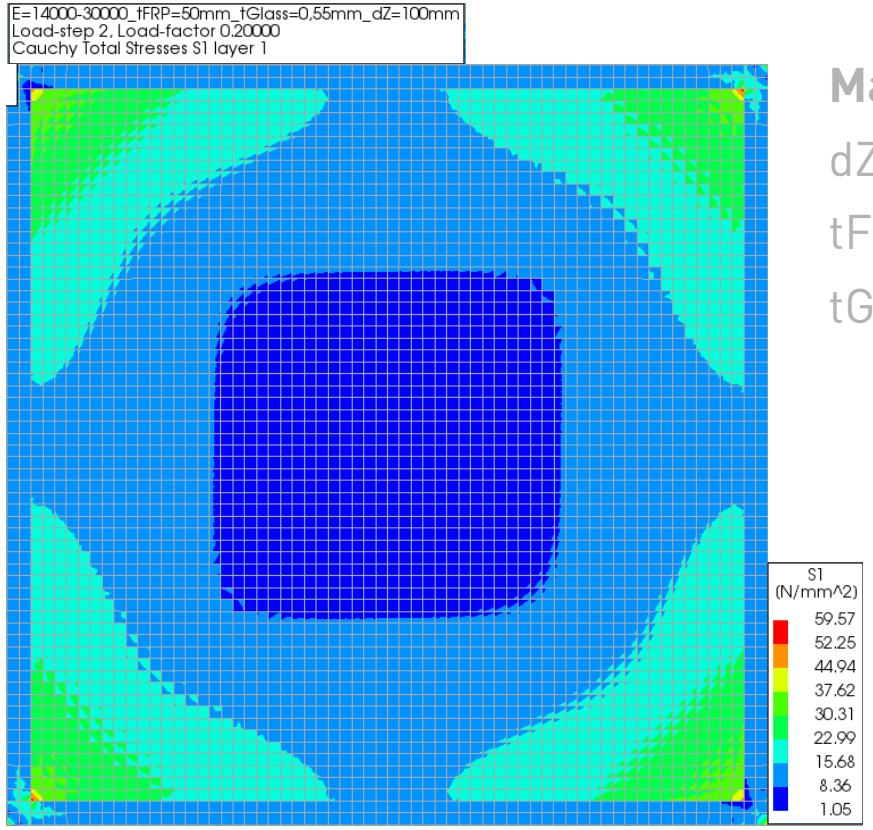


B. Linear decreased stiffness

→ **Highest tension in the *FRP***



MODEL III STIFFNESS IN THE CORNERS NEED TO BE HIGHER THAN MIDDLE

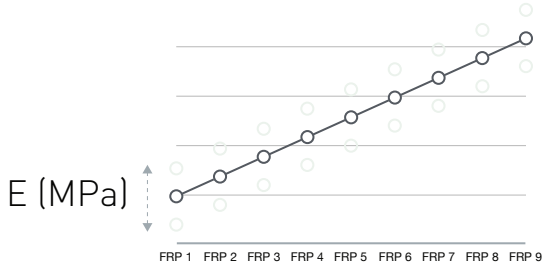


Maximum twist

dZ = ***20mm***

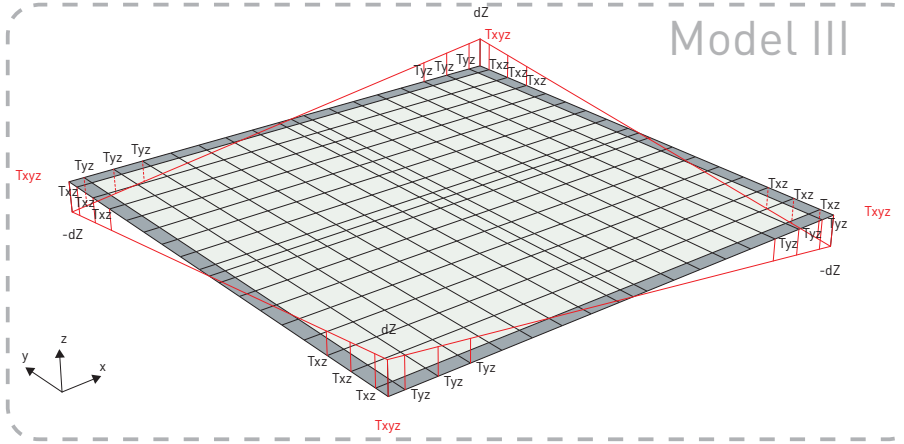
tFRP = 50mm

tGlass = 0.55mm

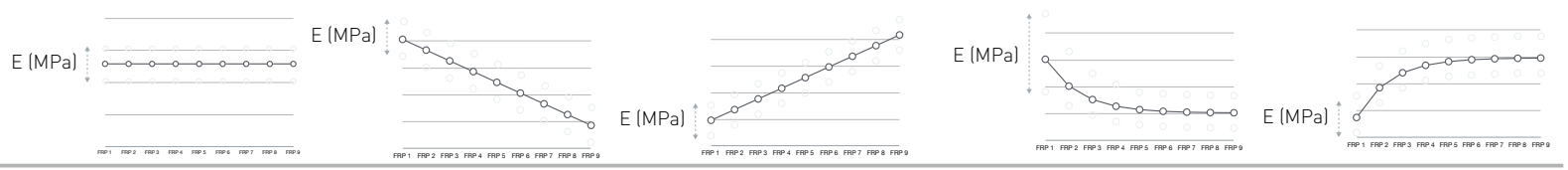


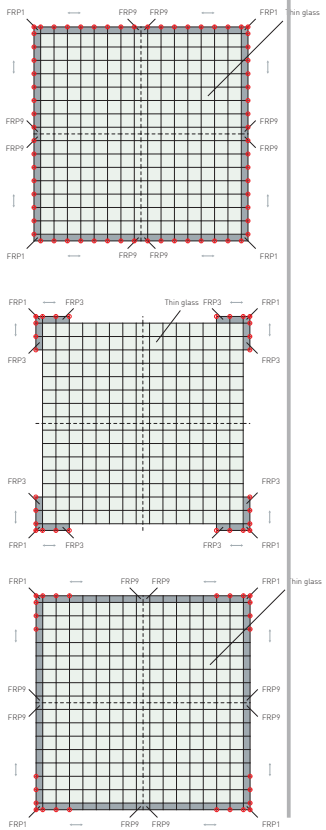
C. Linear increased stiffness

→ **Highest tension in the *glass***



APPLYING THE 5 DIFFERENT STIFFNESS GRADIENTS TO THE MODELS

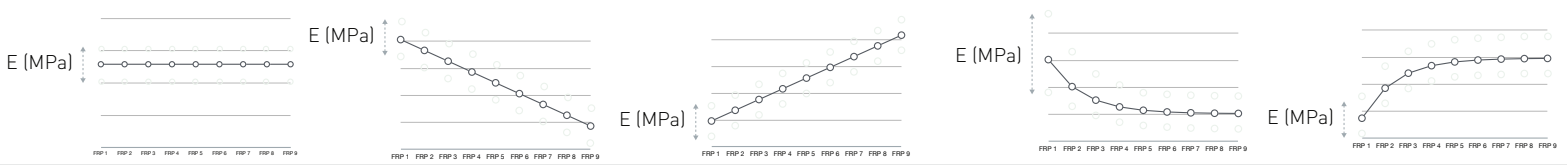


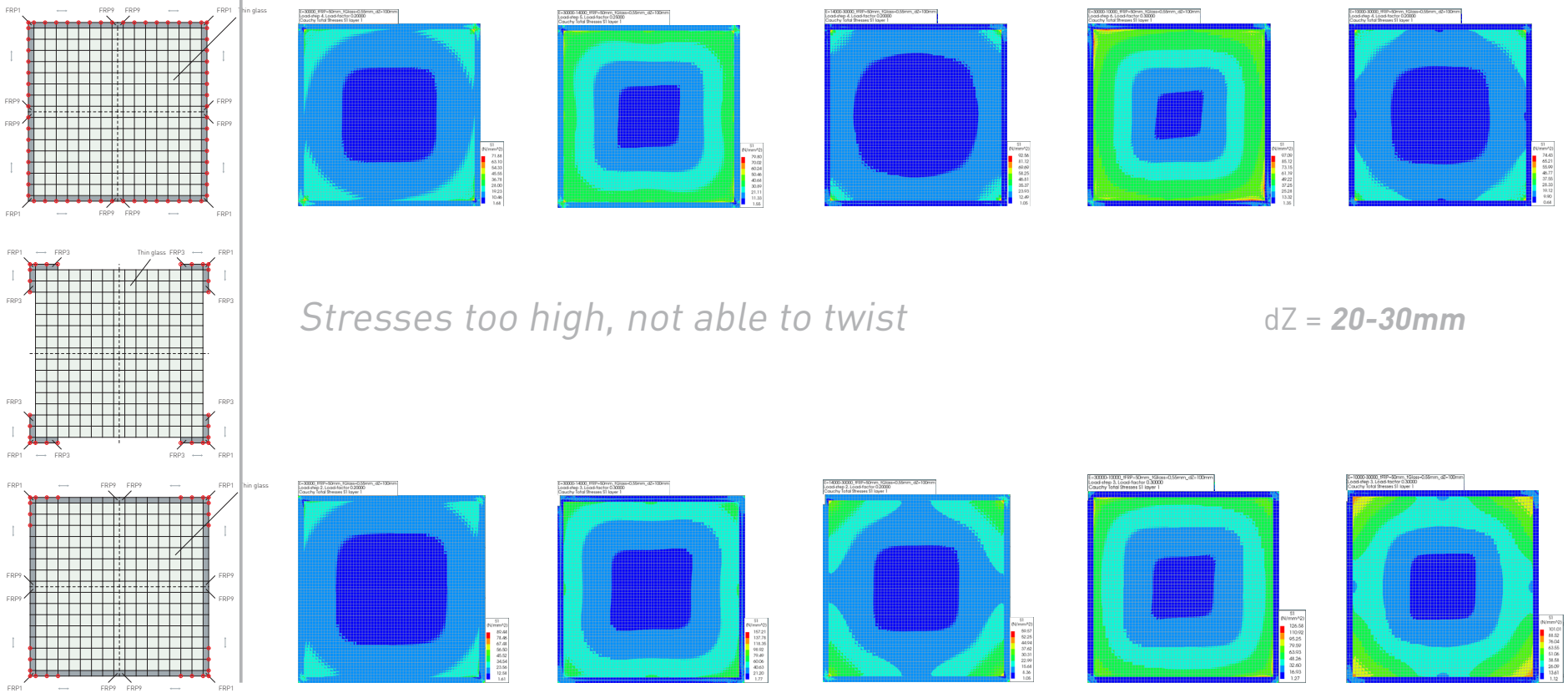


APPLYING THE 5 DIFFERENT STIFFNESS GRADIENTS TO THE MODELS

tFRP = 50mm

tGlass = 0.55mm





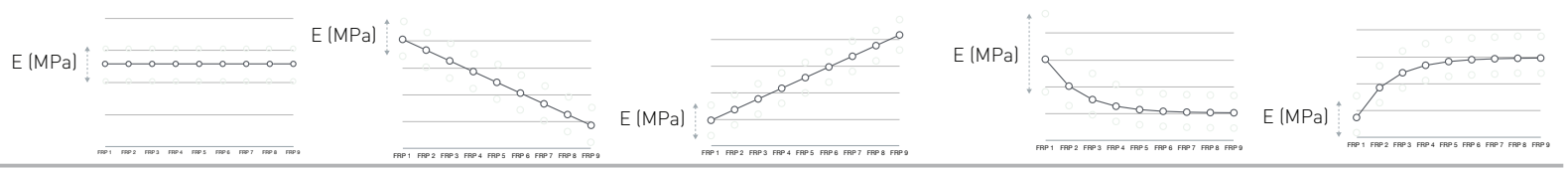
Stresses too high, not able to twist

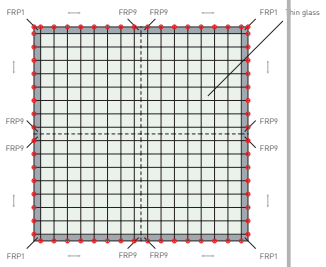
dZ = ***20-30mm***

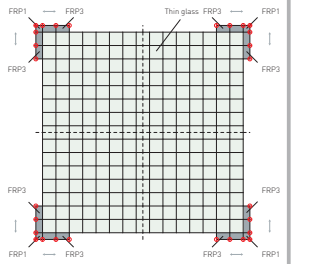
APPLYING THE 5 DIFFERENT STIFFNESS GRADIENTS TO THE MODELS

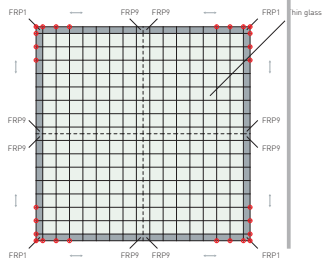
tFRP = 5mm

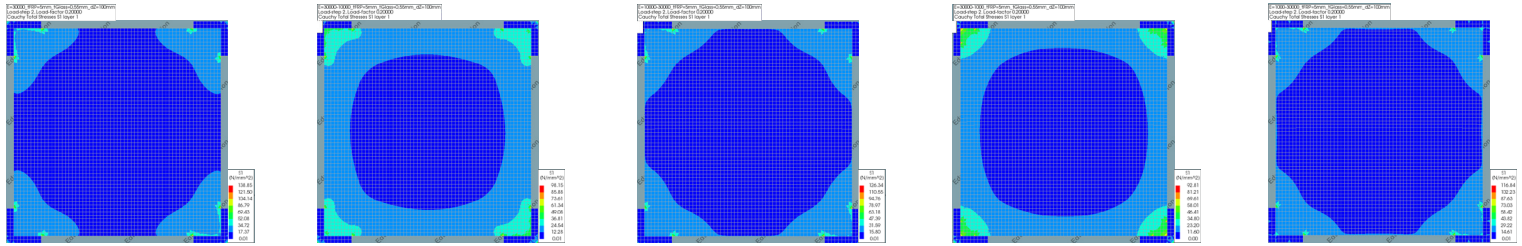
tGlass = 0.55mm





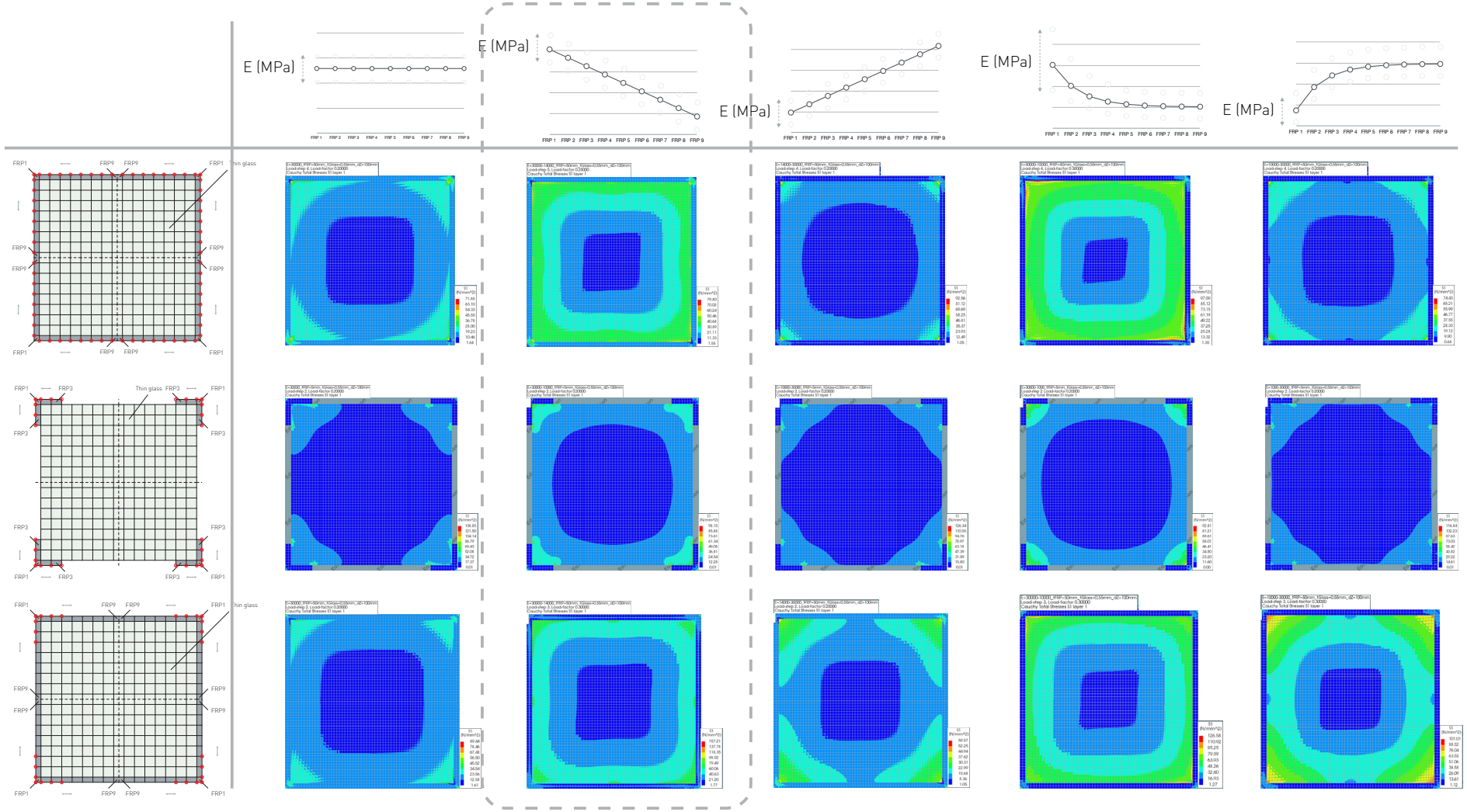






dZ = ***20mm***

APPLYING THE 5 DIFFERENT STIFFNESS GRADIENTS TO THE MODELS



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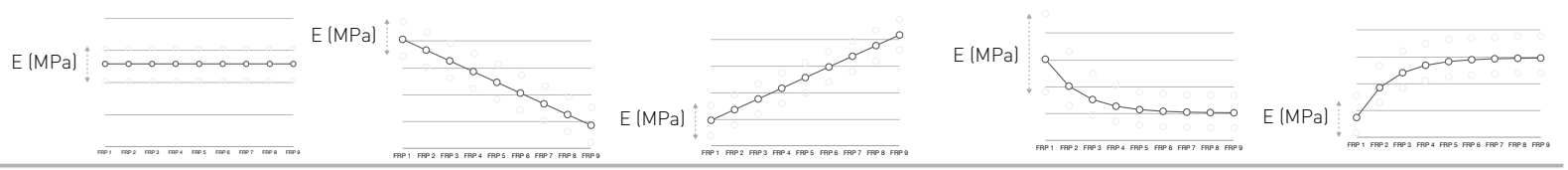
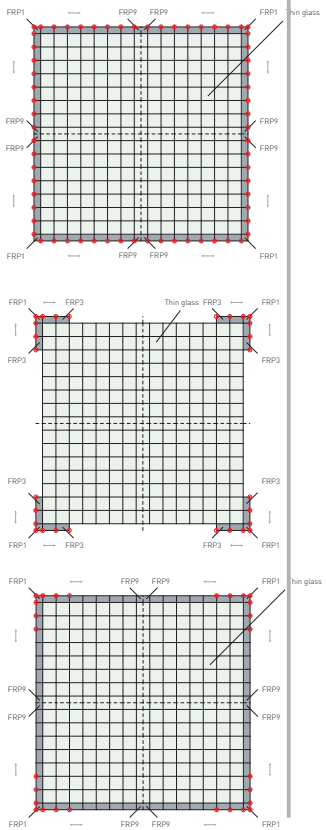
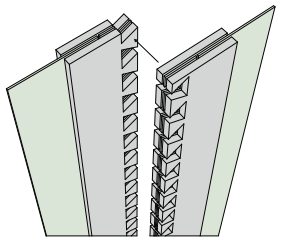
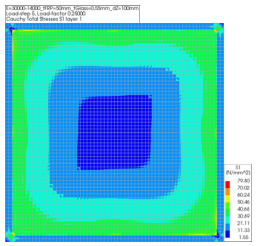
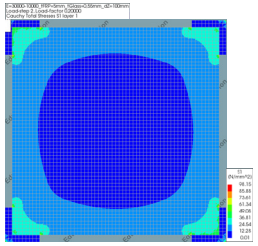
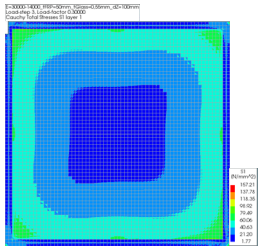










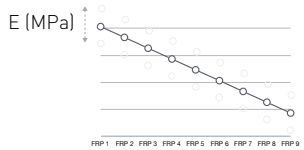


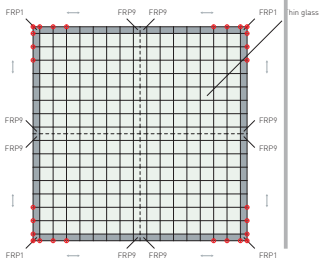
I. Twisting from the middle
Supports difficult to design

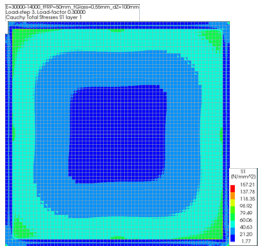
II. Twisting from the cornes
FRP gets too thin
Connection in mind would fail

III. Twisting from the cornes
FRP thick enough where the connection is in mind

APPLYING THE 5 DIFFERENT STIFFNESS GRADIENTS TO THE MODELS



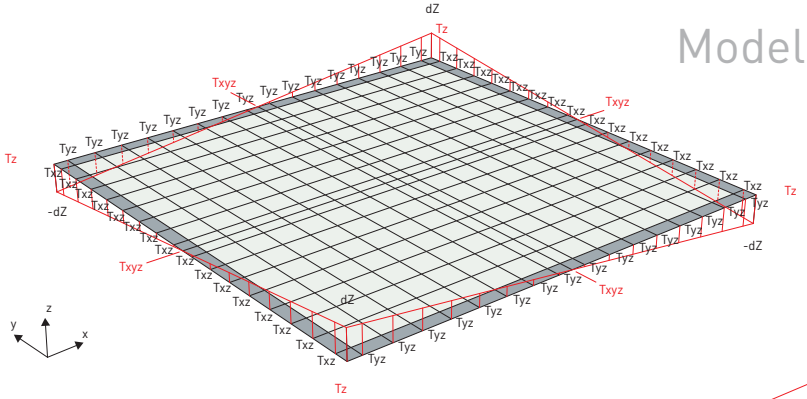


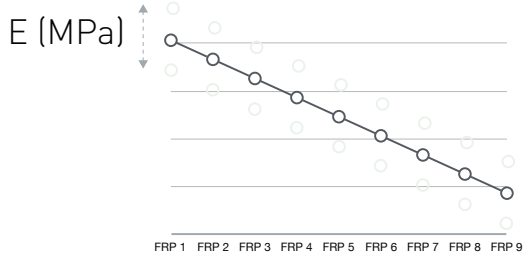


III. Twisting from the cornes

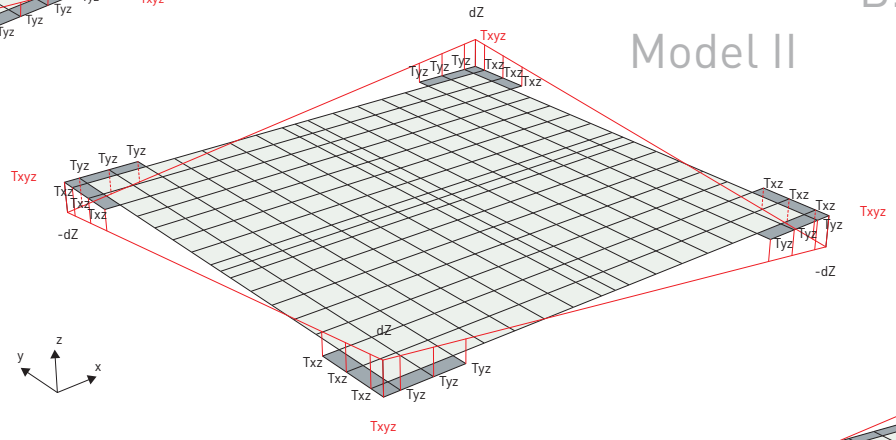
Most appropriate one for a definitive design

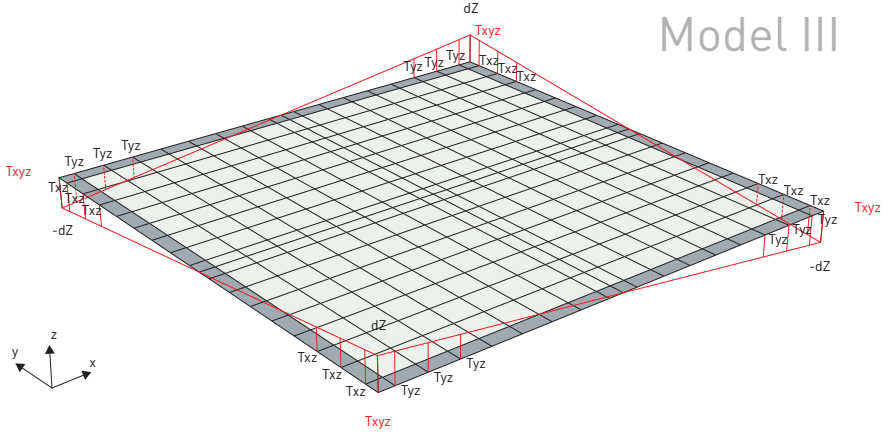
LINEAR DECREASED EDGE STIFFNESS FOR *ALL* MODELS





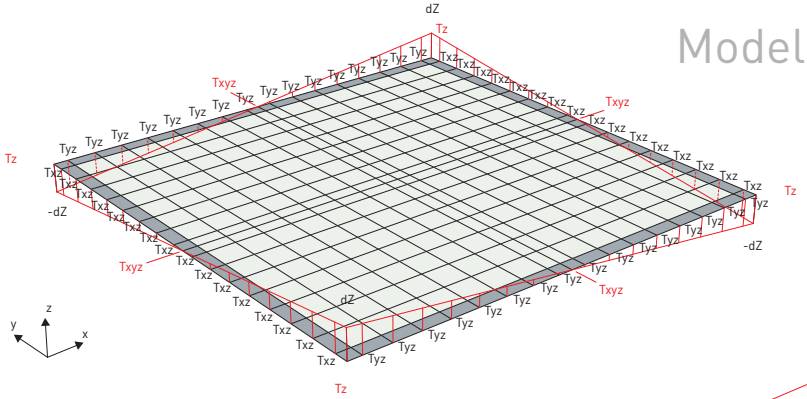
B. Linear decreased stiffness

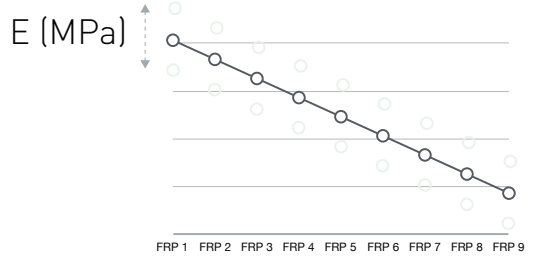




LINEAR DECREASED EDGE STIFFNESS FOR *ALL* MODELS

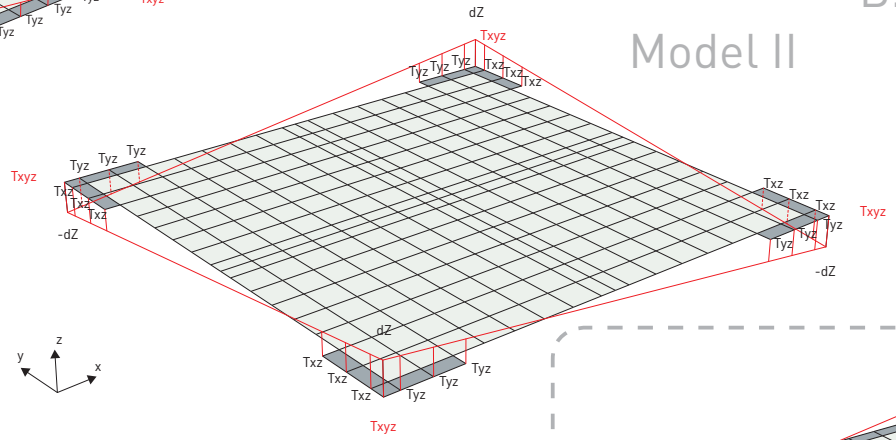
Model I



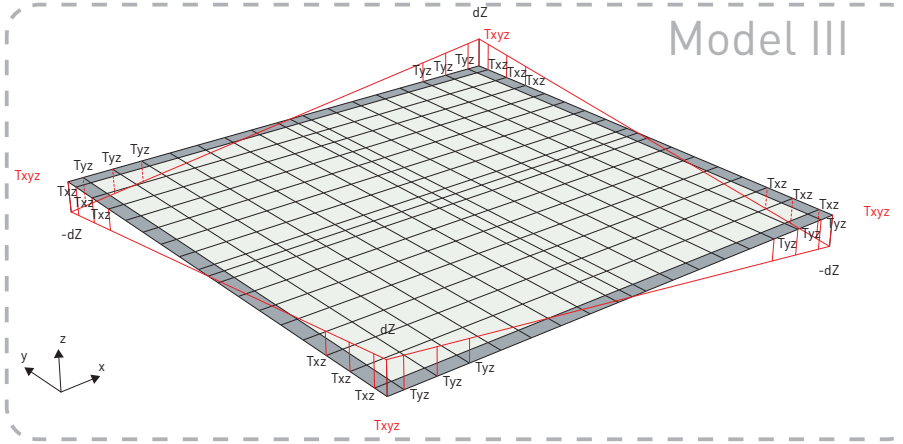


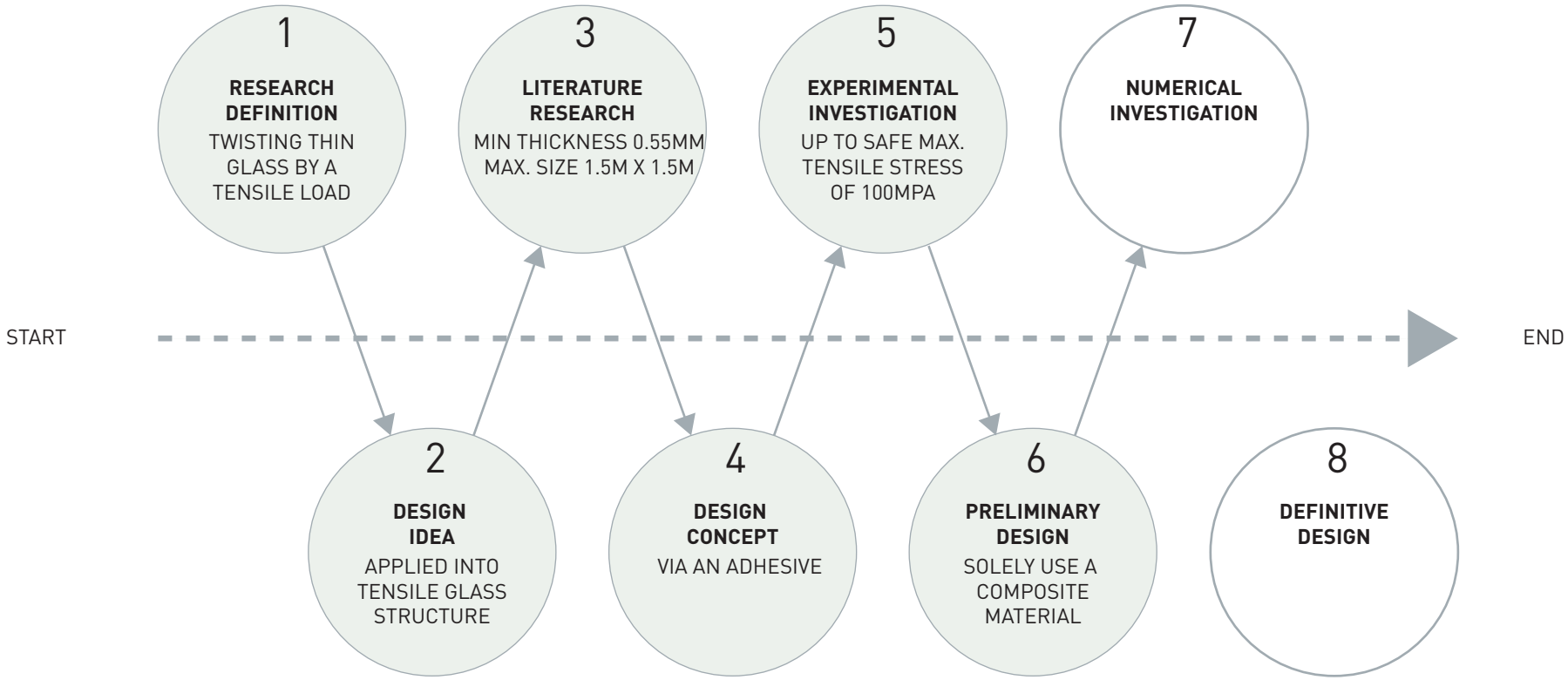
B. Linear decreased stiffness

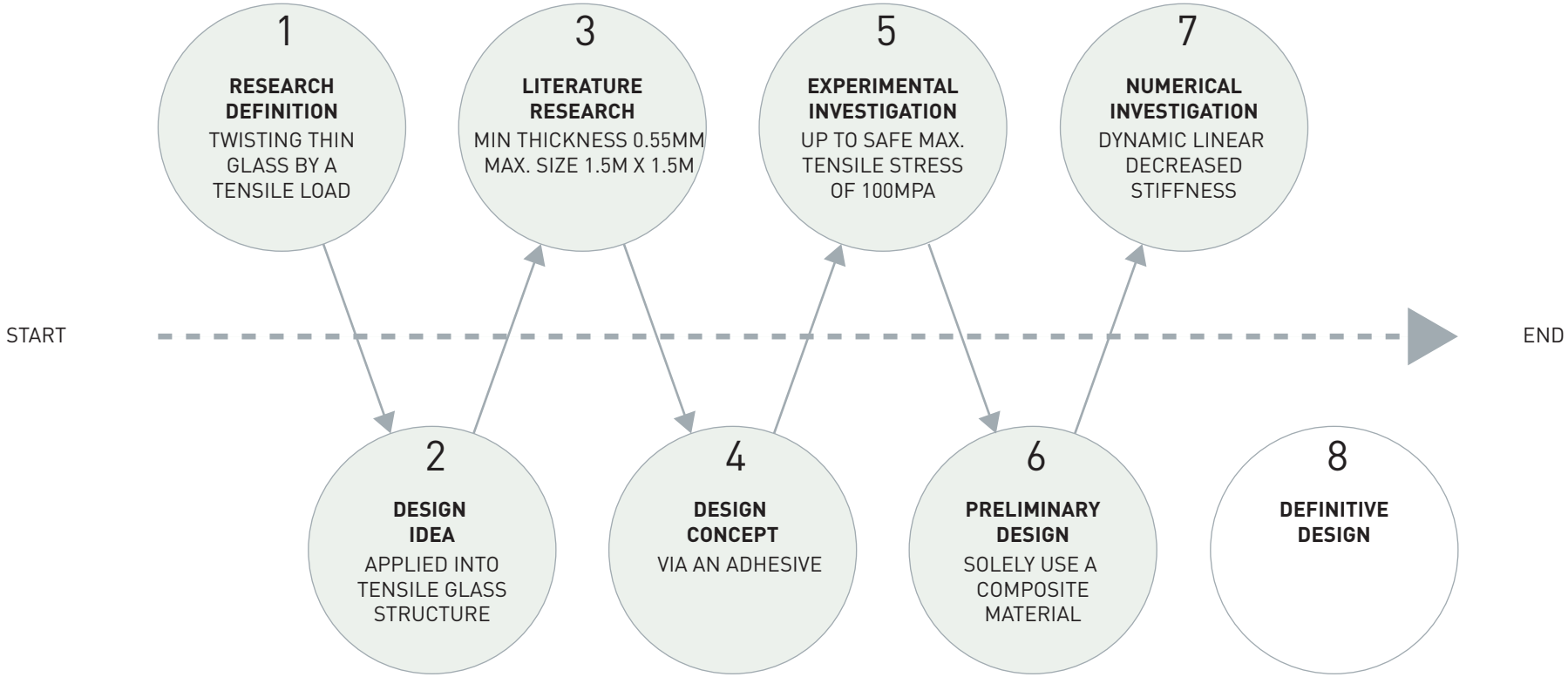
Model II



Model III




1
RESEARCH DEFINITION
TWISTING THIN GLASS BY A TENSILE LOAD
2
DESIGN IDEA
APPLIED INTO TENSILE GLASS STRUCTURE
3
LITERATURE RESEARCH
MIN THICKNESS 0.55MM MAX. SIZE 1.5M X 1.5M
4
DESIGN CONCEPT
VIA AN ADHESIVE
5
EXPERIMENTAL INVESTIGATION
UP TO SAFE MAX. TENSILE STRESS OF 100MPA
6
PRELIMINARY DESIGN
SOLELY USE A COMPOSITE MATERIAL
7
NUMERICAL INVESTIGATION
8
DEFINITIVE DESIGN
START
END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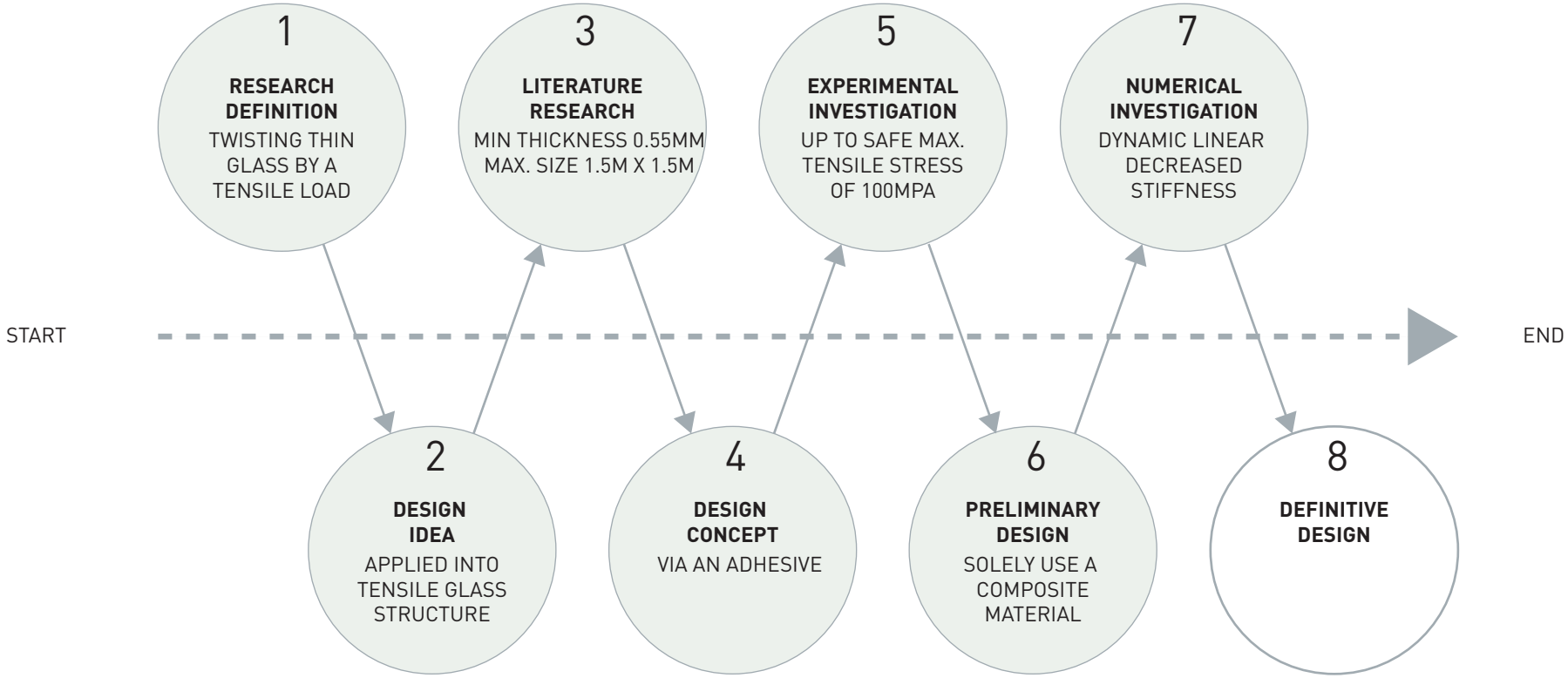
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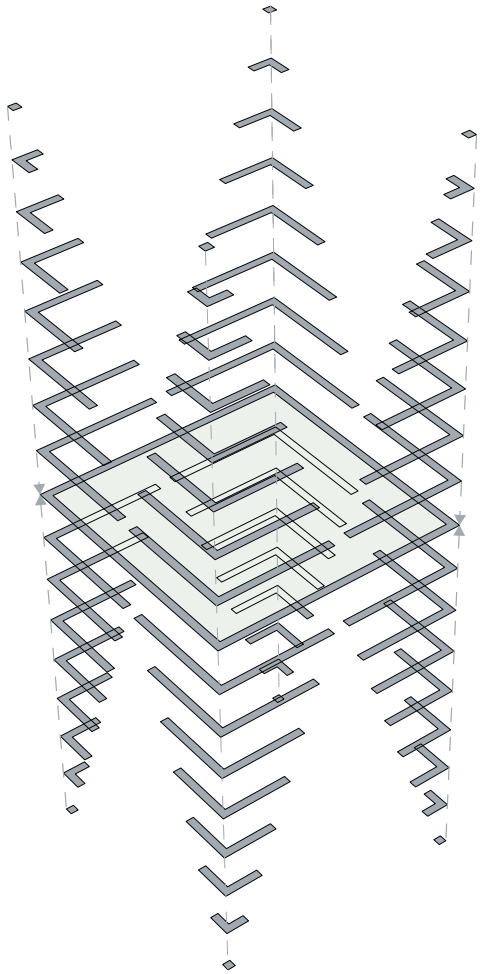
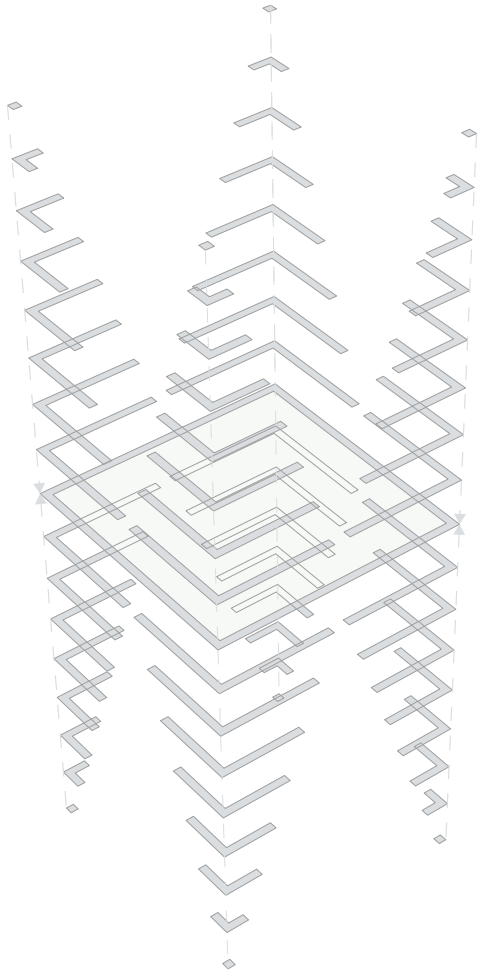
DEFINITIVE DESIGN
START
END

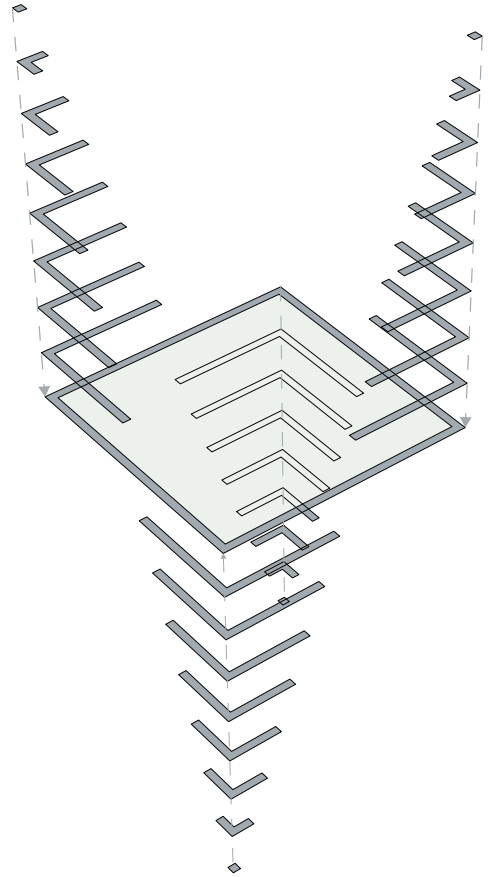
DEFINITIVE DESIGN

LINEAR DECREASED EDGE STIFFNESS *THROUGH* THE AMOUNT OF LAYERS

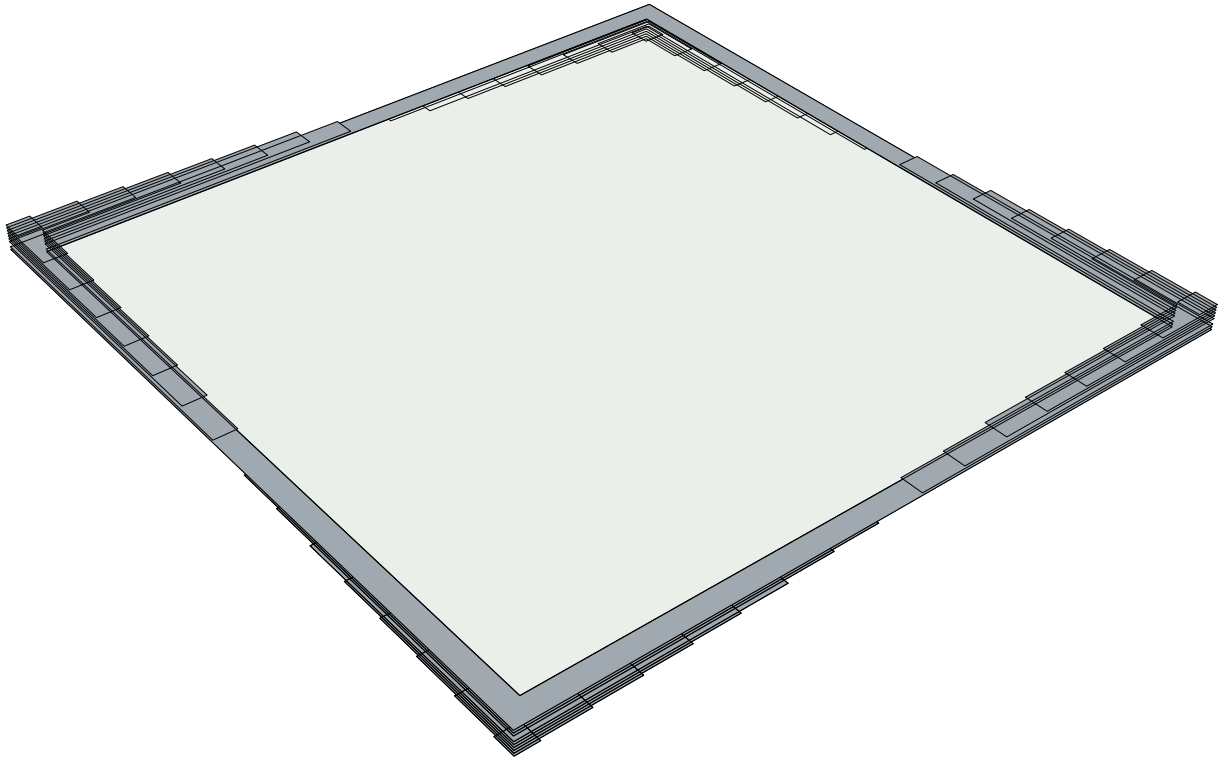


LINEAR DECREASED EDGE STIFFNESS *THROUGH* THE AMOUNT OF LAYERS

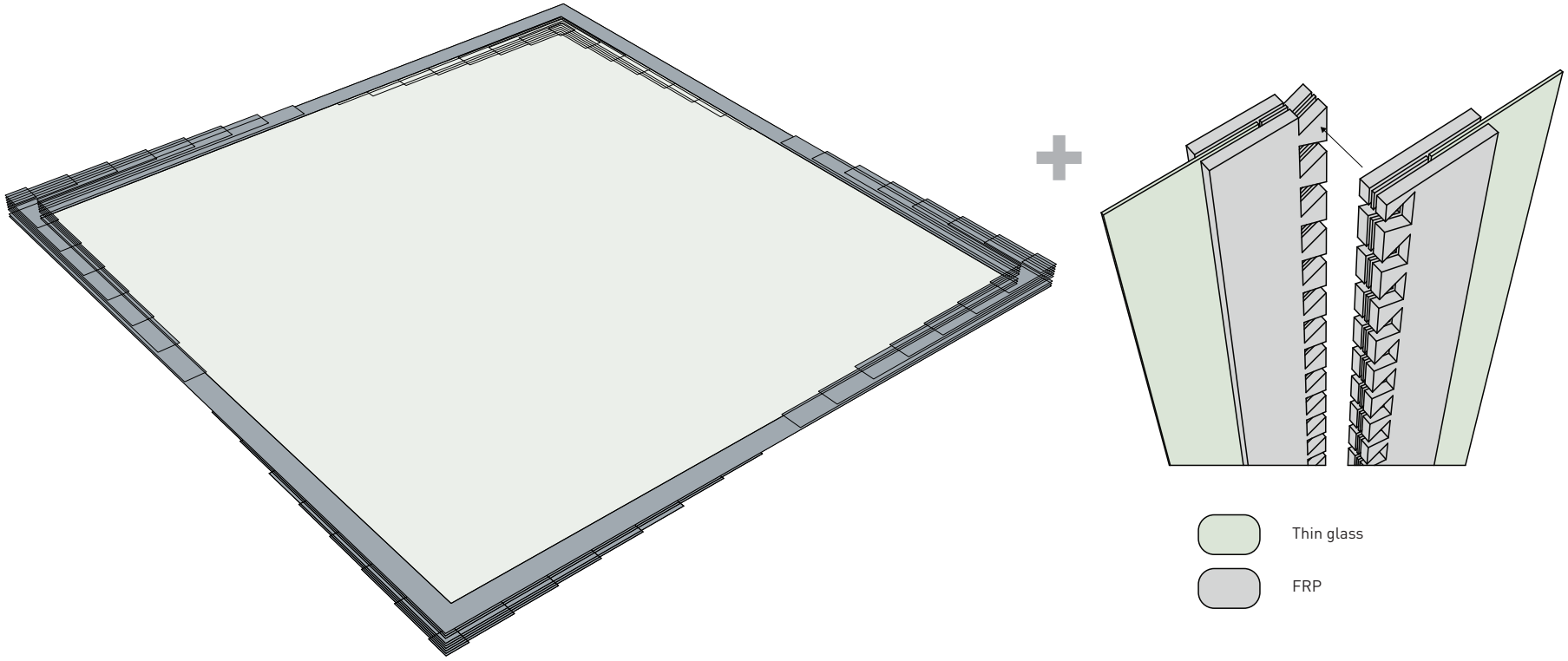




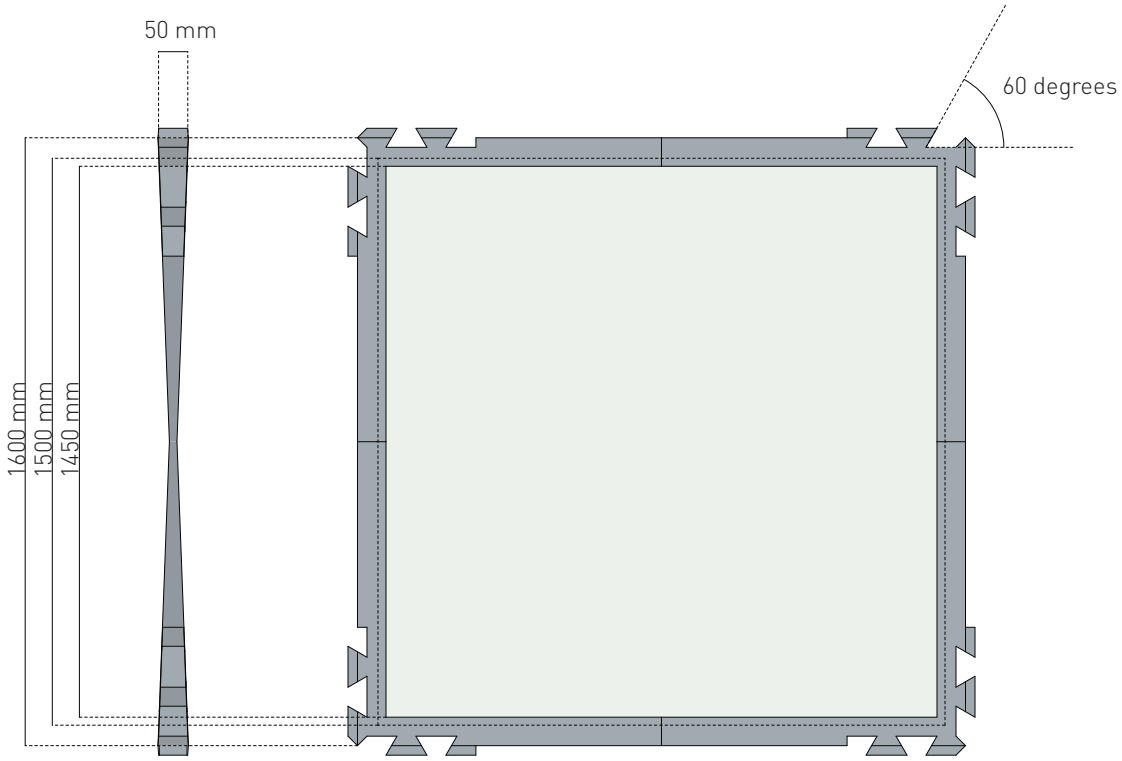
INTEGRATING THE DOVETAIL JOINT WITHIN THE GFRP EDGES



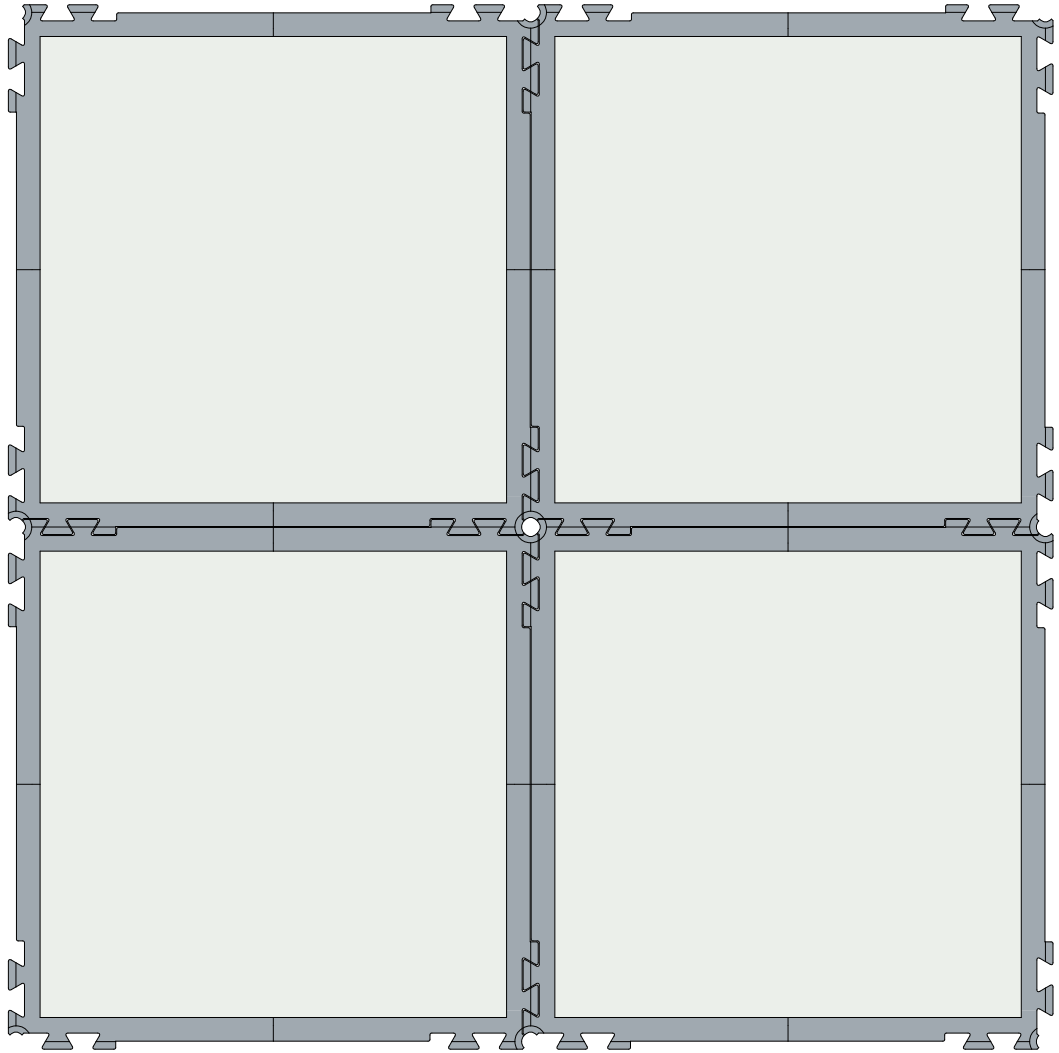
INTEGRATING THE DOVETAIL JOINT WITHIN THE GFRP EDGES



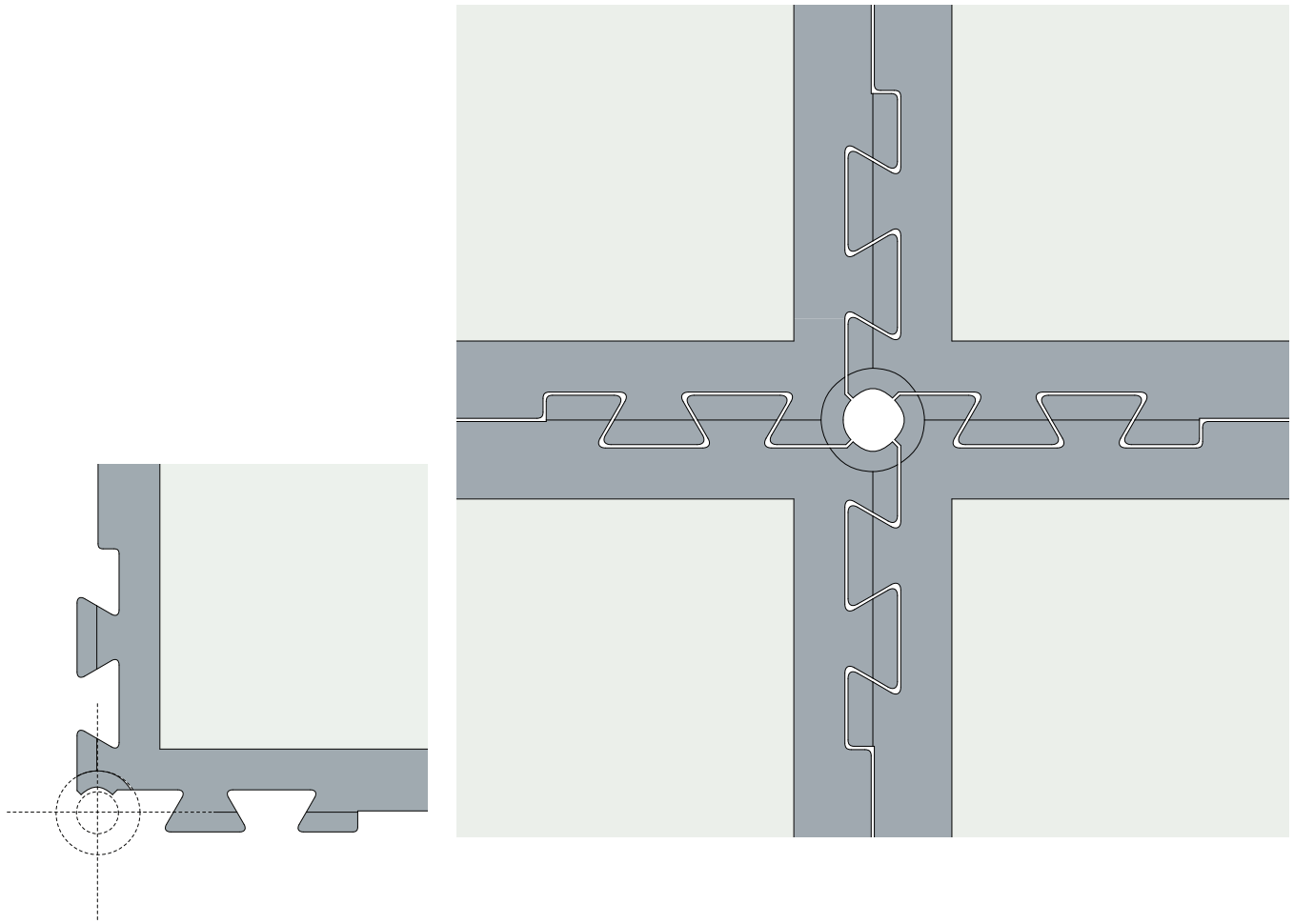
SUPPORT GFRP EDGE AT THE CORNERS



REPETITIVE HYPAR SURFACE

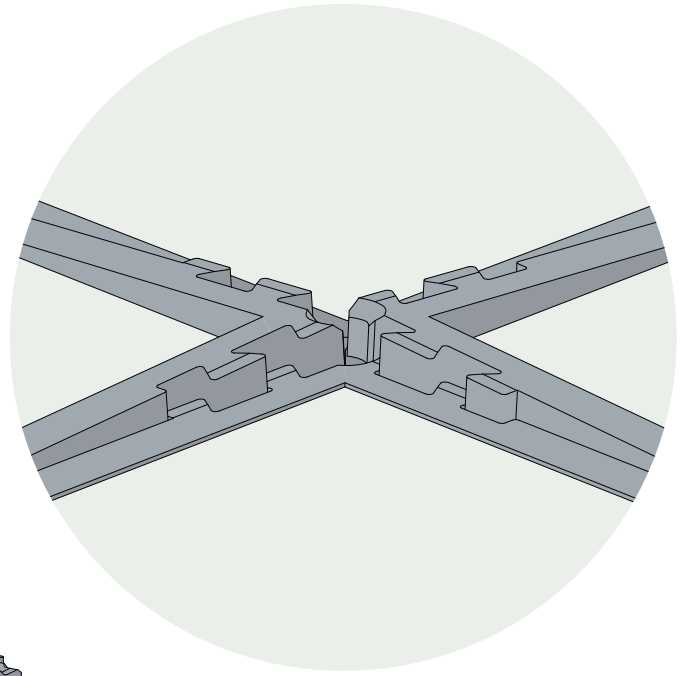


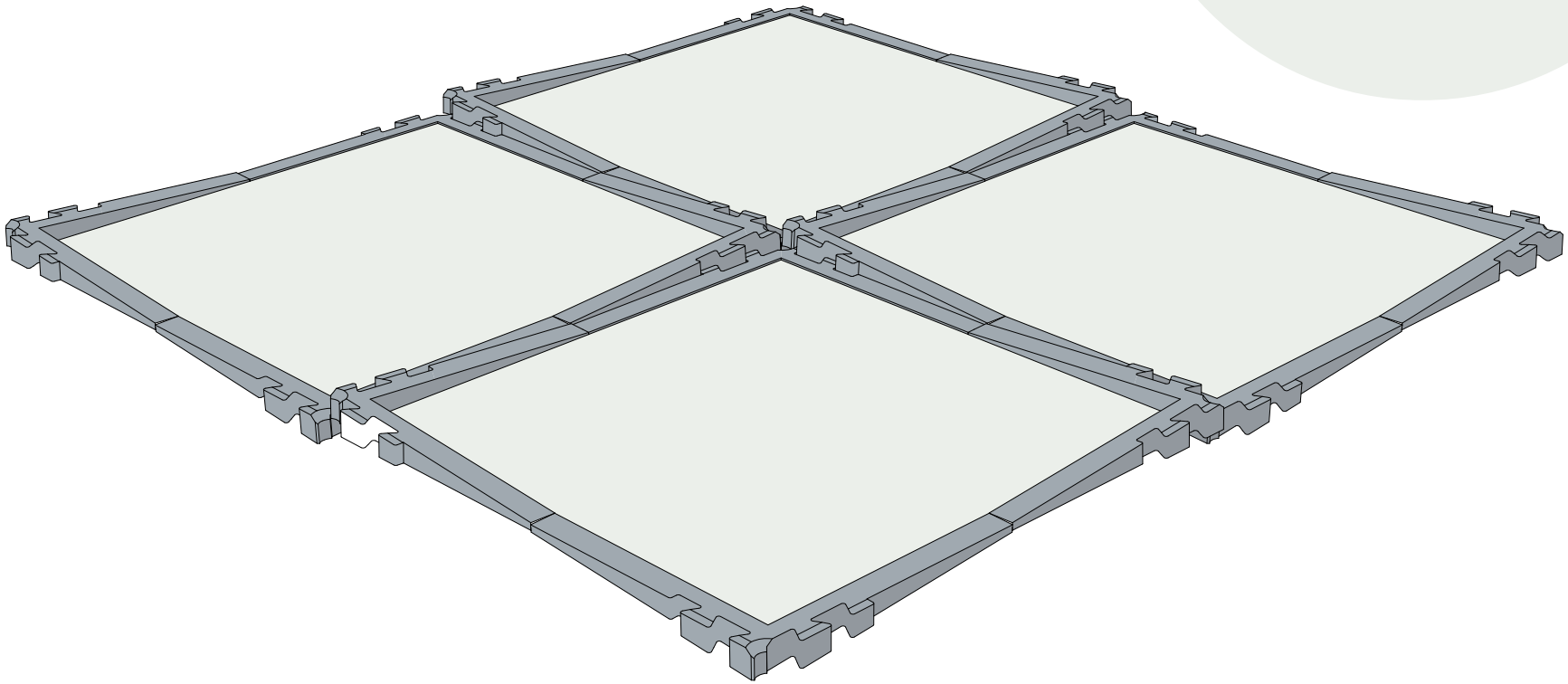
BY ASSEMBLING EACH PANEL TO EACH OTHER



BY ASSEMBLING EACH PANEL TO EACH OTHER

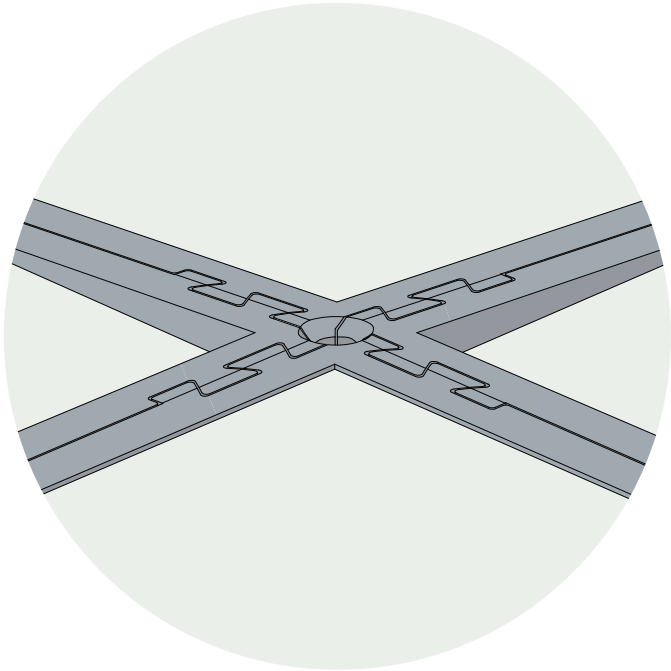
FROM FLAT, THIN GLASS

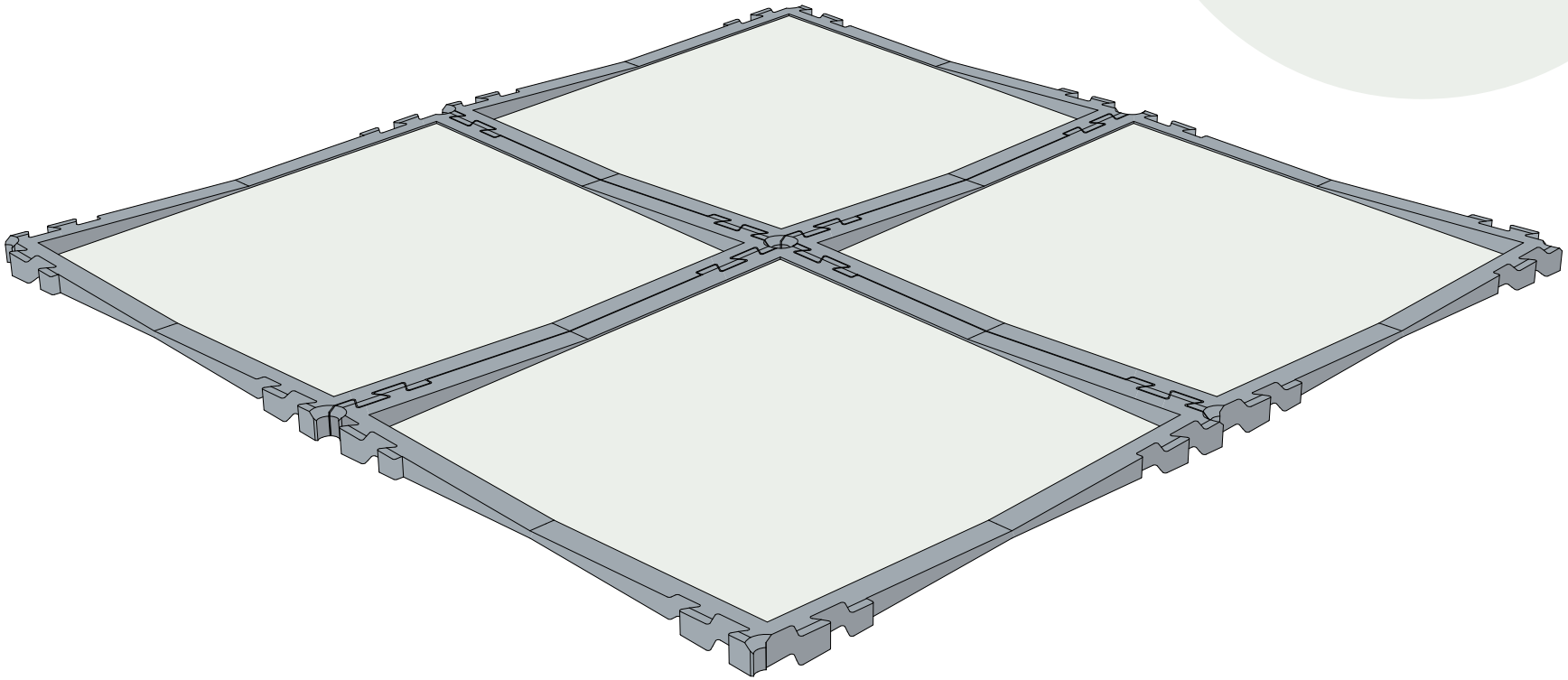




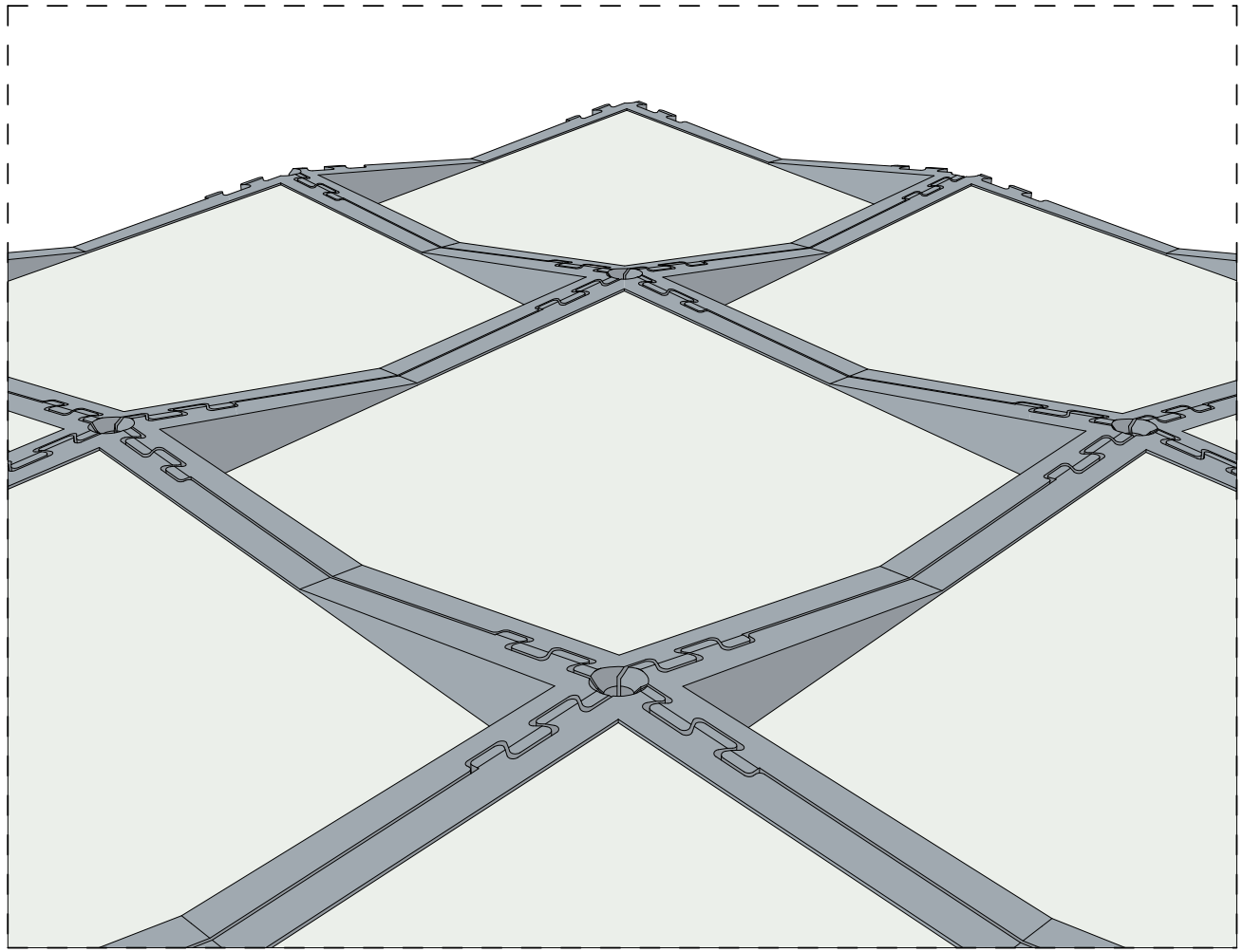
BY ASSEMBLING EACH PANEL TO EACH OTHER

TO DOUBLE, ANTICLASTIC, COLD BENT, THIN GLASS





MAXIMUM TENSILE STRESS CAPACITY



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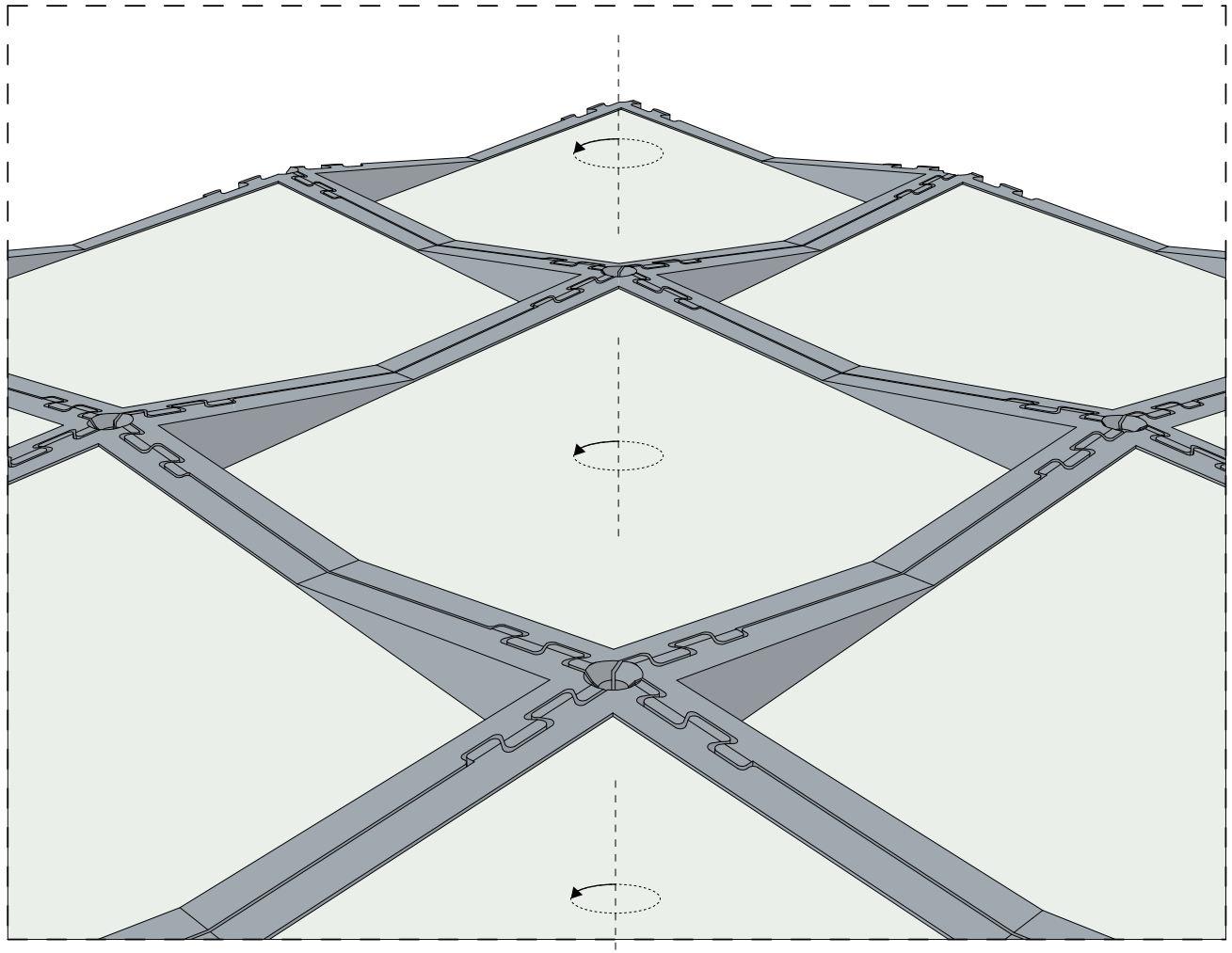

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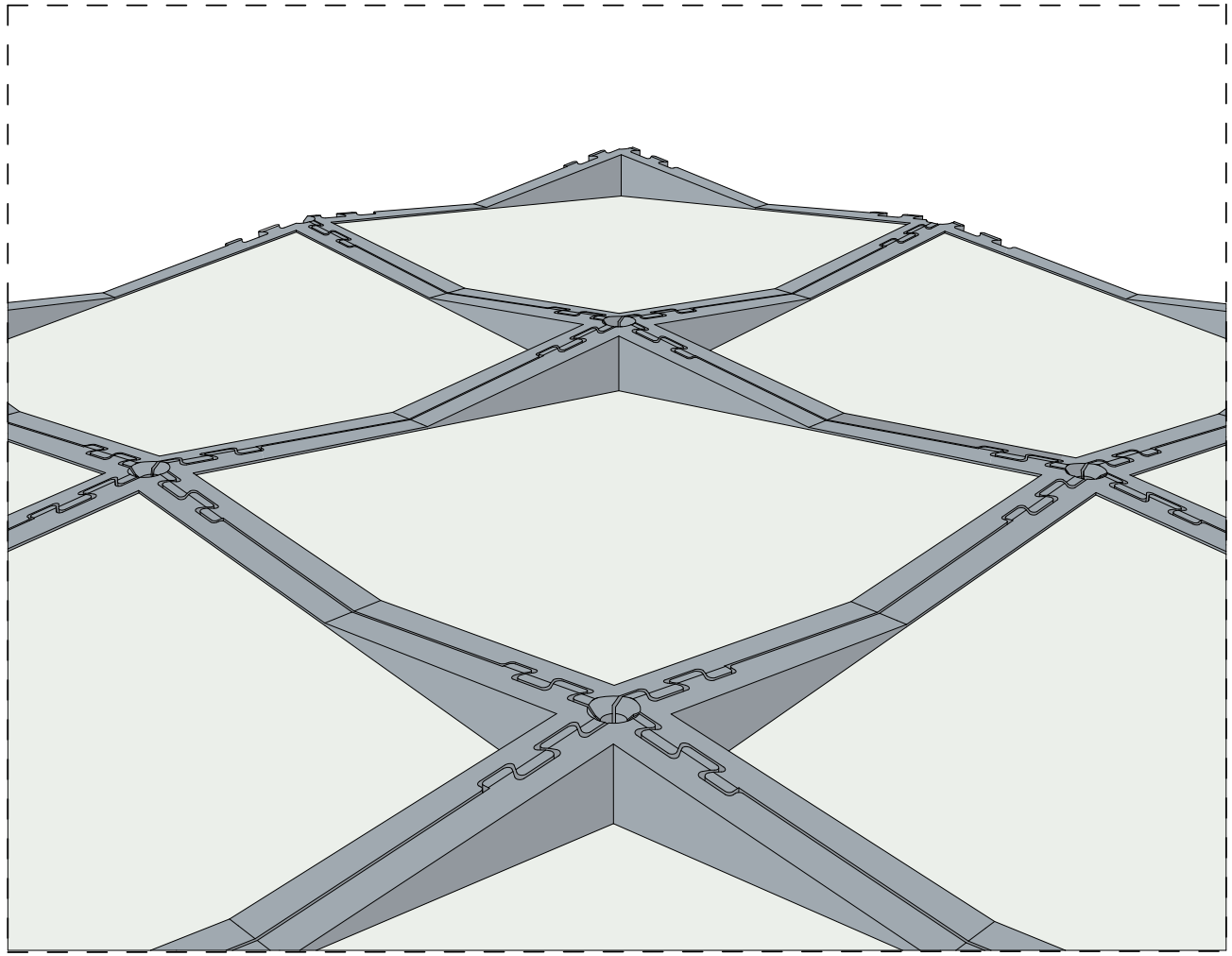

“TO WHAT EXTENT IS IT POSSIBLE TO CURVE A FLAT SHEET OF THIN GLASS INTO A DOUBLE ANTICLASTIC BENT SURFACE BY ADDING TENSION TO THE CURRENTLY USED COLD TWISTING TECHNIQUE?”

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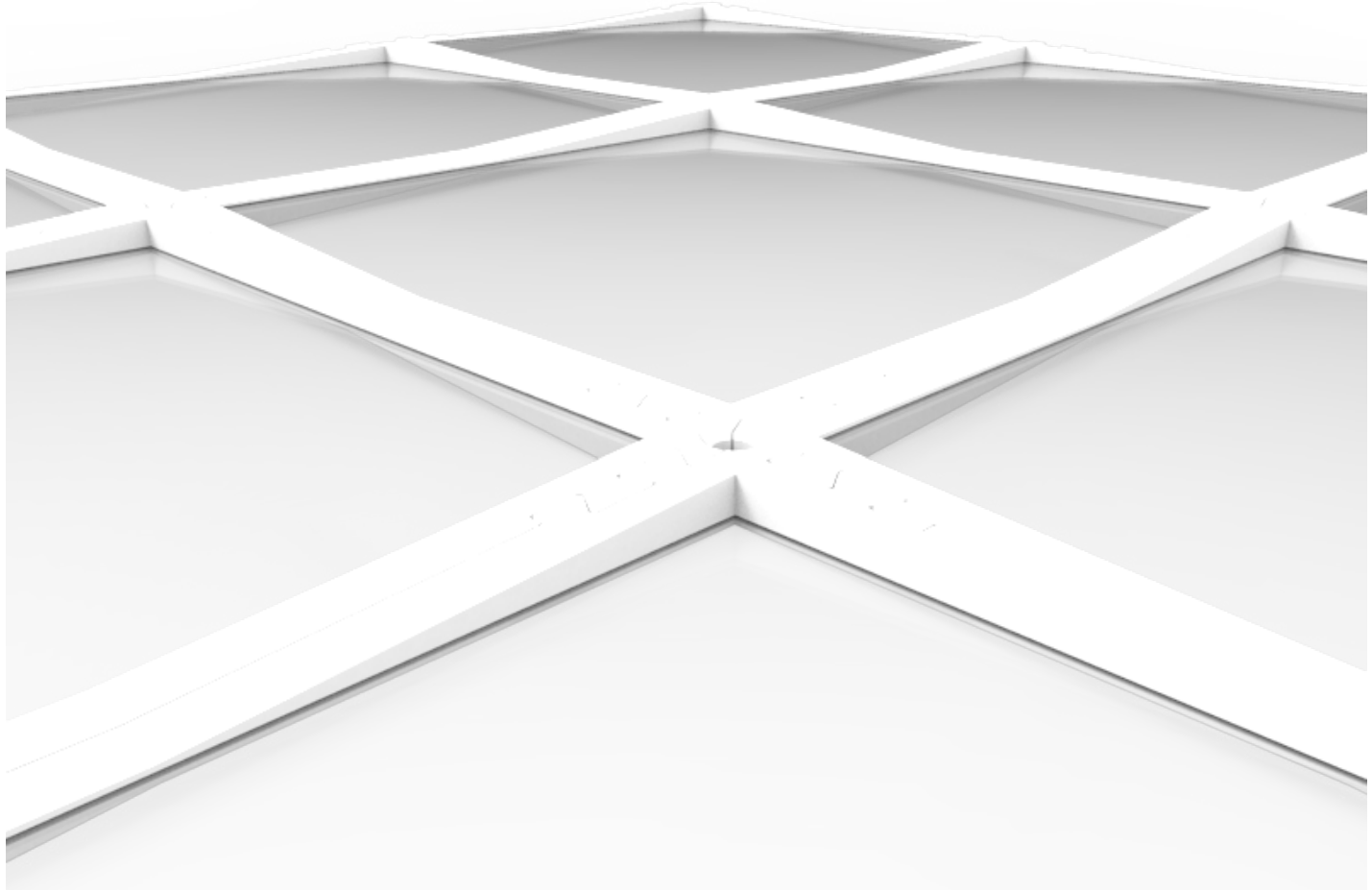


HIGH STRENGTH THIN GLASS
AS
STIFF STRUCTURAL FABRIC
?

HIGH STRENGTH THIN GLASS
AS
STIFF STRUCTURAL FABRIC