Reconstructing vaults 2.0

The potential of cast glass for reconstructing historical buildings

P5
2019-2020

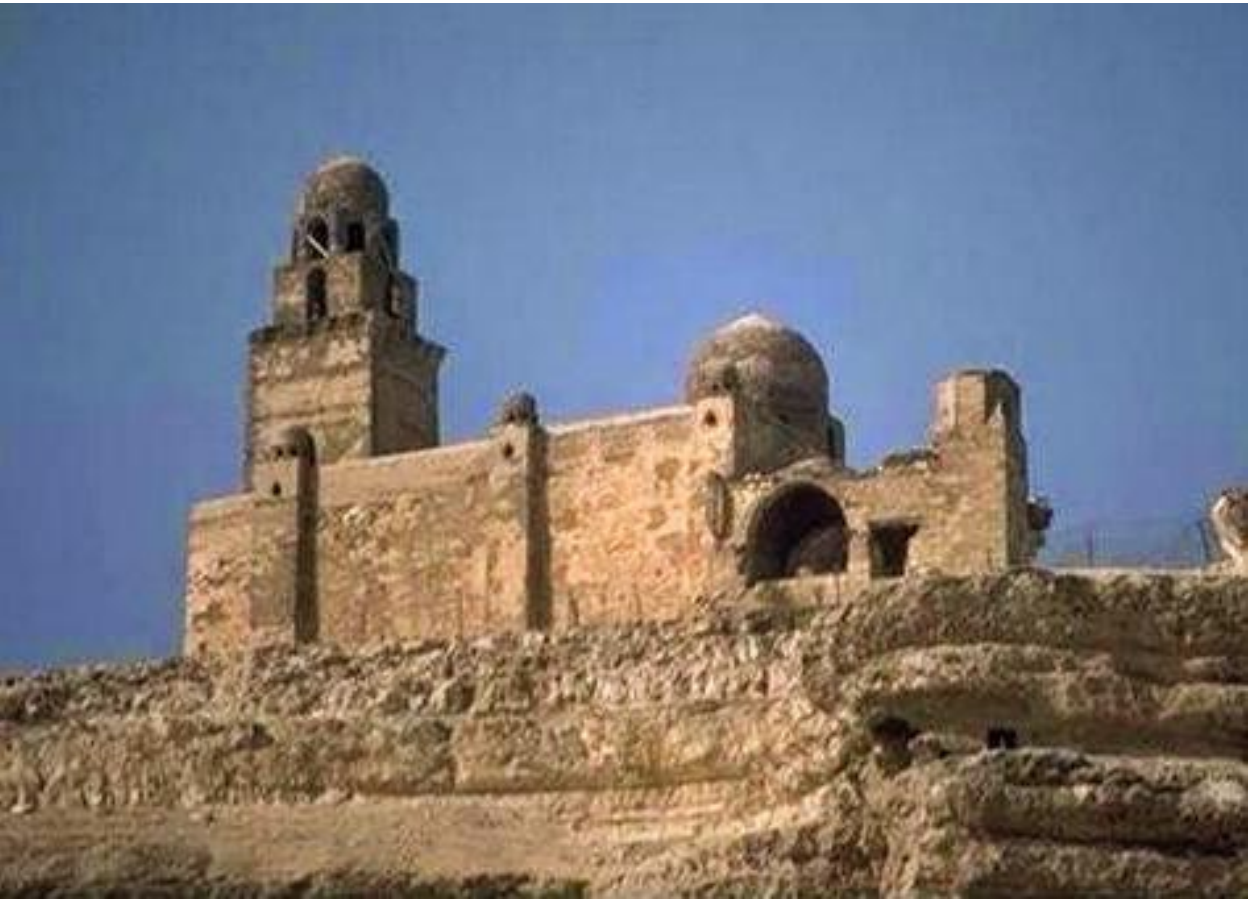
Angela Smit
4463021

Retrieved from: https://i2.wp.com/www.agoda.com/wp-content/uploads/2019/05/Marais-Paris-Notre-Dame-Cathedral.jpg

Retrieved from: https://img.theculturetrip.com/wp-content/uploads/2017/07/crowds-at-notre-dame--lionel-allorge-wikimedia-commons.jpg

Retrieved from: https://images1.persgroep.net/rcs/FMGrPhsjlPQQKYTuzJHvfM2pP4/diocontent/145781944/_fitwidth/694/?appId=21791a8992982cd8da851550a453bd7f&quality=0.8

Restore?



Fatimid era Al-Juyushi Mosque in Moqattam. Retrieved from https://lh5.googleusercontent.com/-PlLWXztRnPA/VEJnGD72BBI/AAAAAAAAfrM/5_xuN5jYFPM/s697/Photo%252520140181511 41.jpg

Reconstruct?

Steel roof structure (Apple store). Retrieved from Worldarchitecturenews (2011).

Wooden roof structure (Chiddingstone Orangery Castle). Retrieved from Carpenteroak (2007).

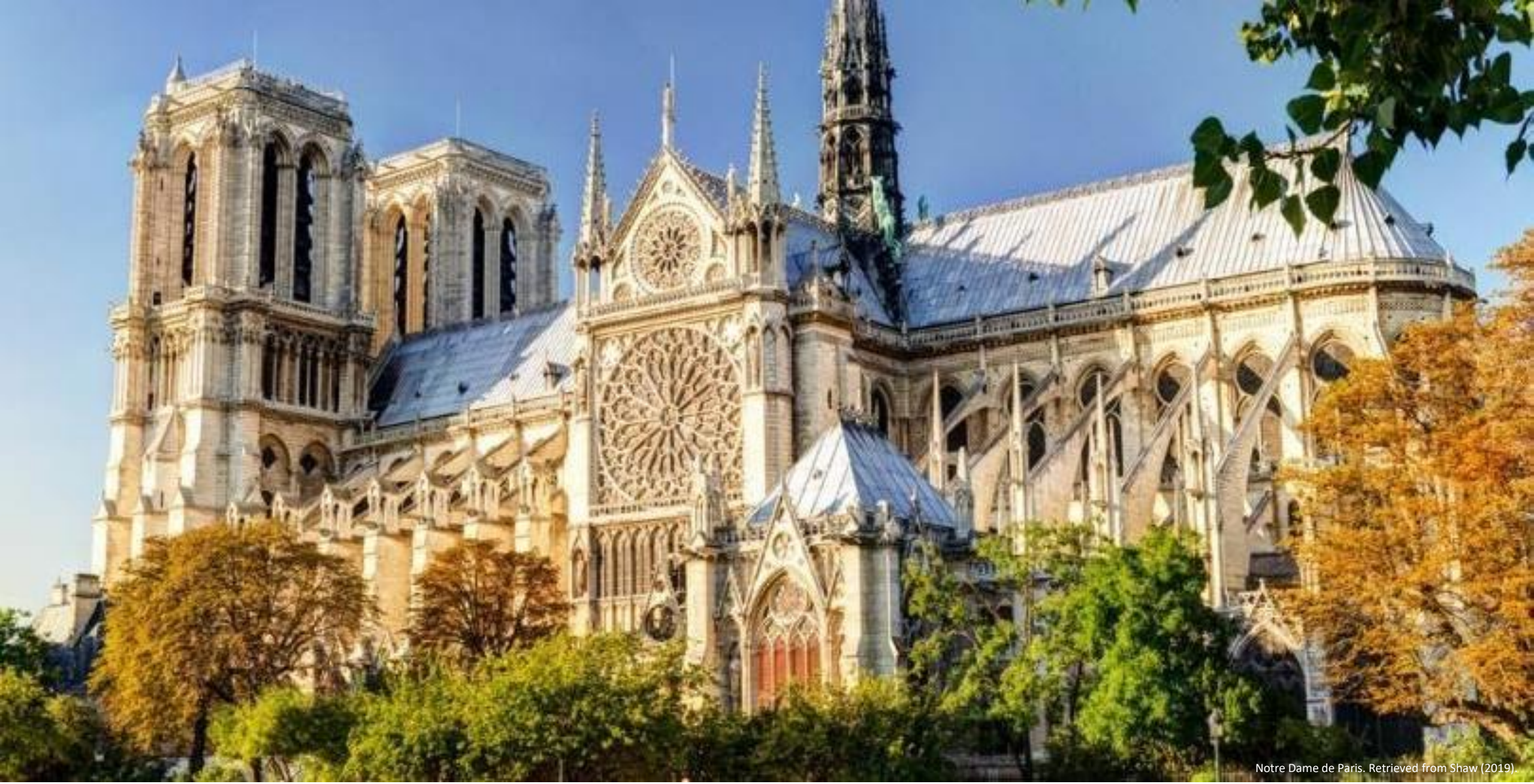
Glass roof structure (Castle Ruurlo). Retrieved from Verlaan&Bouwstra (2013).

Cast glass façade for the Chanel Crystal house in Amsterdam. Retrieved from ABT (2016).

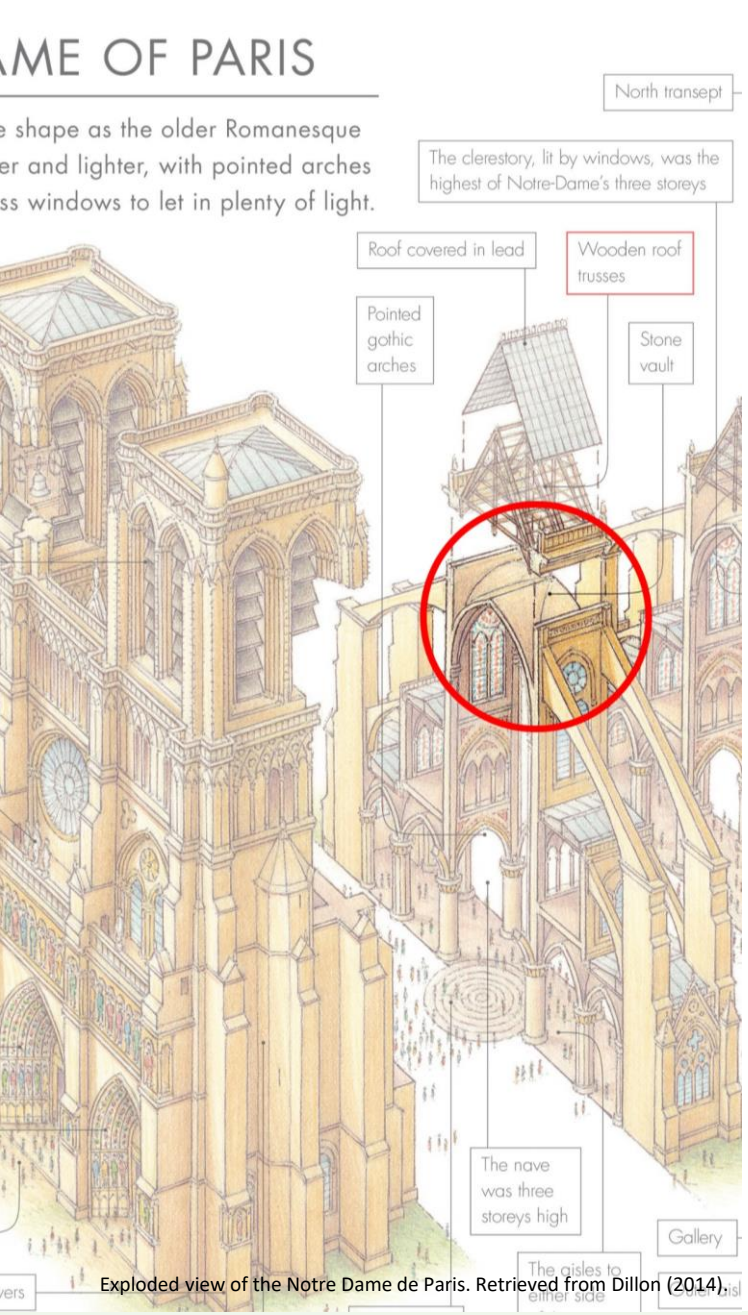
Retrieved from https://www.cluttermagazine.com/news/2016/02/cast-glass-sculptures-christina-bothwell

Retrieved from http://www.castglassforms.com/glass-sculpture.html

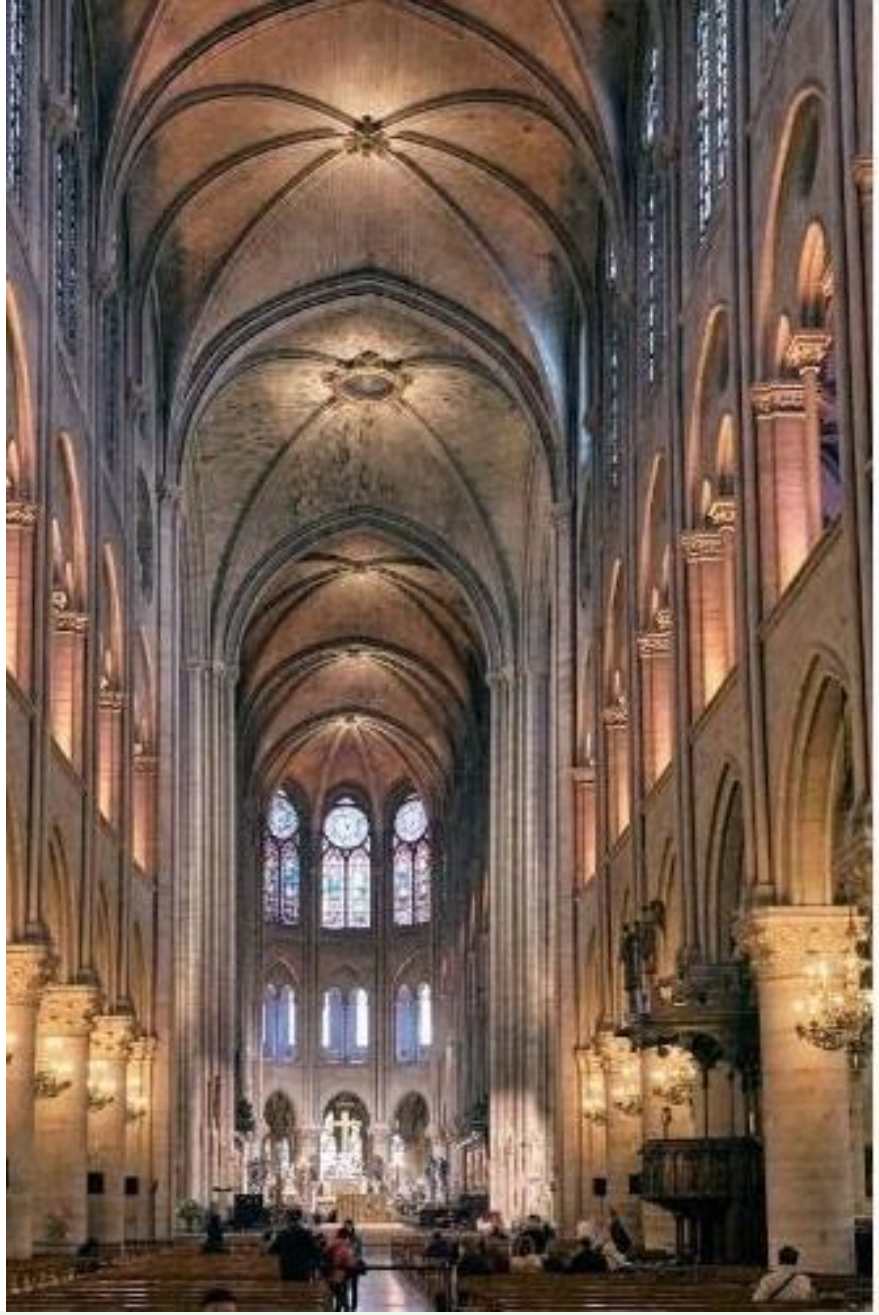
Retrieved from https://lorenzocafebar.com/#cast-glass-sculpture



Notre Dame de Paris. Retrieved from Shaw (2019).



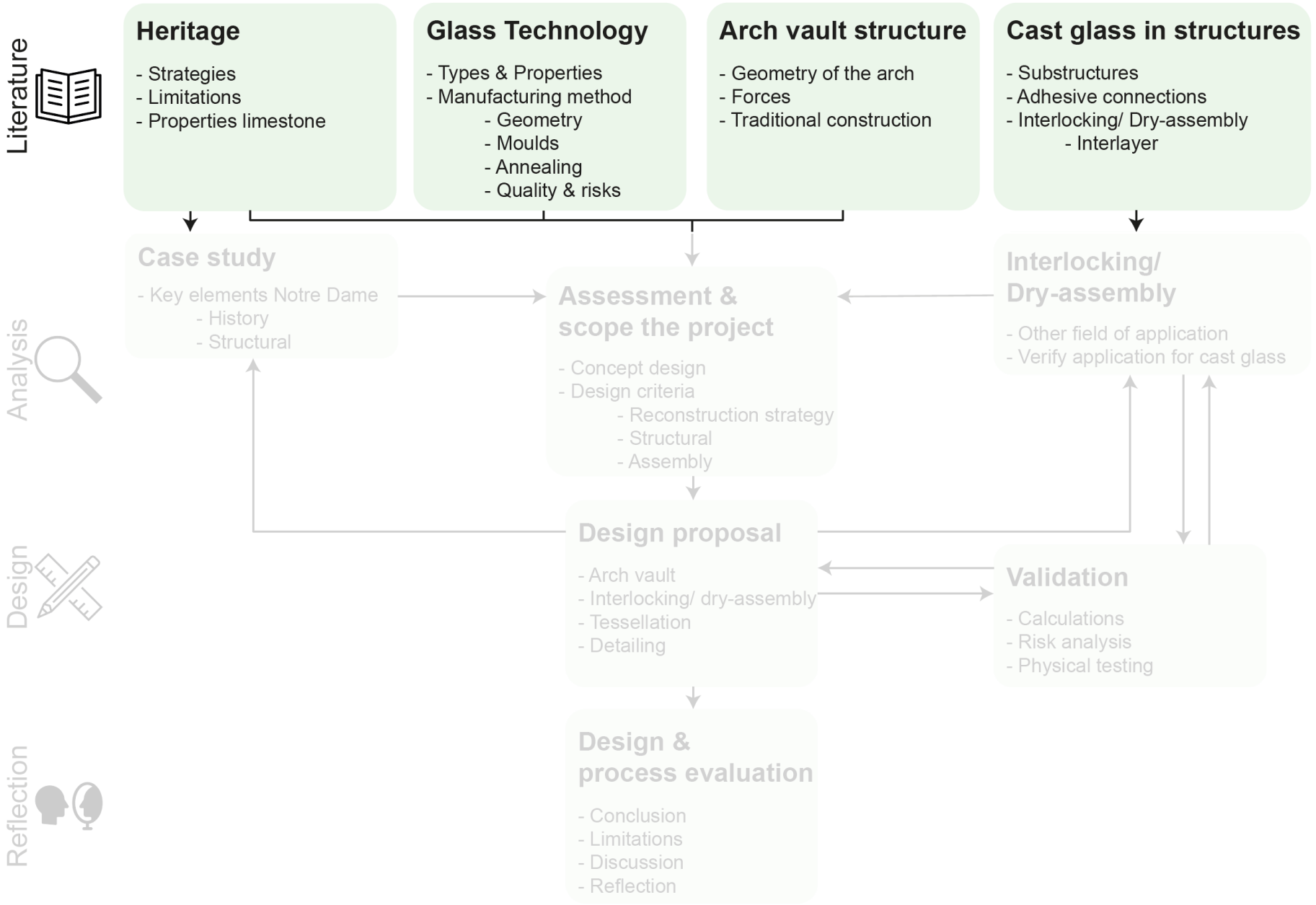
Exploded view of the Notre Dame de Paris. Retrieved from Dillon (2014).



Interior before & after the fire (bottom). Retrieved from Shaw (2019).

To what extent can a historical masonry arch vault be reconstructed by using cast glass components?

Cast glass arch vaults



Understanding heritage

Guidelines

Understanding history

Minimalizing intervention

Maximizing reversibility

Analyzing finance

‘Restore the heritage as original!’

‘Adjust the heritage to the needs of today!

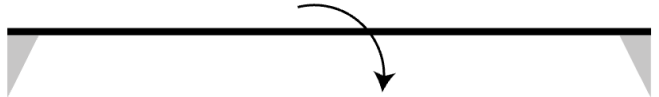
Even when new technology is needed’

Understanding masonry vaults

Strength

Stiffness

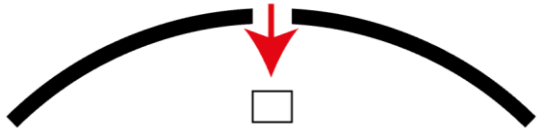
Stability



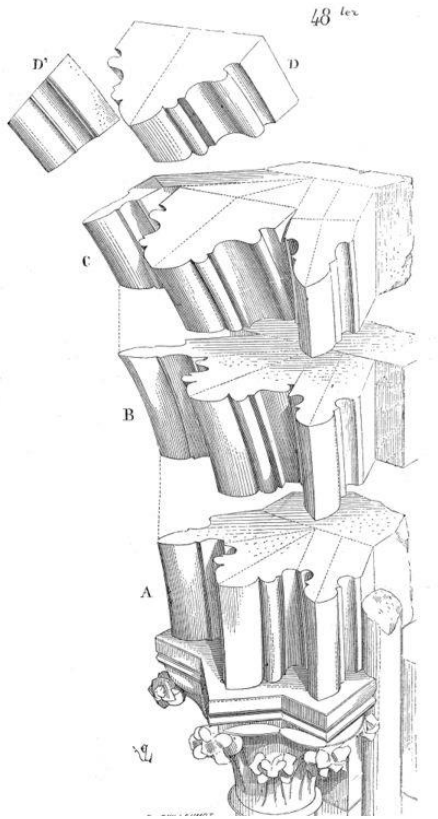
Compression only

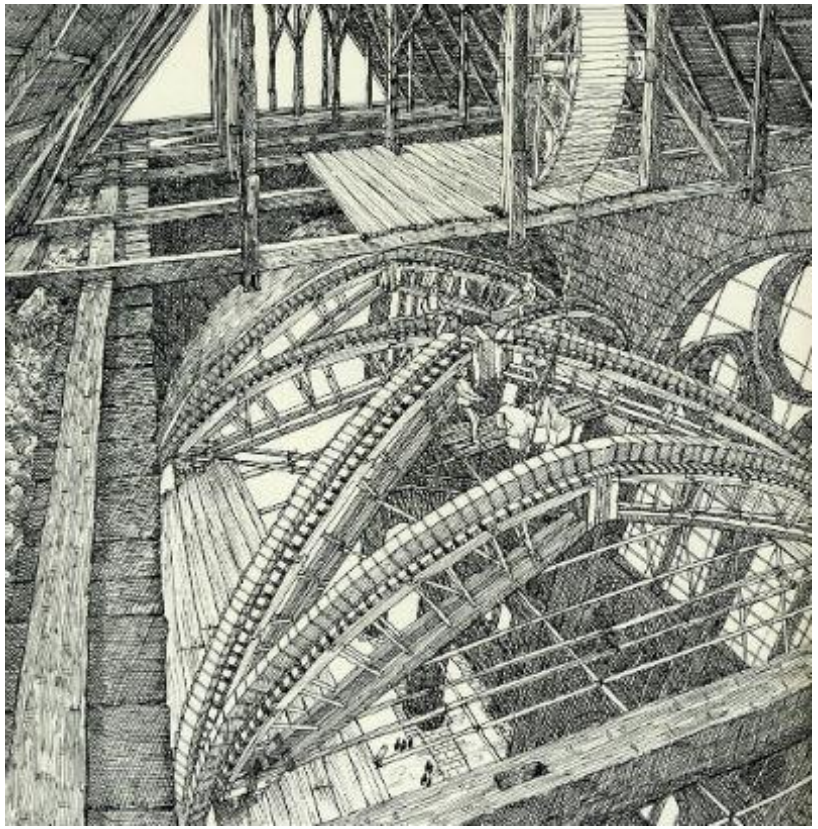
Tensile stress by forces

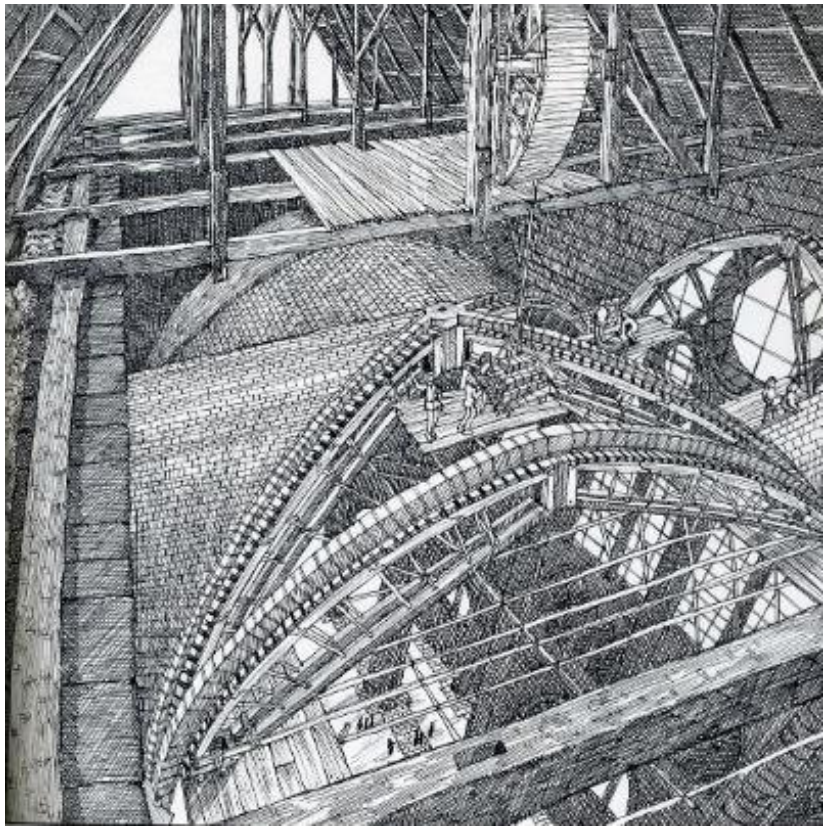
No sliding failure



Traditional construction





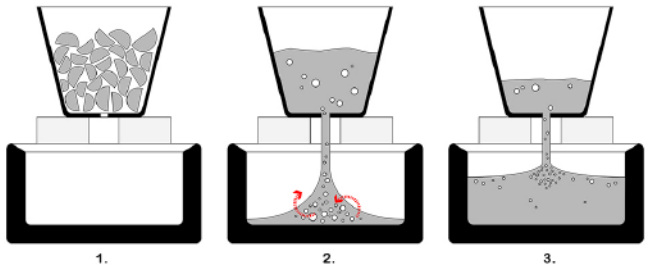


Construction order of a cathedral's rib vault. Retrieved from Stöver (n.d.) and Courtenay (1997).

Understanding structural glass

Properties	Unit	Soda-Lime glass	Borosilicate Glass	Lead Silicate glass	Limestone (average)
Densitiy	10^3 kg/m^3	2.5	2.2-2.5	2.8-2.9	2.55-2.6
Young's Modulus	Gpa	68-72	61-64	53-64	35-55
Compressive Strength	Mpa	300-420	260-350	230-1370	30-200
Tensile Strength	MPa	30-35	22-32	23-137	8-22
Thermal Expansion Coef.	10^{-6} K^1	8.5-9.5	3.2-4	9.1	3.7-6.3
Thermal Conductivity	W/m°C	0.9-1.1	1.1-1.3	0.9-1.3	0.92-2.15
Porosity	%	0	0	0	0.006-0.12

Hot-forming casting. Retrieved from Oikonomopoulou (2019) and Bristogianni (2017).



Kiln casting. Retrieved from Oikonomopoulou (2019) and Bristogianni (2017).

Primary process (Hot-forming casting)

Raw materials

Mix and melt

Pour liquid into mould

Cooling down from softening point till annealing point (Anneal soak)

Poured glass in new mould for annealling process

Secondary process (Kiln casting)

Small pieces of glass

Melt

Liquid flows into mould (incl. Anneal soak)

Annealling process

Initial Cooling (from annealing point till strain point)

2nd Cooling (From strain point till 50°C)

Final Cooling (From 50°C till room temp.)

Quality check

Hot-forming casting. Retrieved from Oikonomopoulou (2019) and Bristogianni (2017).

Kiln casting. Retrieved from Oikonomopoulou (2019) and Bristogianni (2017).

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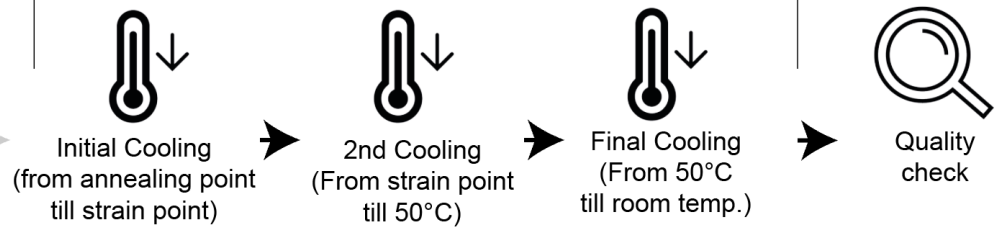
Annealling process



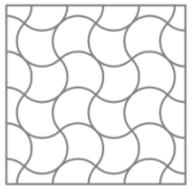
Thickness (mm)	12	19	25	38	50	62	75	100	150	200
Min. Time (hours)	5	9	14	28	47	70	99	170	375	654

Safety of glass structures

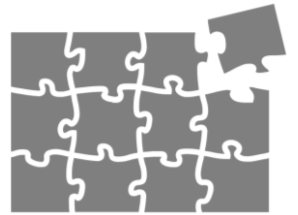
Risk assessments

Reduce element size

Fragmenting



Redundancy



Understanding cast glass in structures

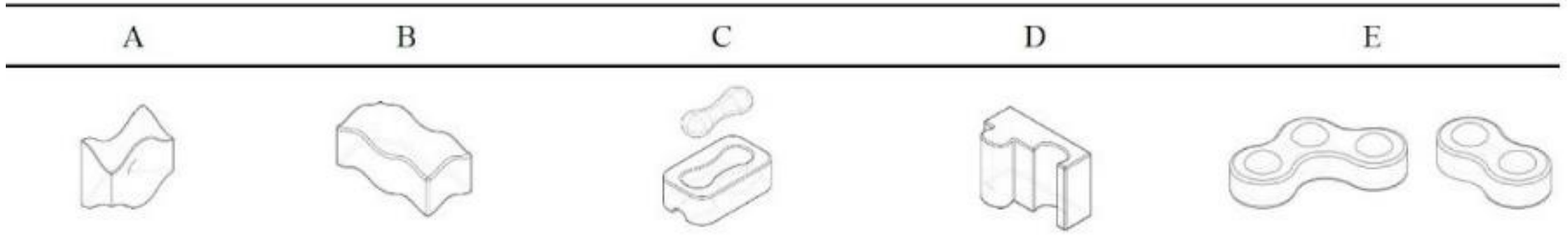
Metal substructures

Optical house. Retrieved from Hiroshi (n.d.)

Adhesive bonded

Cast glass façade for the Chanel Crystal house in Amsterdam. Retrieved from ABT (2016).

Interlocking

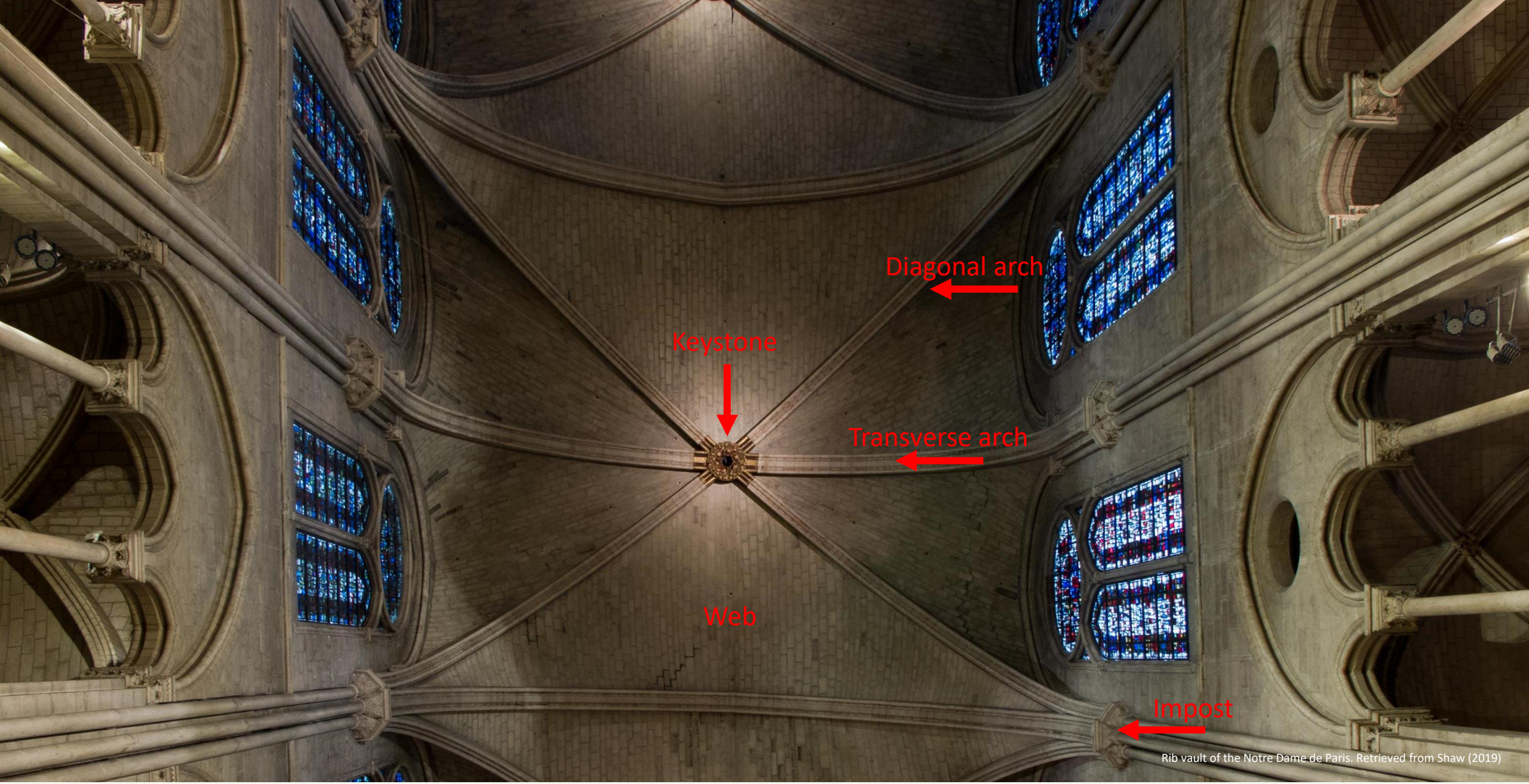


Researched interlocking systems by Oikonomopoulou. Retrieved from Oikonomopoulou (2019).

Dry-assembly interlocking glass bridge structure. Retrieved from Aurik, Snijder, Noteboom, Nijsse, & Louter (2018).

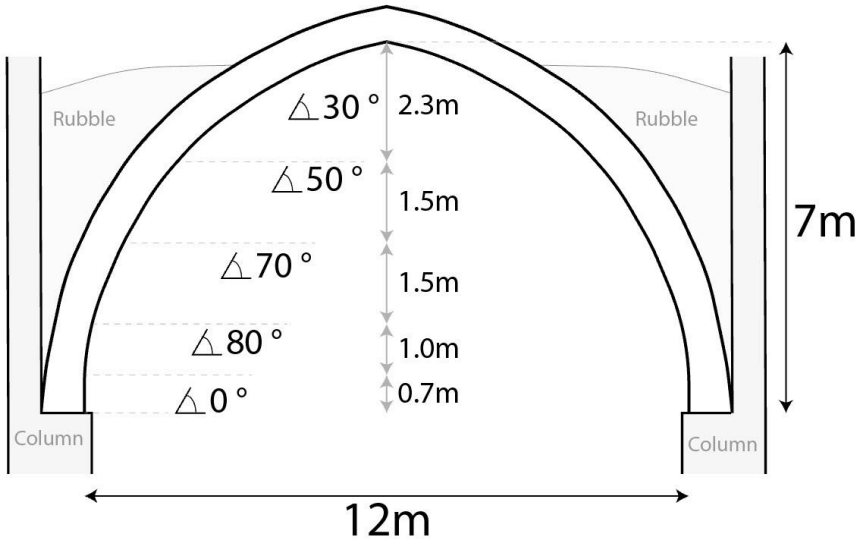
Design process

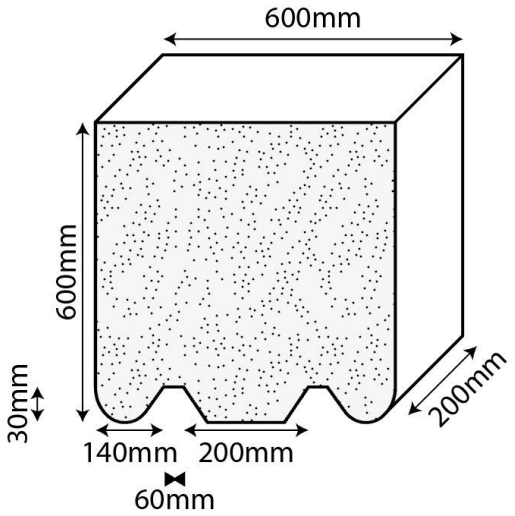
Rib vault of the Notre Dame de Paris. Retrieved from Shaw (2019)



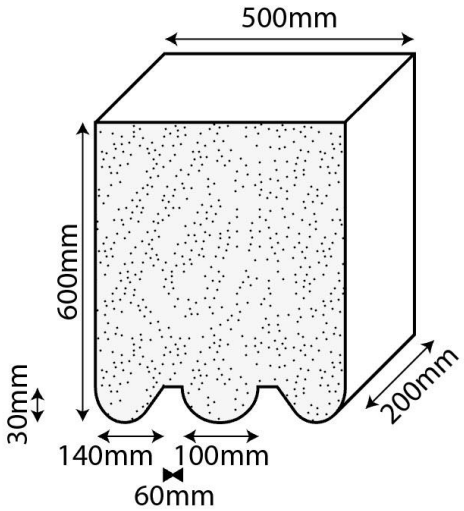
Rib vault of the Notre Dame de Paris. Retrieved from Shaw (2019)

Criteria





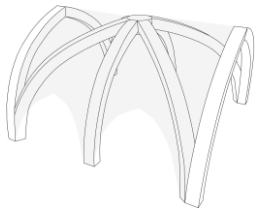
Cross section
Transverse arch



Cross section
Diagonal arch

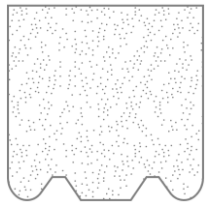
Compatibility

One rib vault



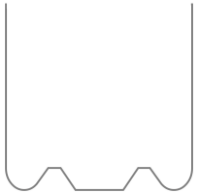
No interference

Cast glass

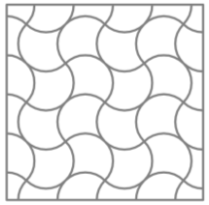


Geometry

Outline & Top



Tessellation



Safe structure

Production

Organic shape

Max. 25kg

Limit moulds

Interlocking

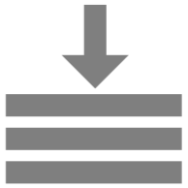
Simple & organic

Tolerance

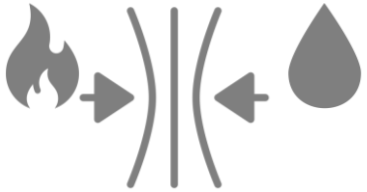
Height<width

Interlayer

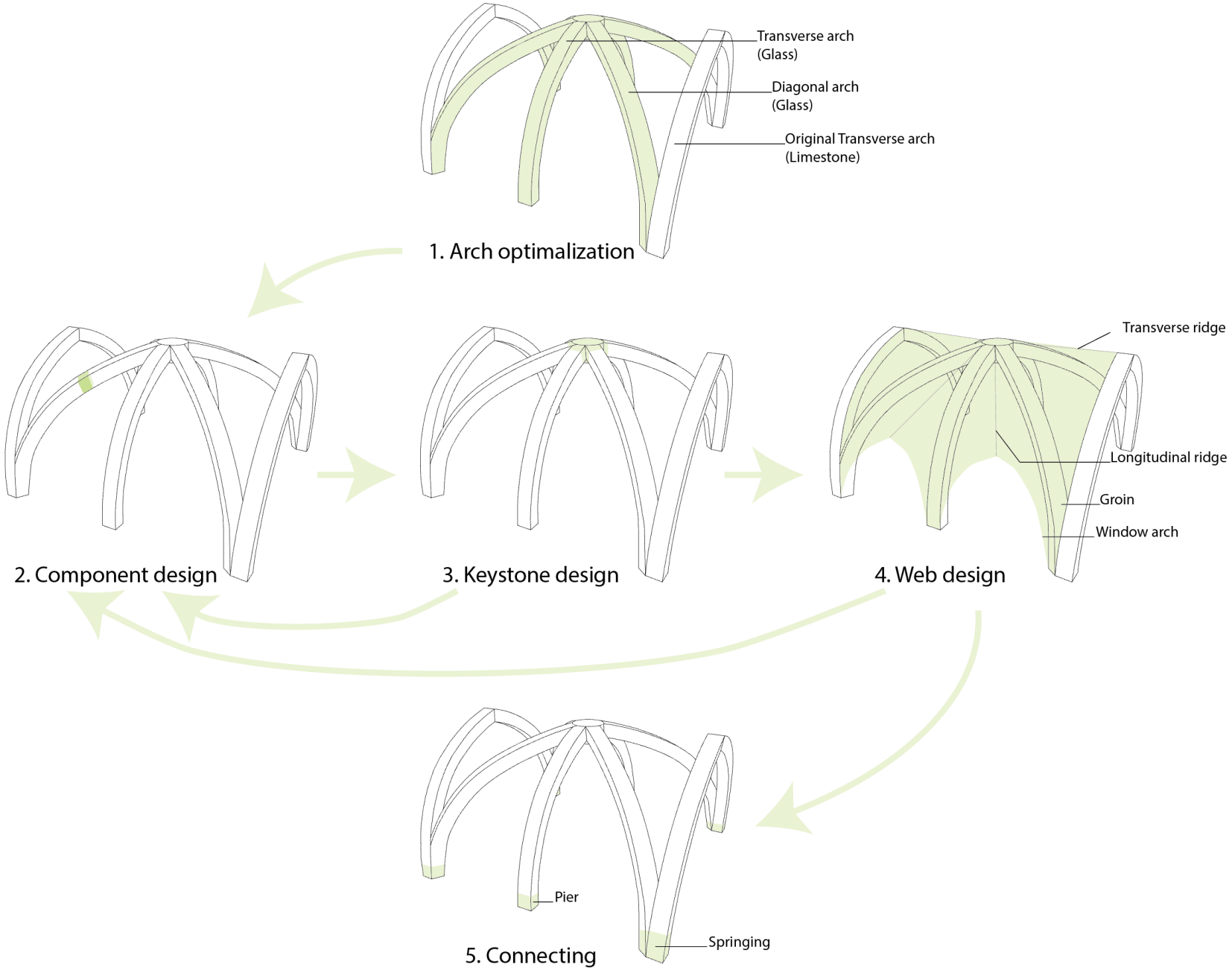
Compression >20Mpa

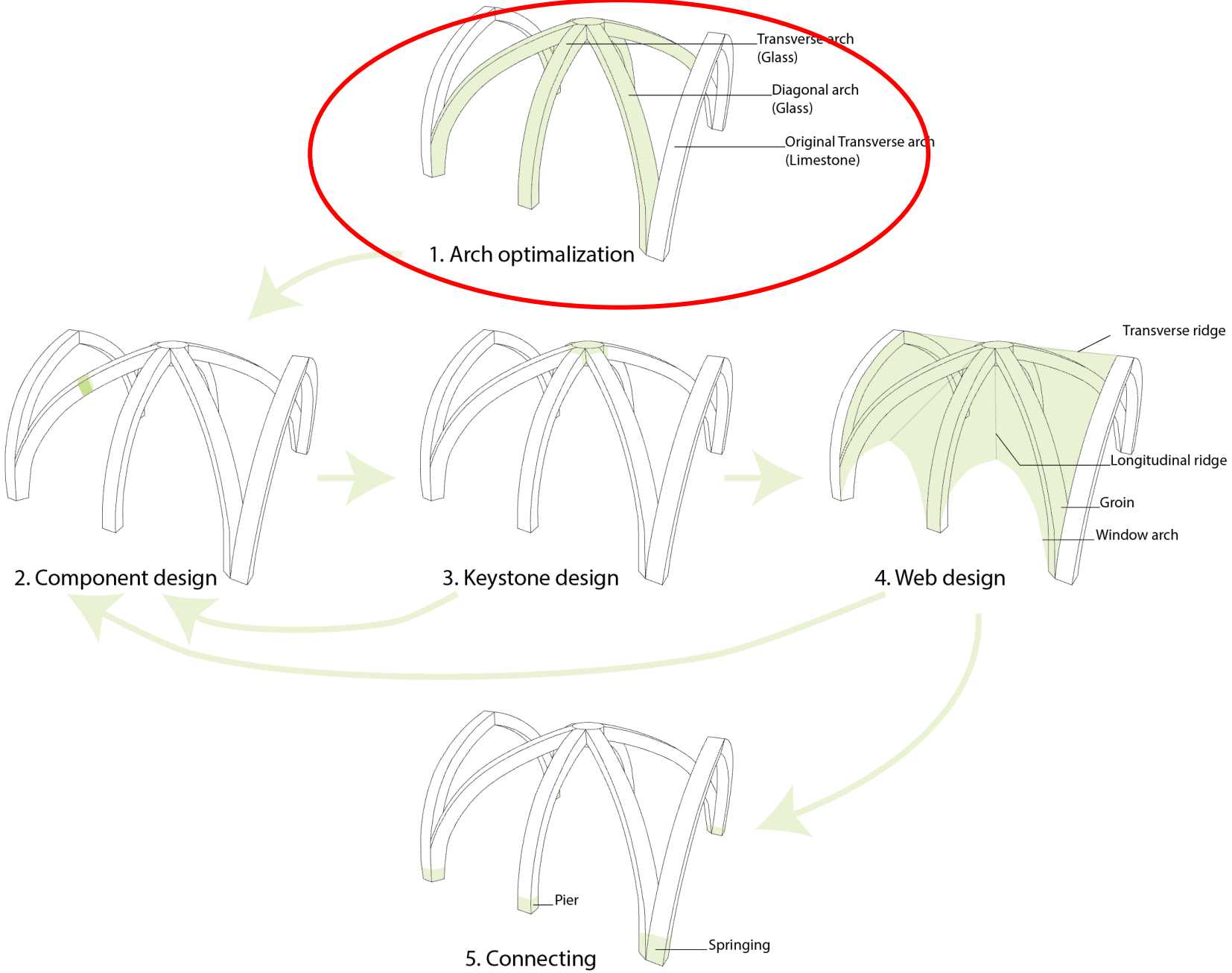


Creep, water & fire



Flexible & transparent


Transverse arch
(Glass)
Diagonal arch
(Glass)
Original Transverse arch
(Limestone)
1. Arch optimalization
2. Component design
3. Keystone design
Transverse ridge
Longitudinal ridge
Groin
Window arch
4. Web design
Pier
Springing
5. Connecting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Transverse ridge
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Groin
Window arch
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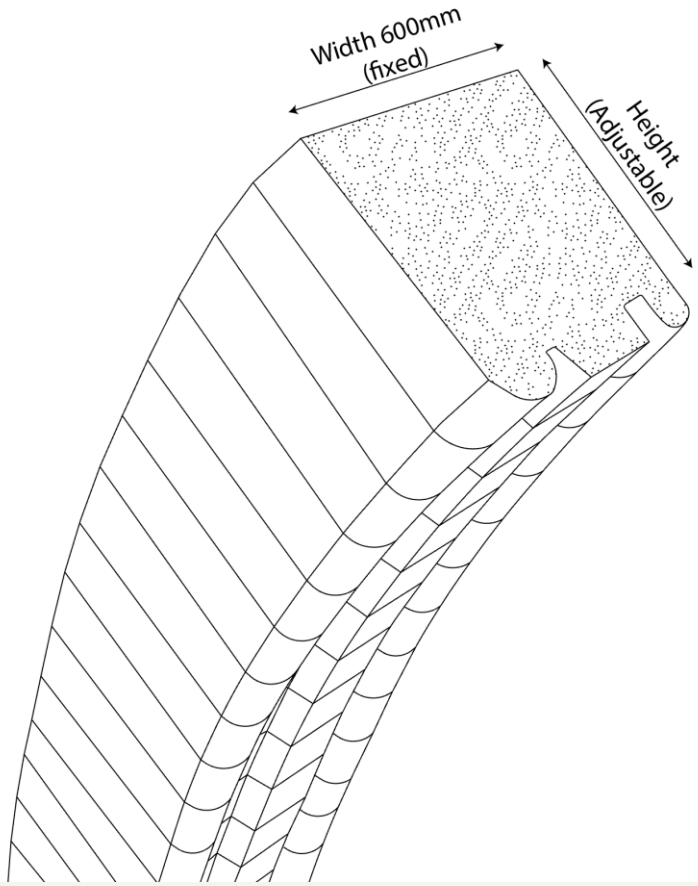
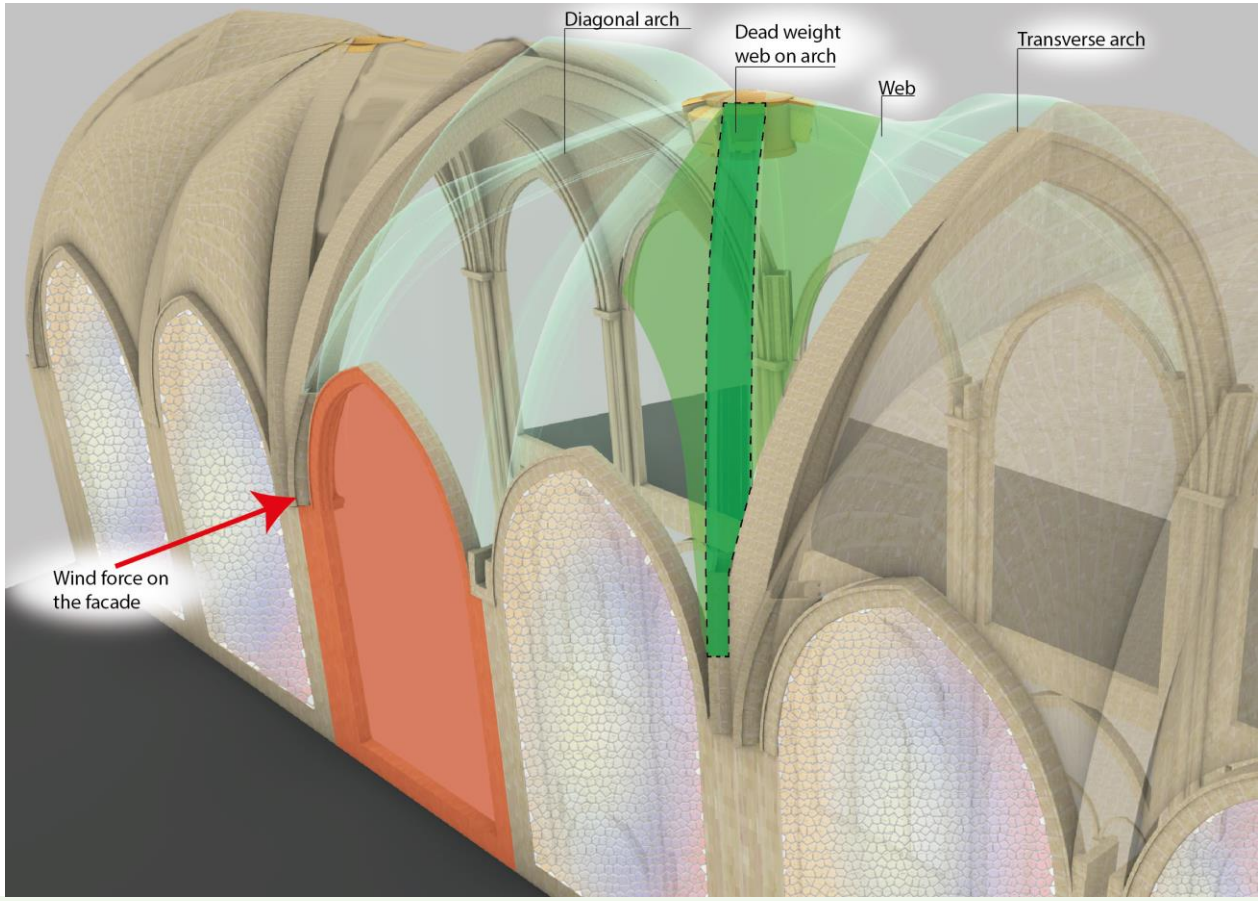
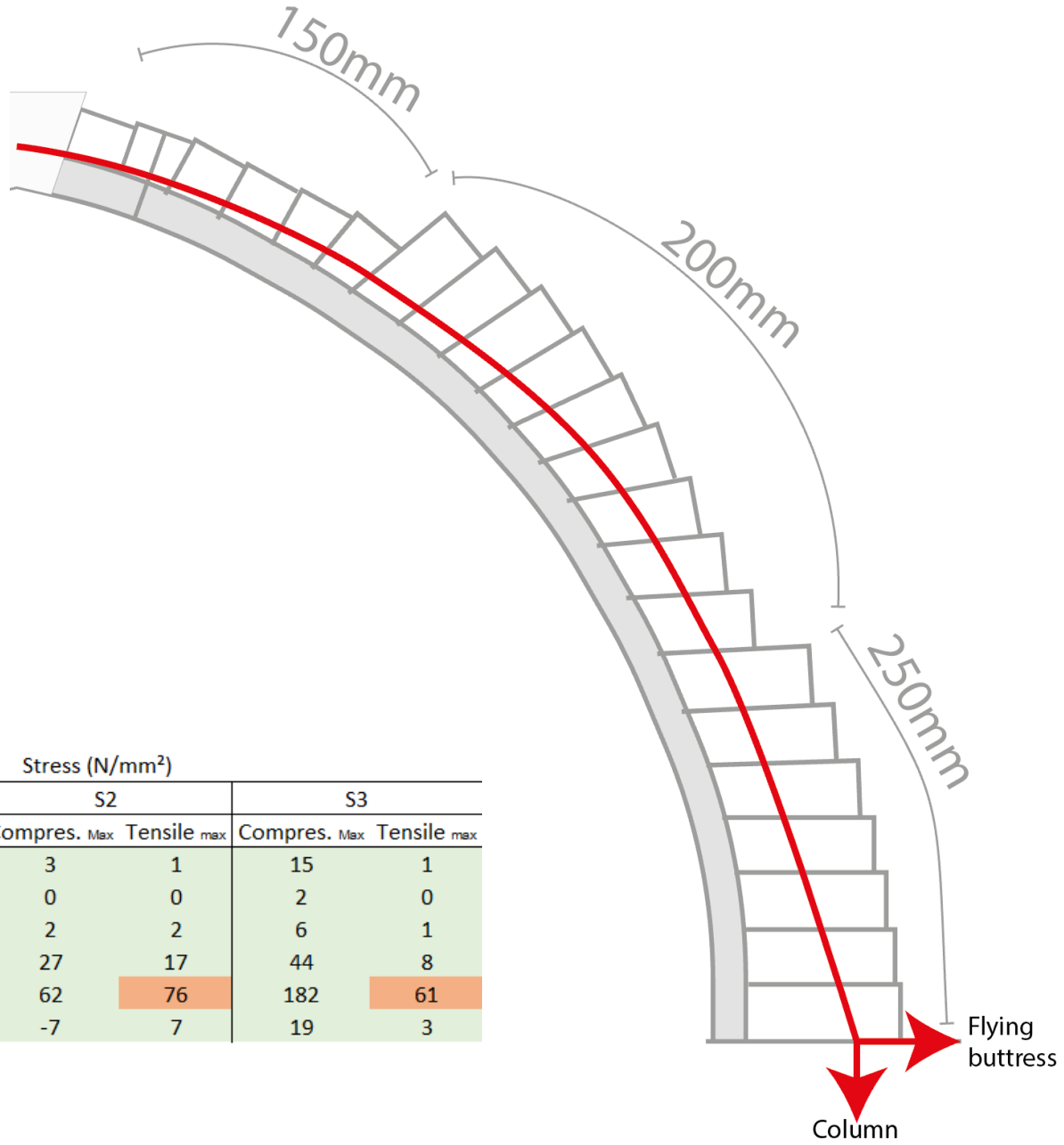
Pier
Springing
5. Connecting

Arch in general





	Dimension section (mm)		Deflection (mm)		Stress (N/mm²)							
Variant	Bottom	Top	Allowed	Simulated$_{max}$	Glass Compres. $_{max}$	Glass Tensile $_{max}$	S1 Compres. $_{Max}$	S1 Tensile $_{max}$	S2 Compres. $_{Max}$	S2 Tensile $_{max}$	S3 Compres. $_{Max}$	S3 Tensile $_{max}$
Current	600 x 600	600 x 600	100	0,42	260	22	1	10	3	1	15	1
1	600 x 600	300 x 600	50	0,31	260	22	0	2	0	0	2	0
2	300 x 600	300 x 600	50	0,84	260	22	1	5	2	2	6	1
3	150 x 600	150 x 600	25	11	260	22	10	33	27	17	44	8
4	50 x 600	50 x 600	8	9	260	22	44	236	62	76	182	61
5	250 x 600	150 x 600	25	3,7	260	22	3	16	-7	7	19	3



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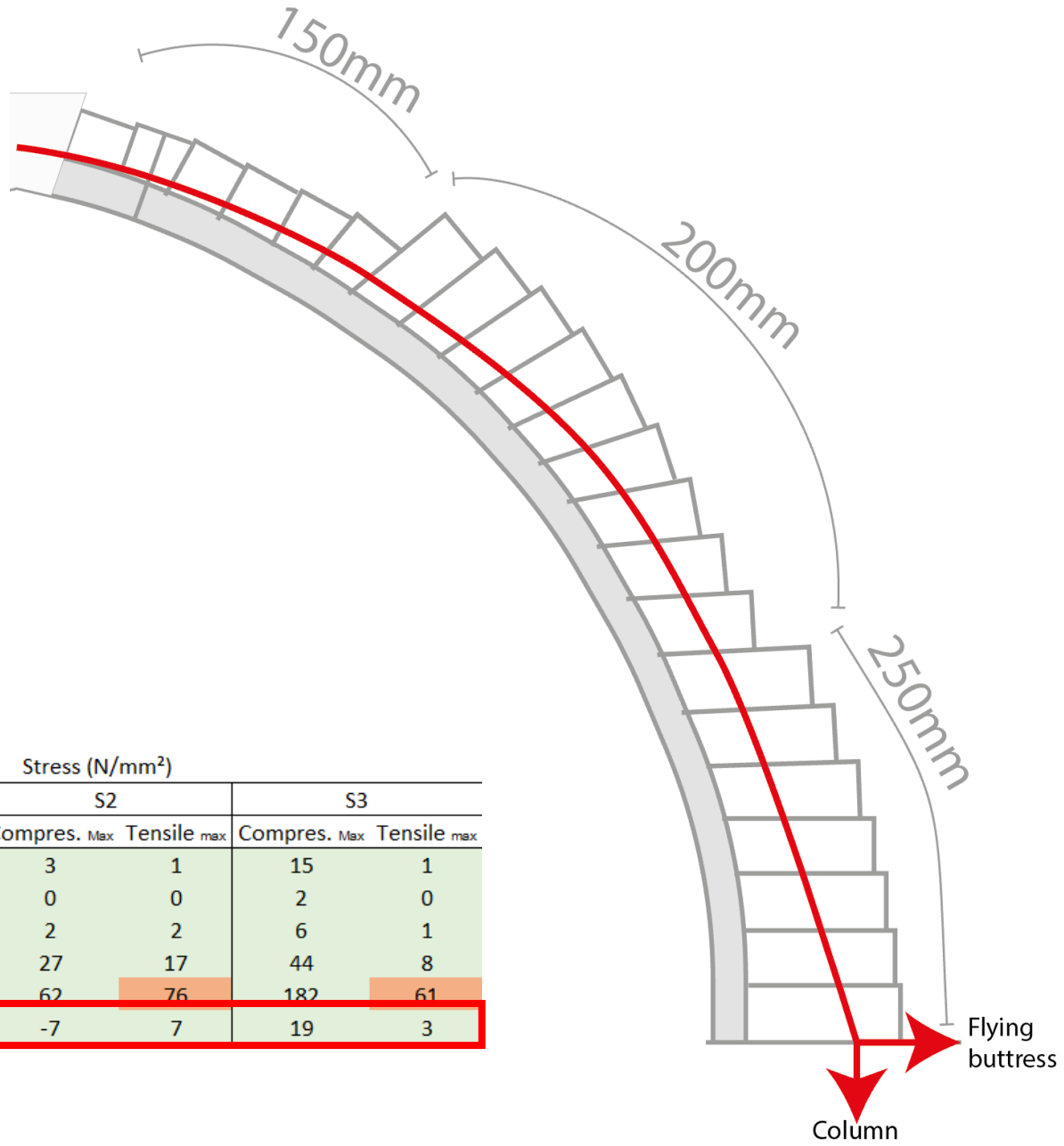
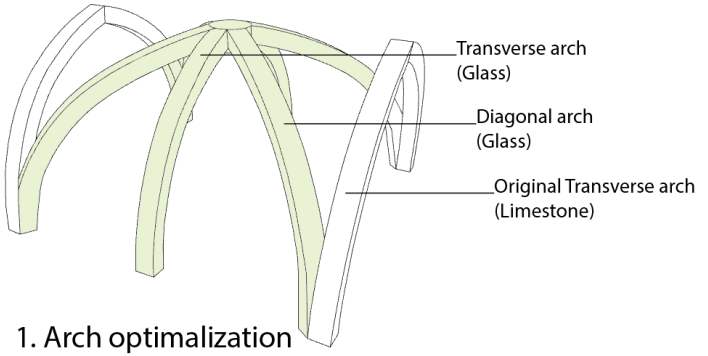
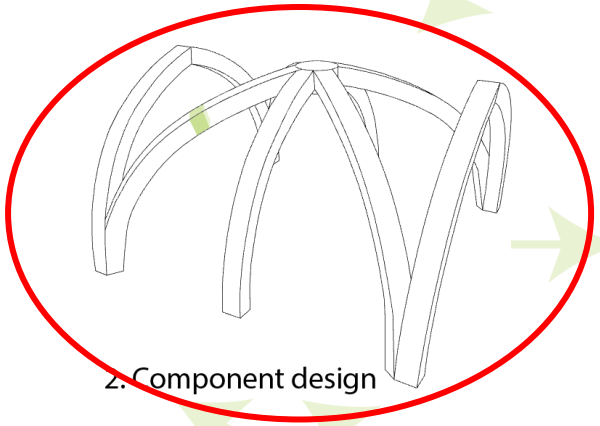
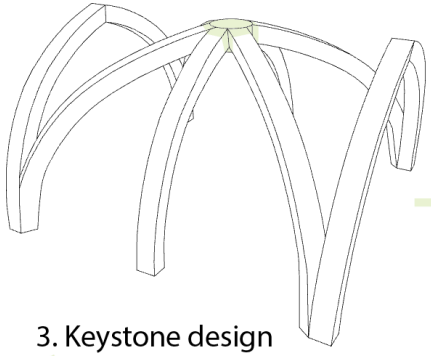




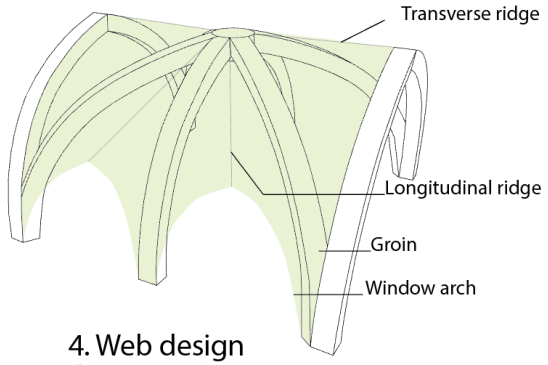
1. Arch optimalization



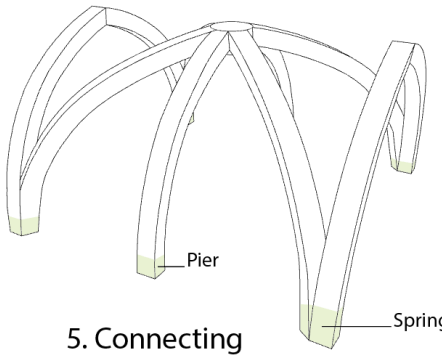
2. Component design



3. Keystone design

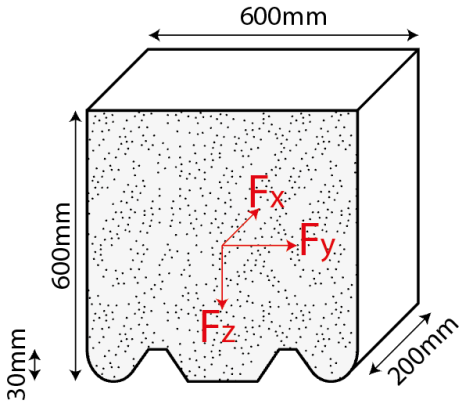


4. Web design

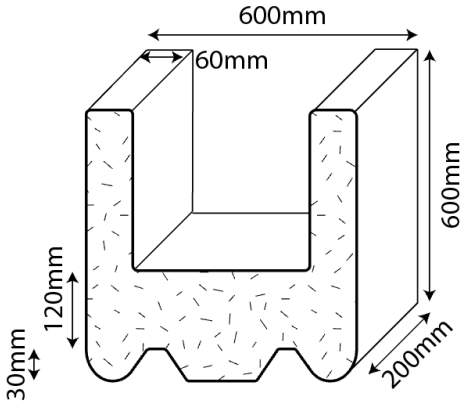


5. Connecting

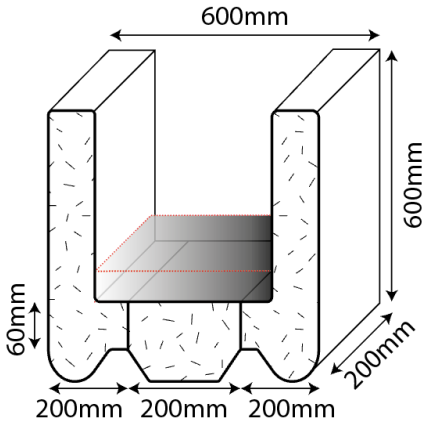
Arch component



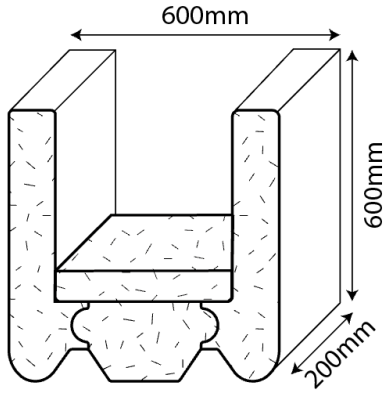
Start
(Original situation)



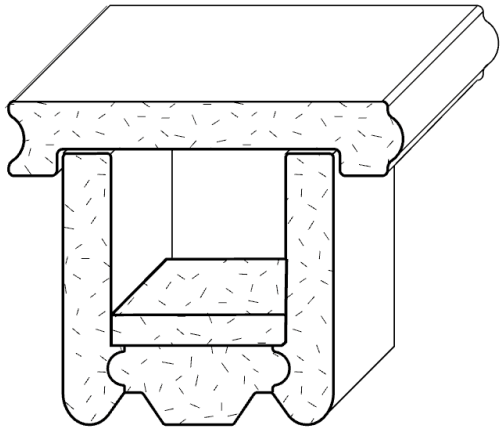
Step 1
(Reducing material)



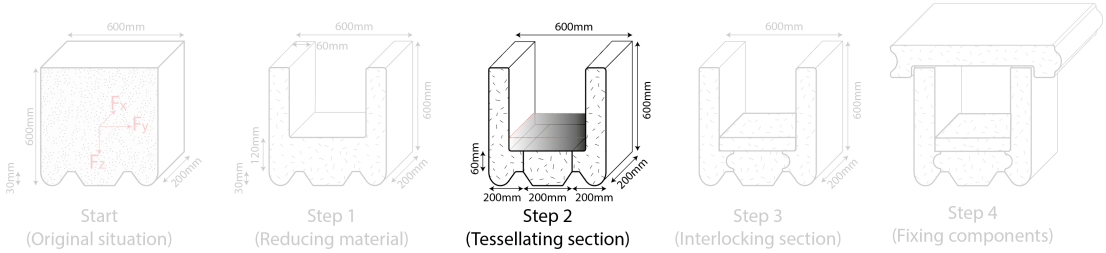
Step 2
(Tessellating section)

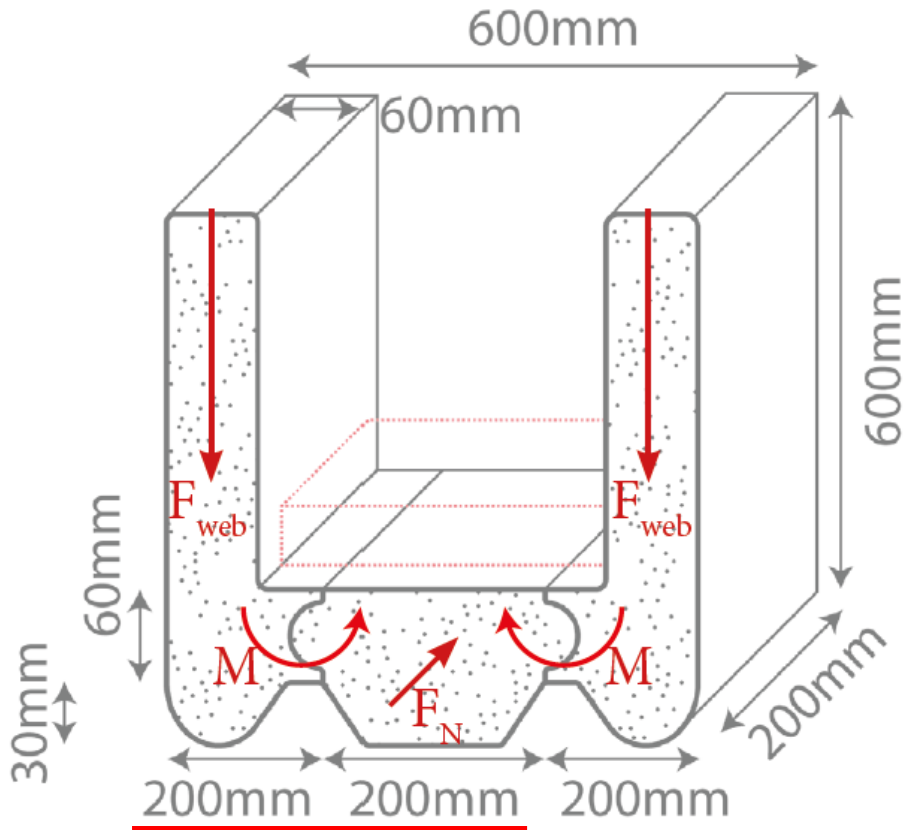


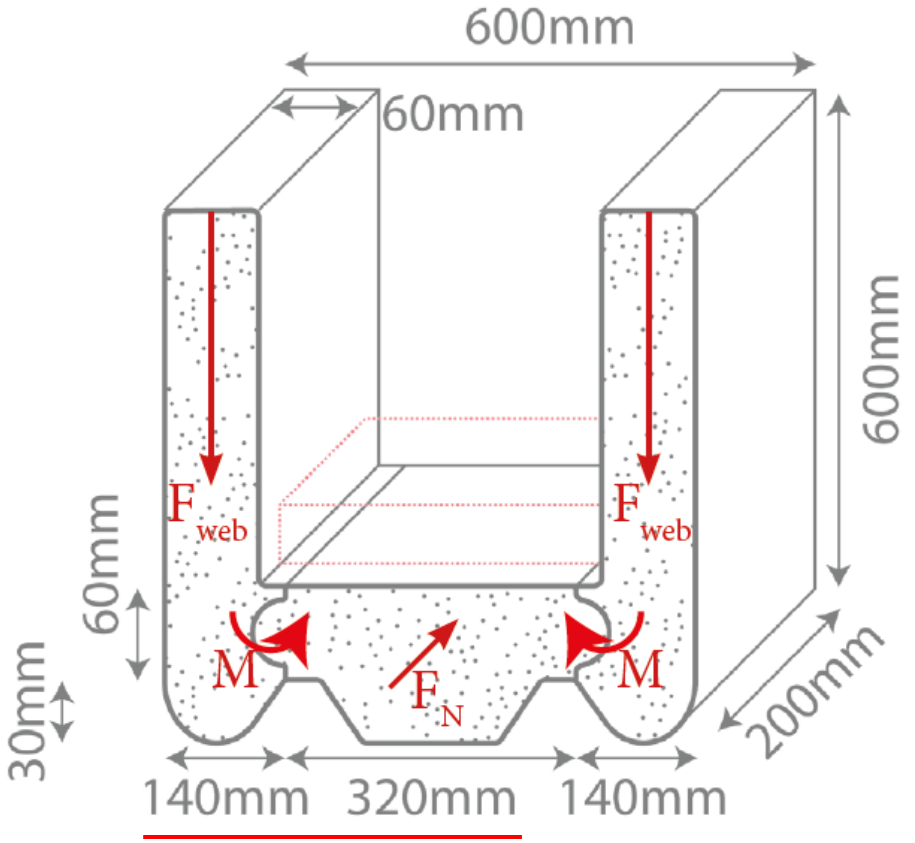
Step 3
(Interlocking section)



Step 4
(Fixing components)


Start
(Original situation)
Step 1
(Reducing material)
Step 2
(Tessellating section)
Step 3
(Interlocking section)
Step 4
(Fixing components)

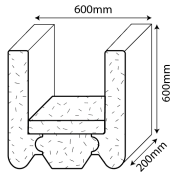

600mm
60mm
600mm
60mm
30mm
200mm
200mm
200mm
F web
F web
M
M
F N


600mm
60mm
600mm
60mm
30mm
200mm
140mm
320mm
140mm
F web
F web
M
M
F N

Start
(Original situation)

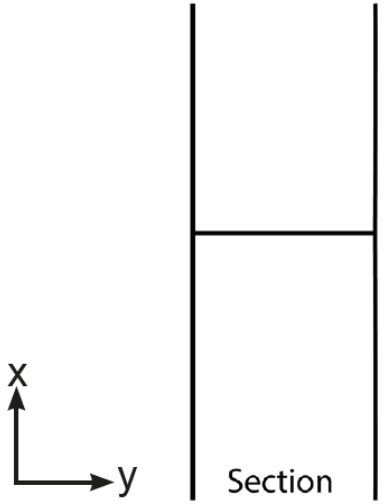
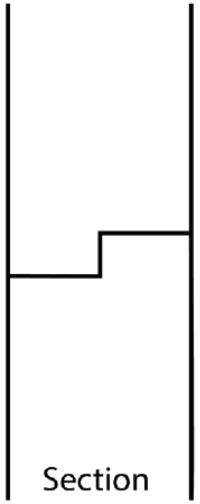
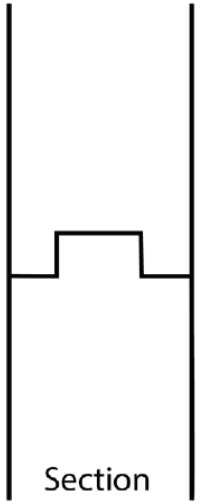
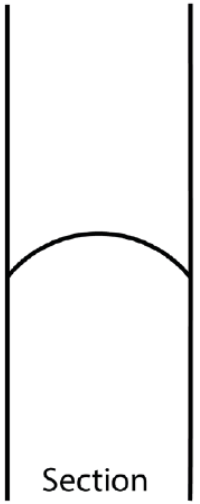
Step 1
(Reducing material)

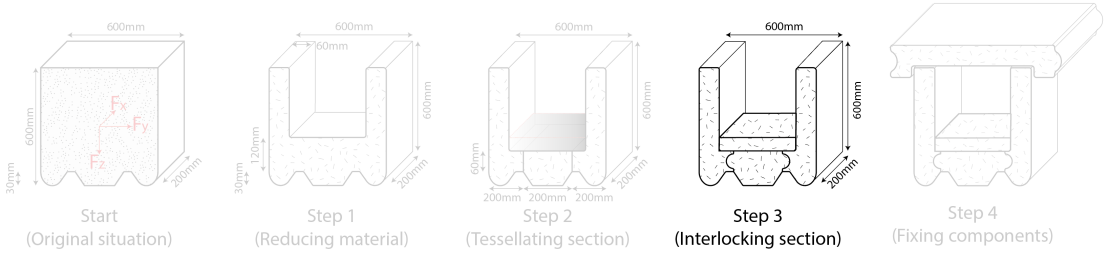
Step 2
(Tessellating section)



Step 3
(Interlocking section)

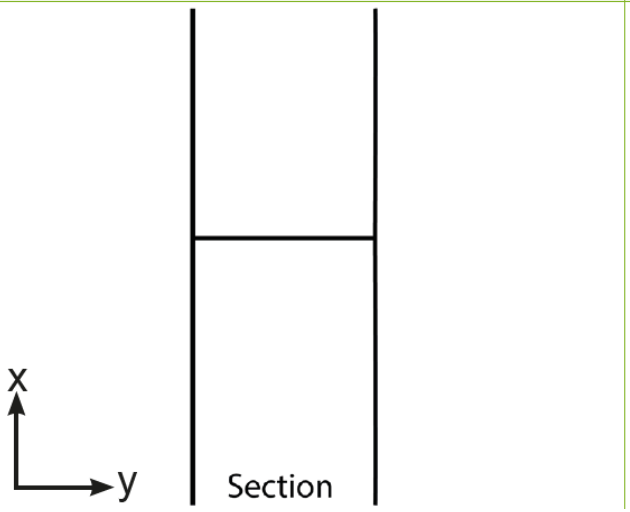
Step 4
(Fixing components)

Variant 1 (Straight)	Variant 2 (Tetris)	Variant 3 (Teeth)	Variant 4 (Curves)
			

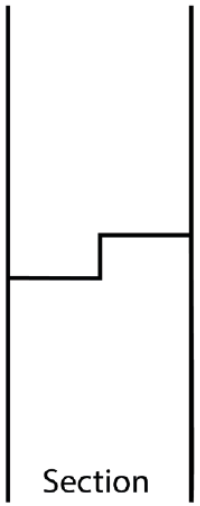


Start (Original situation) | Step 1 (Reducing material) | Step 2 (Tessellating section) | Step 3 (Interlocking section) | Step 4 (Fixing components)

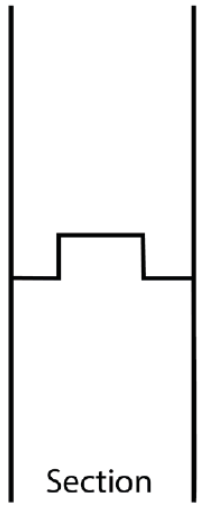
Variant 1 (Straight)



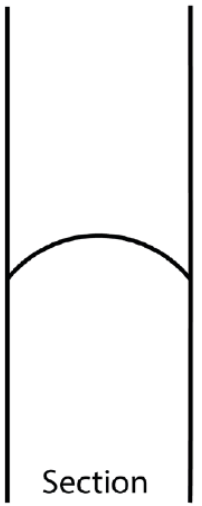
Variant 2 (Tetris)



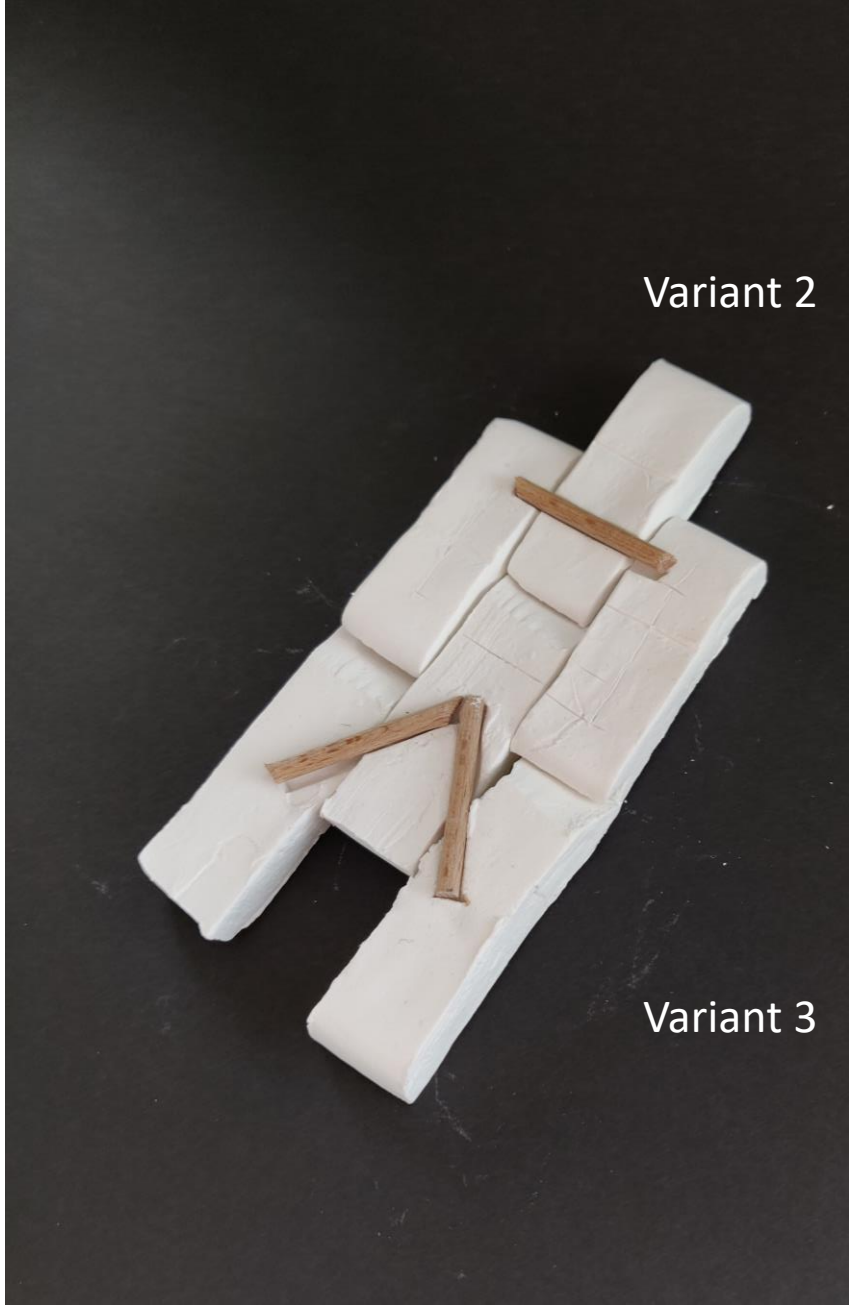
Variant 3 (Teeth)



Variant 4 (Curves)



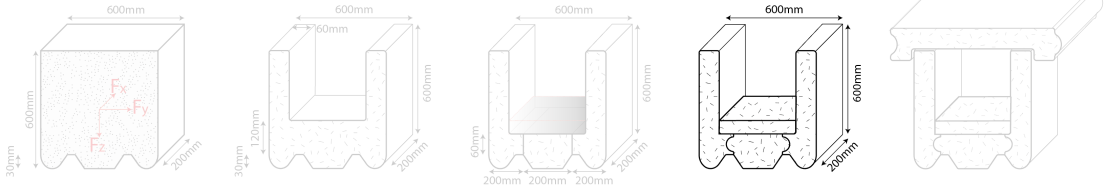

Variant 1


Variant 2
Variant 3

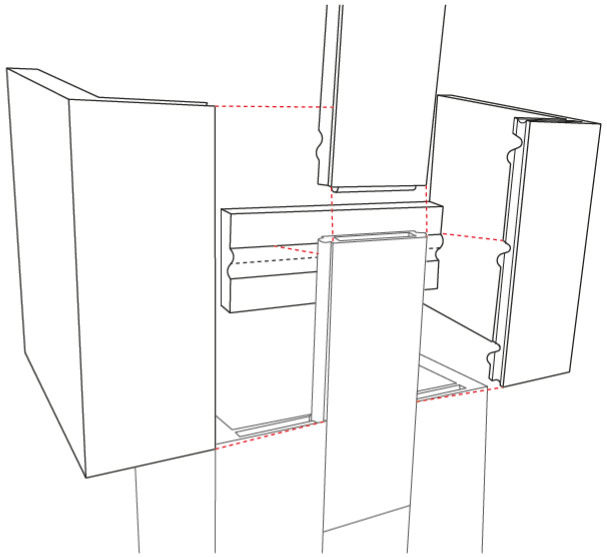

Variant 4

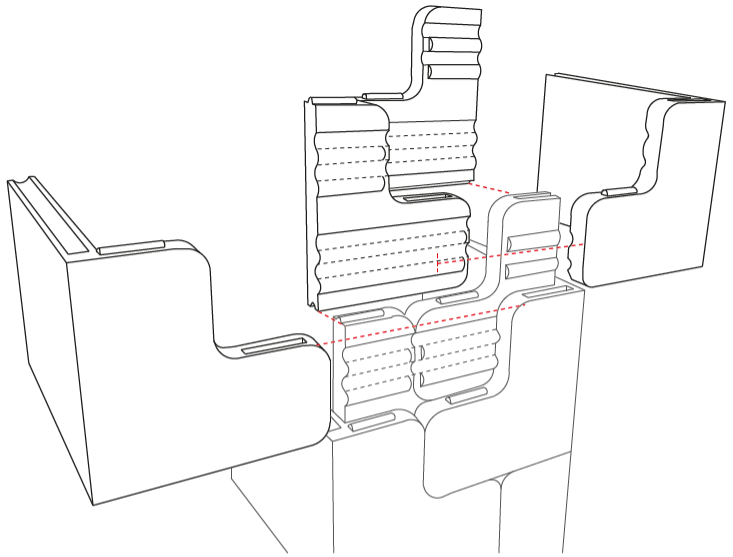

Variant 5


Variant 6



Start (Original situation) | Step 1 (Reducing material) | Step 2 (Tessellating section) | Step 3 (Interlocking section) | Step 4 (Fixing components)



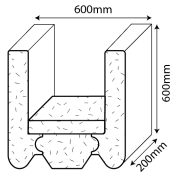


	Variant 4	Variant 6
Number of moulds	4	4
Weight smallest component	11,3 kg	12,5 kg
Weight biggest component	56,1 kg	42,5 kg
Similar to original lay-out?	Yes, longitudinal component	No, square components

Start
(Original situation)

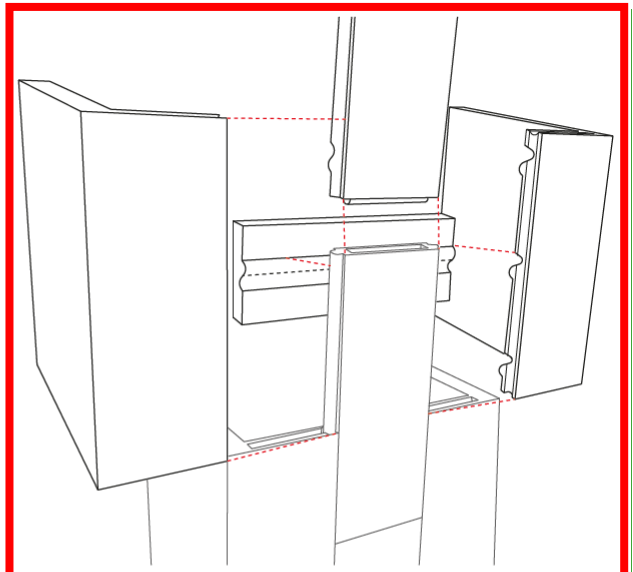
Step 1
(Reducing material)

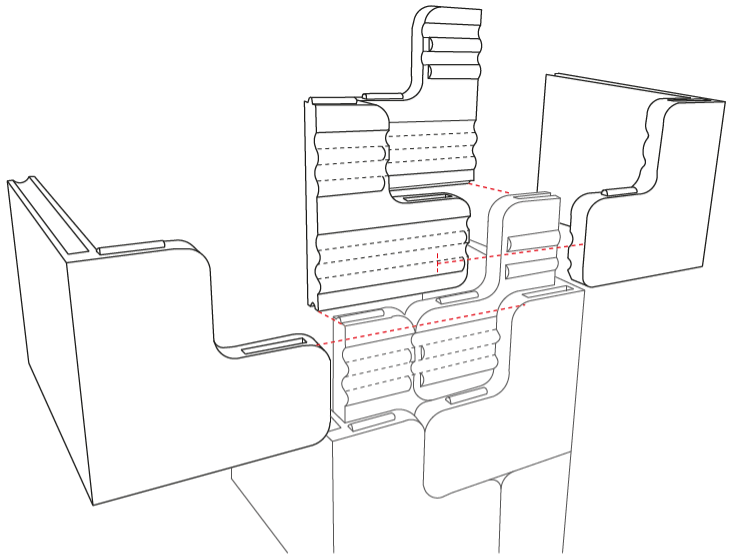
Step 2
(Tessellating section)



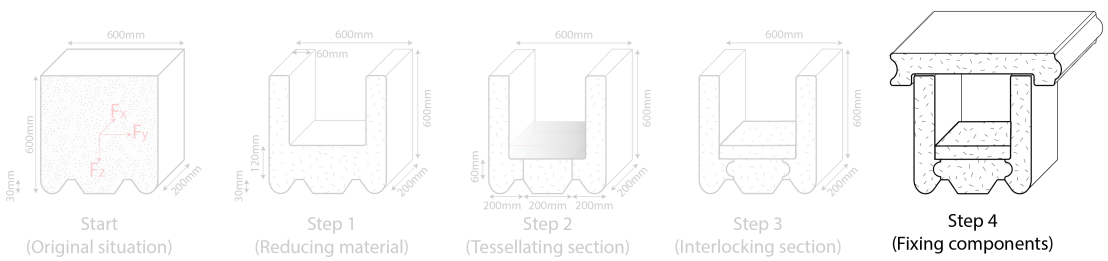
Step 3
(Interlocking section)

Step 4
(Fixing components)

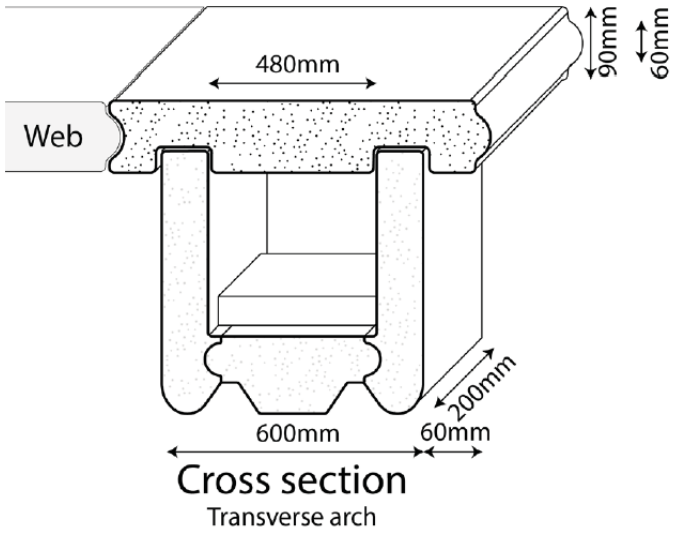




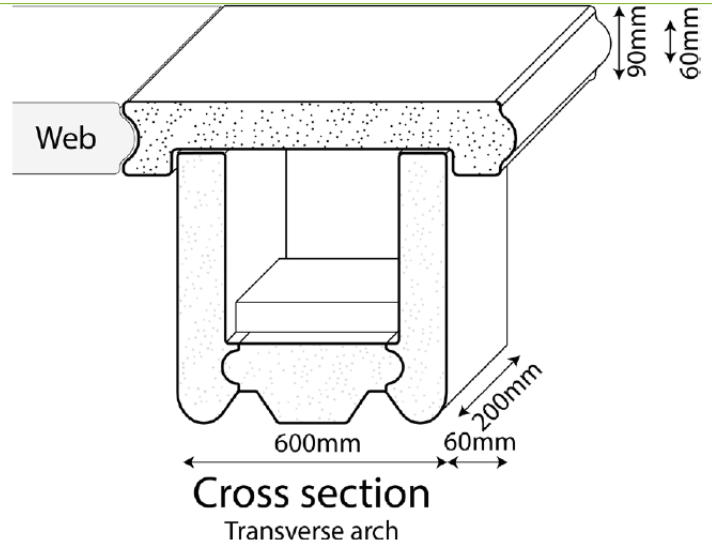
	Variant 4	Variant 6
Number of moulds	4	4
Weight smallest component	11,3 kg	12,5 kg
Weight biggest component	56,1 kg	42,5 kg
Similar to original lay-out?	Yes, longitudinal component	No, square components



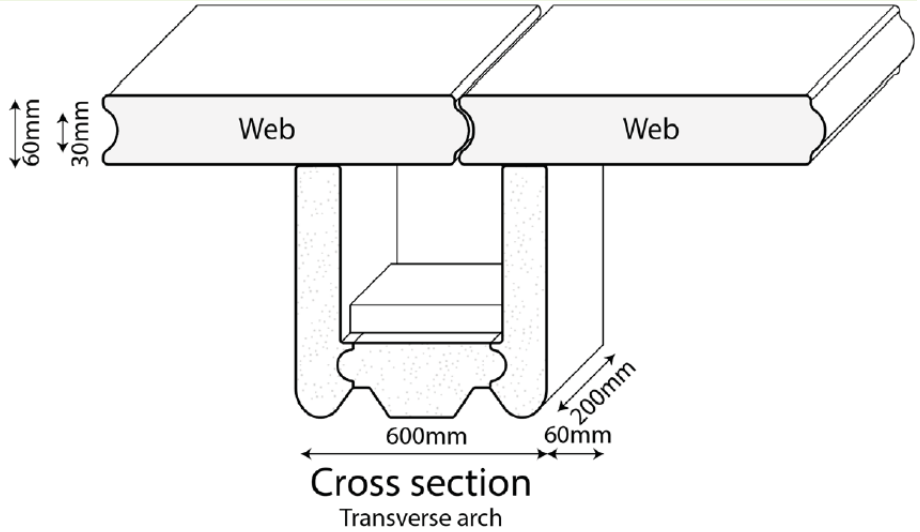
Variant 1 (Fixed)

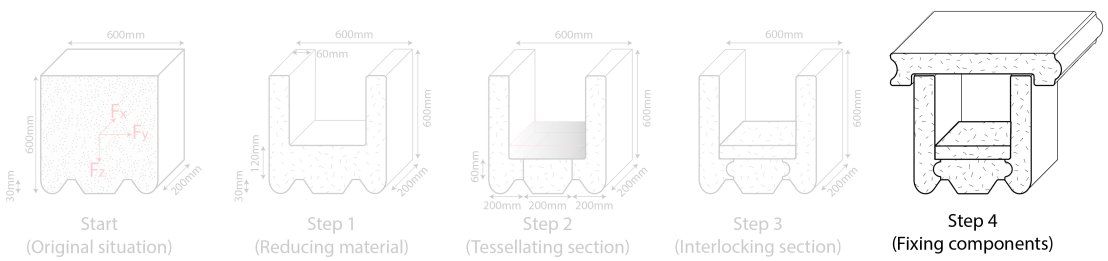


Variant 2 (Push back)

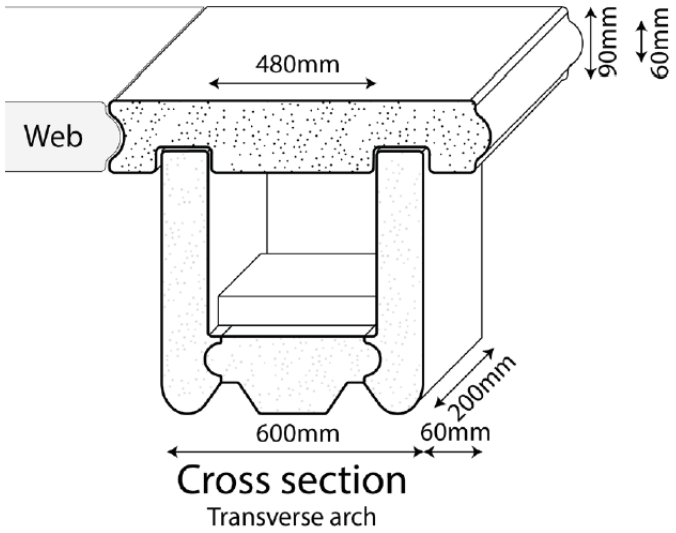


Variant 3 (Compression)

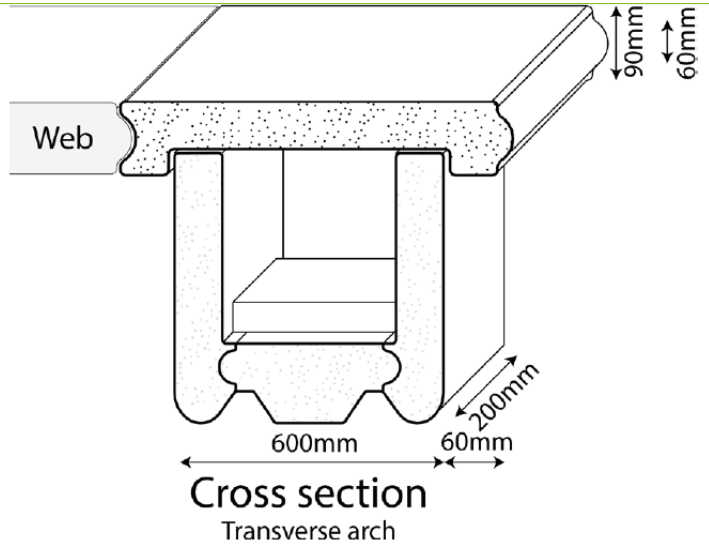




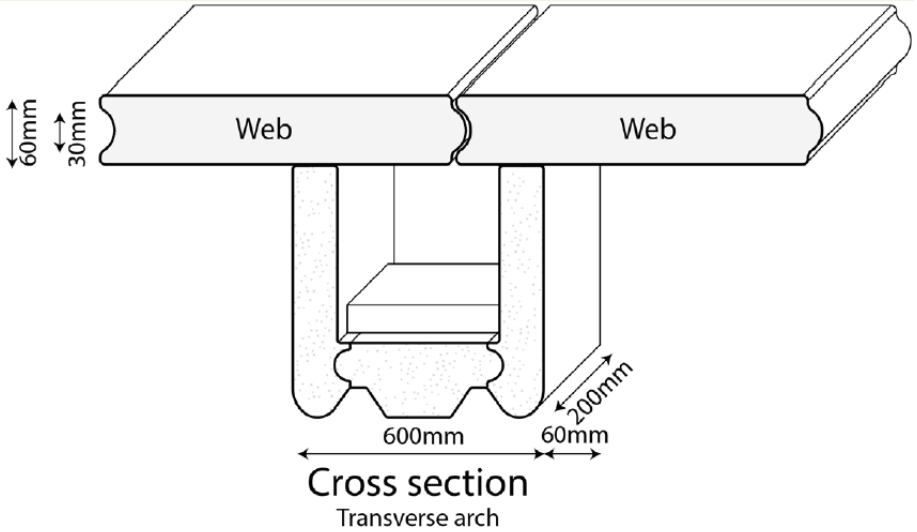
Variant 1 (Fixed)



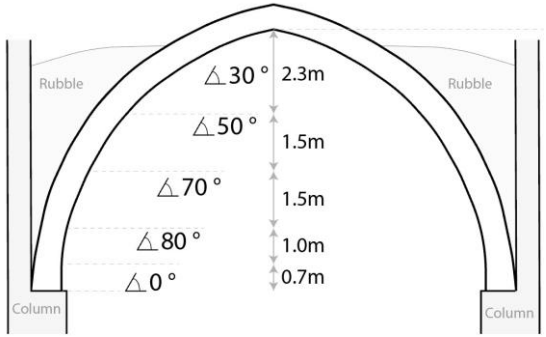
Variant 2 (Push back)

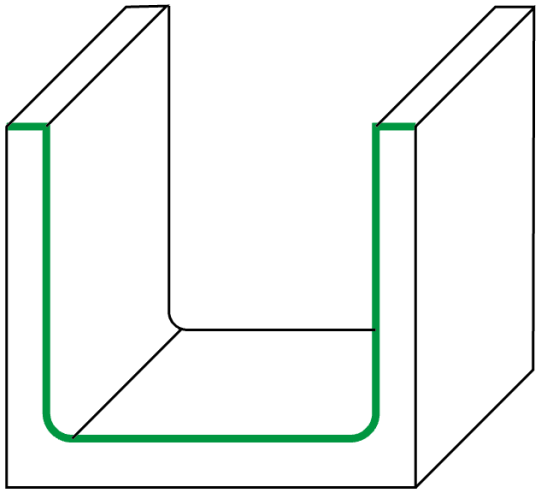


Variant 3 (Compression)

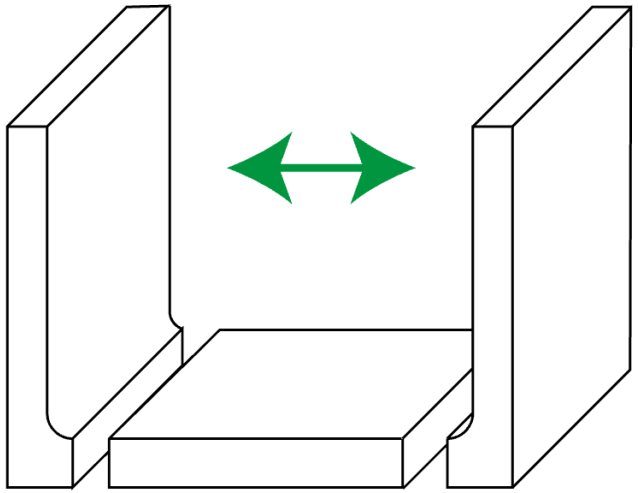


Moulds

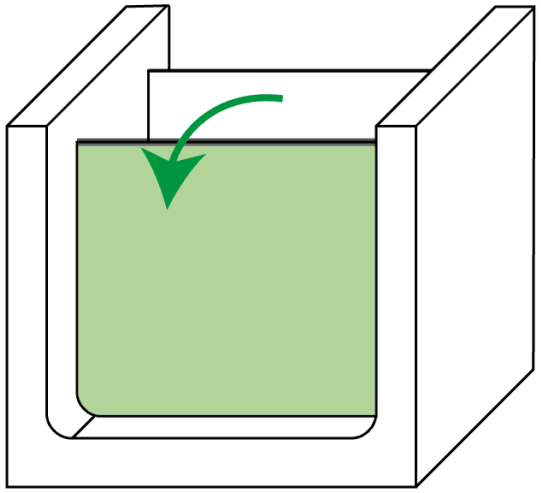




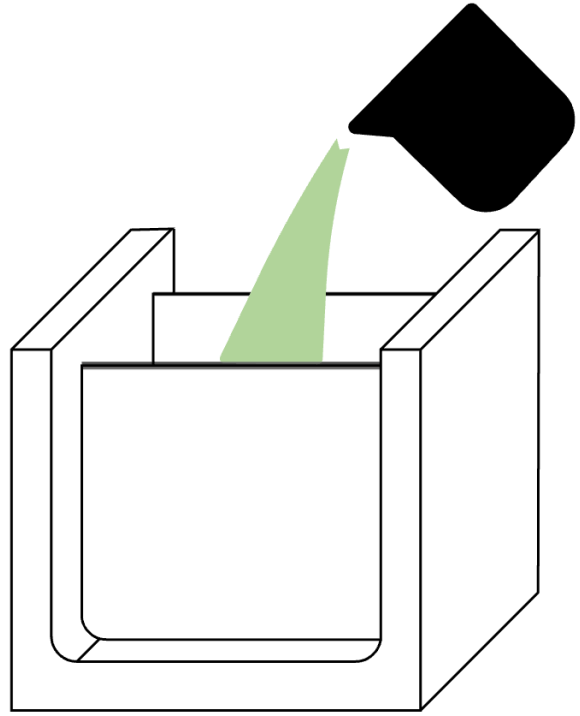
1. No sharp corners
(Inside the mould)



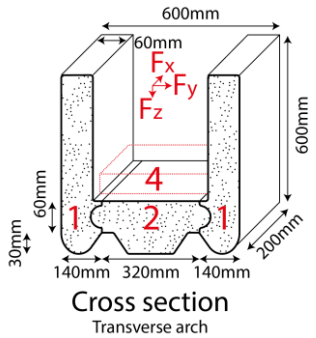
2. Easy assemble and disassembly
(For removing the glass element)



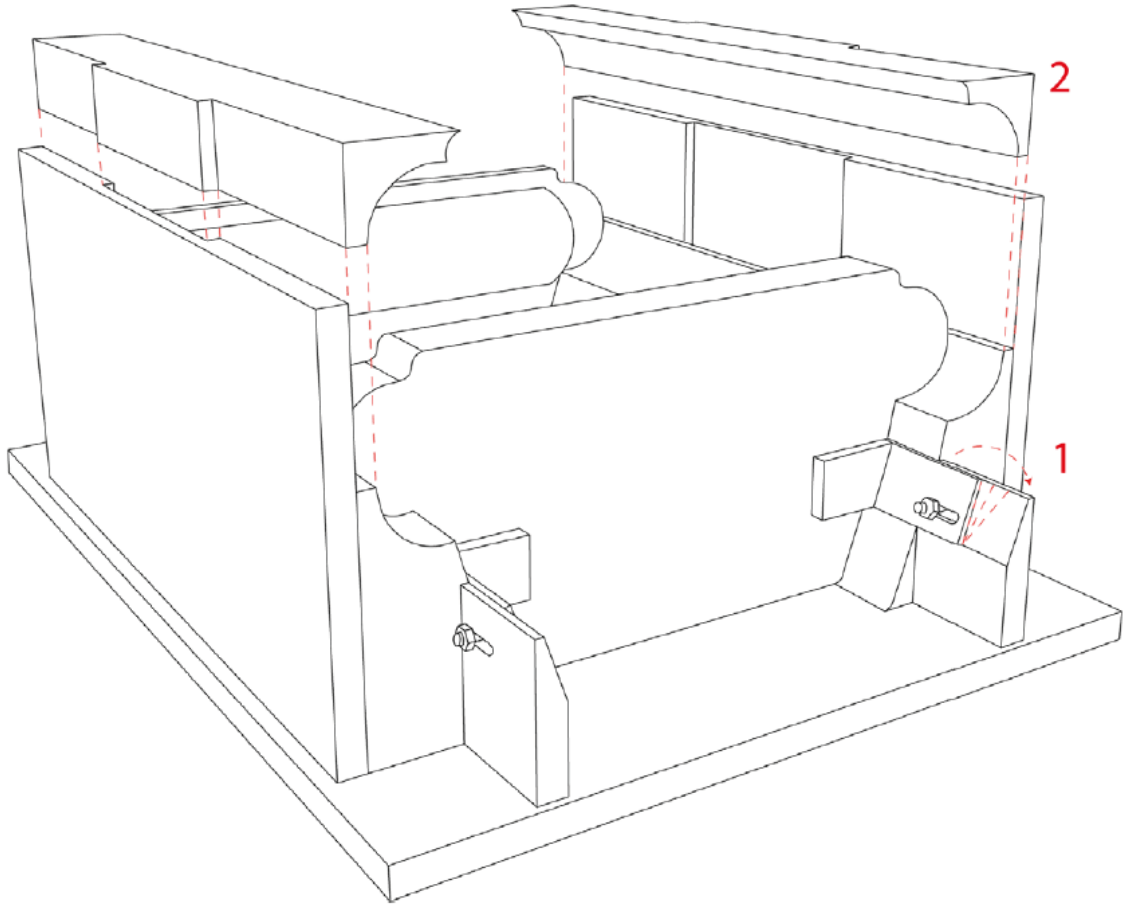
3. Adjustable part - Angle 0° to 2°
(to meet the curvature of the arch)

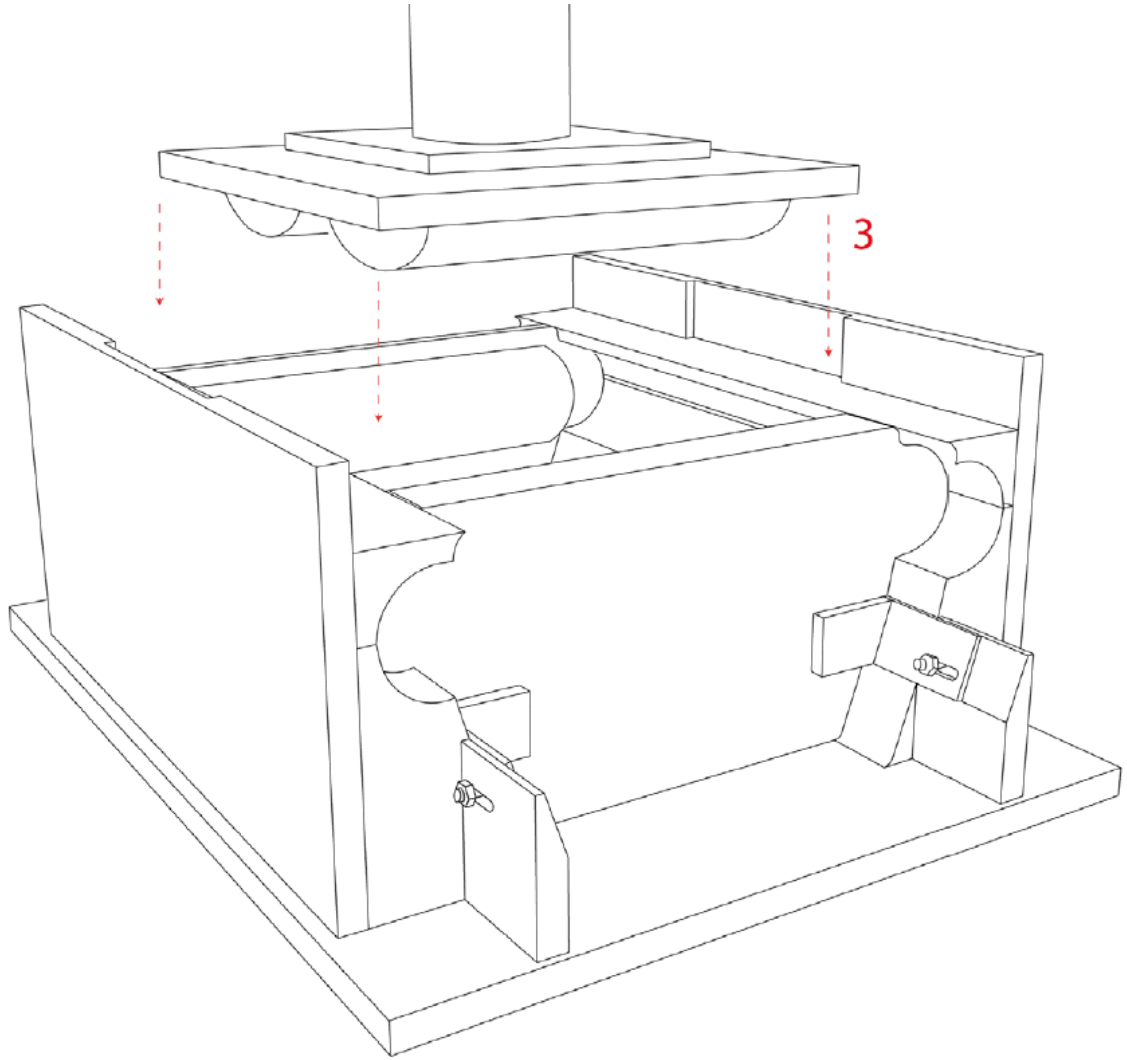


4. Clear opening to pour the glass

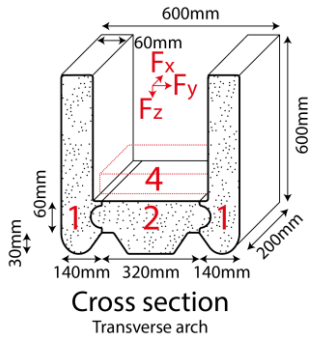


Cross section
Transverse arch

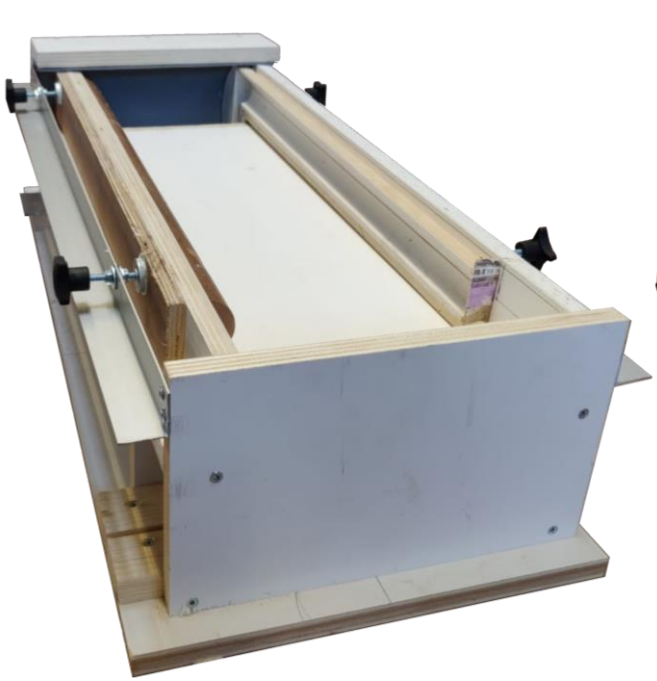


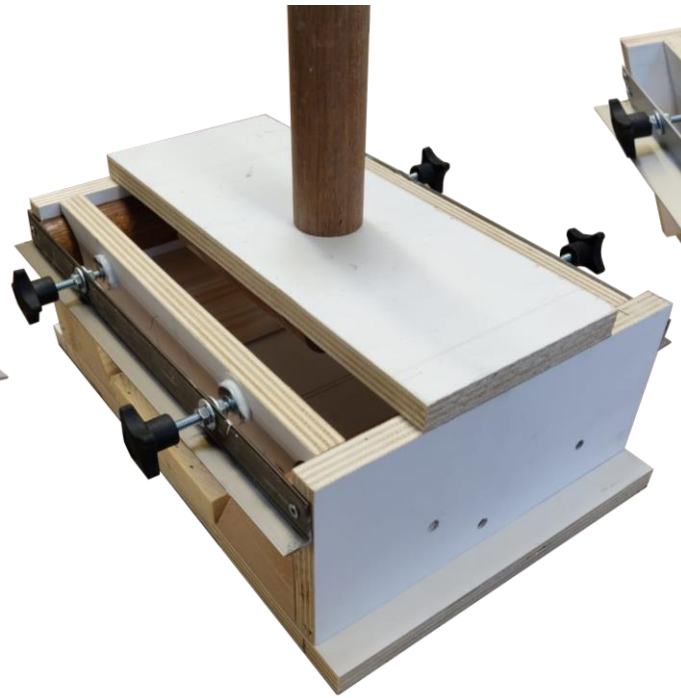


Prototype



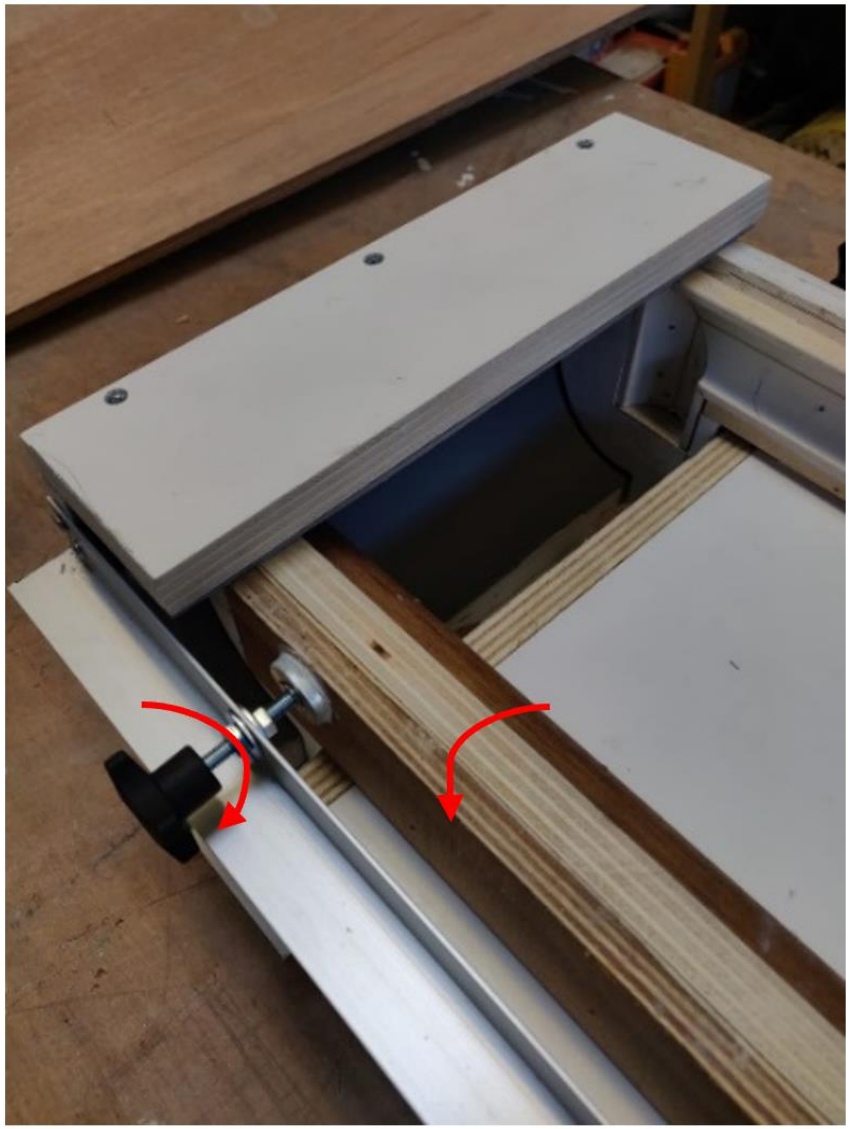
Cross section
Transverse arch

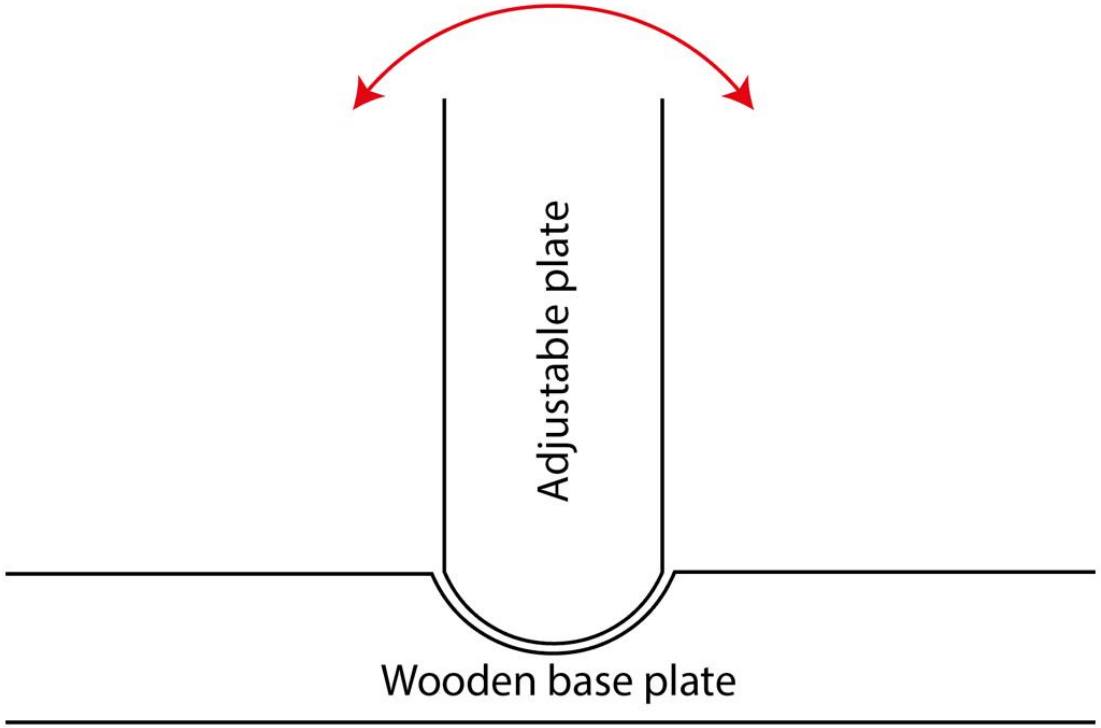

1

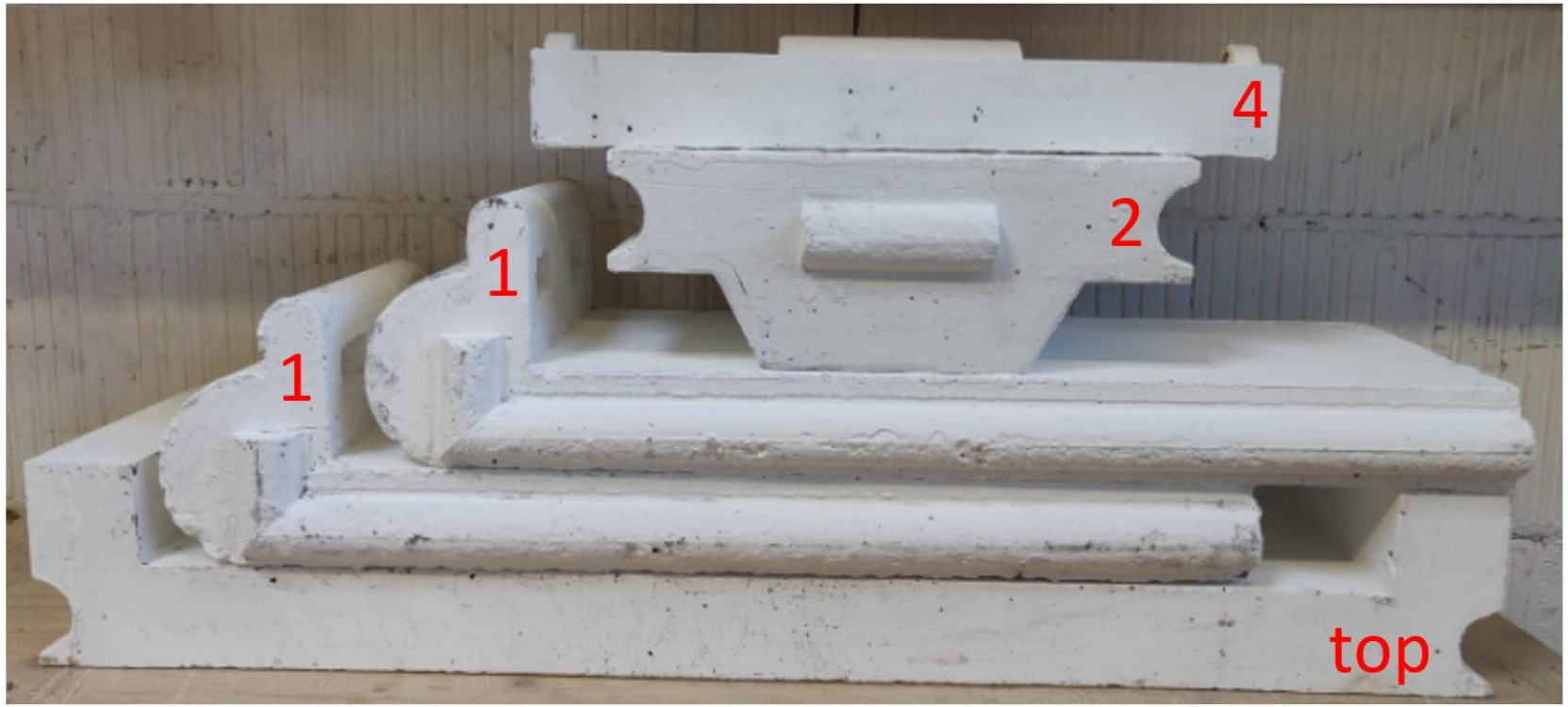

2

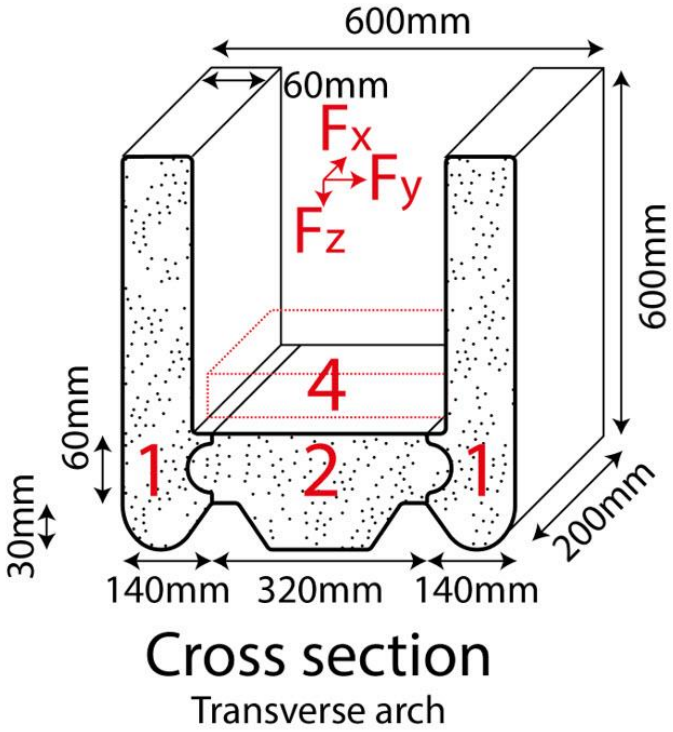

4


top




Adjustable plate
Wooden base plate

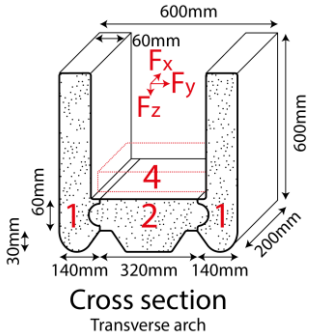




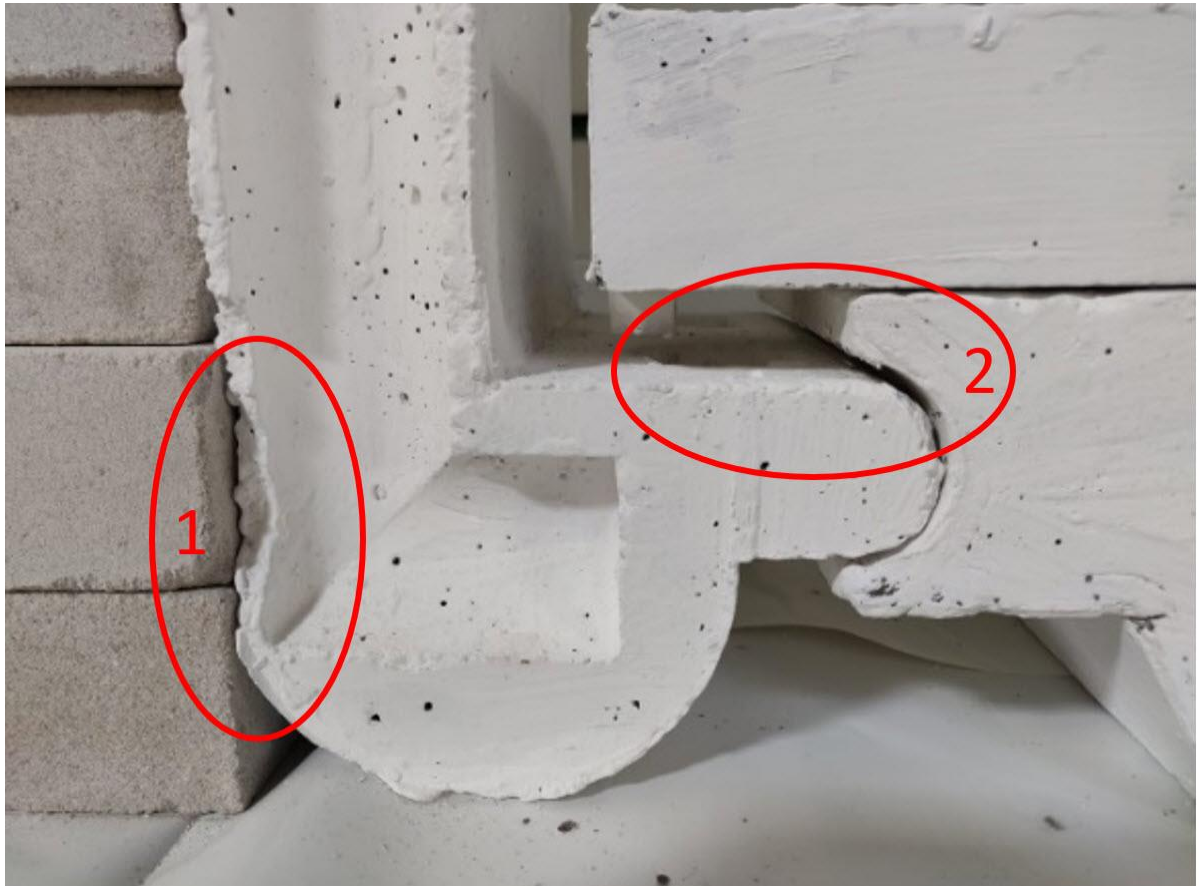
Cross section

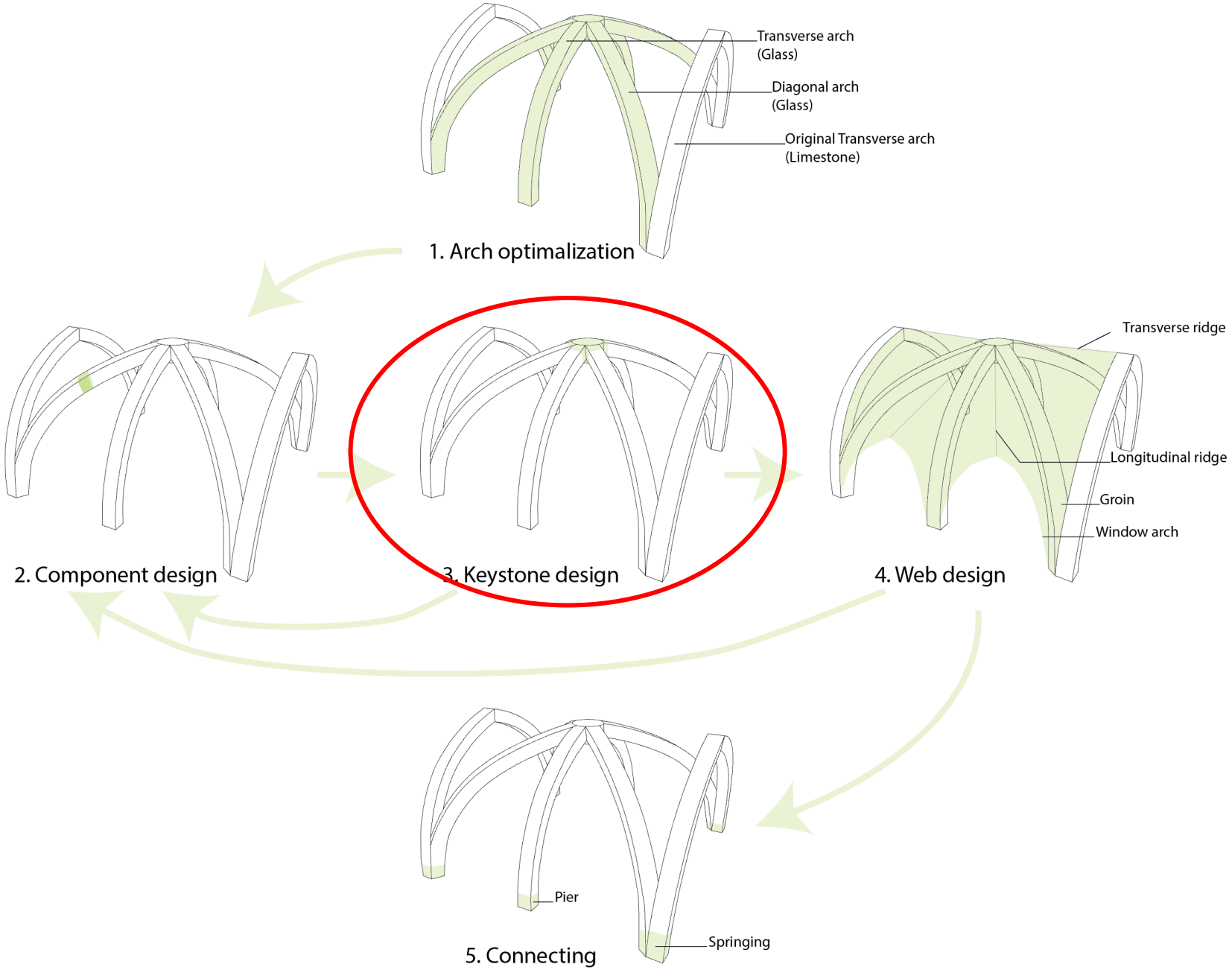
Transverse arch

Prototype


600mm
60mm
Fx
Fy
Fz
600mm
4
60mm
1
2
1
30mm
200mm
140mm
320mm
140mm
Cross section
Transverse arch

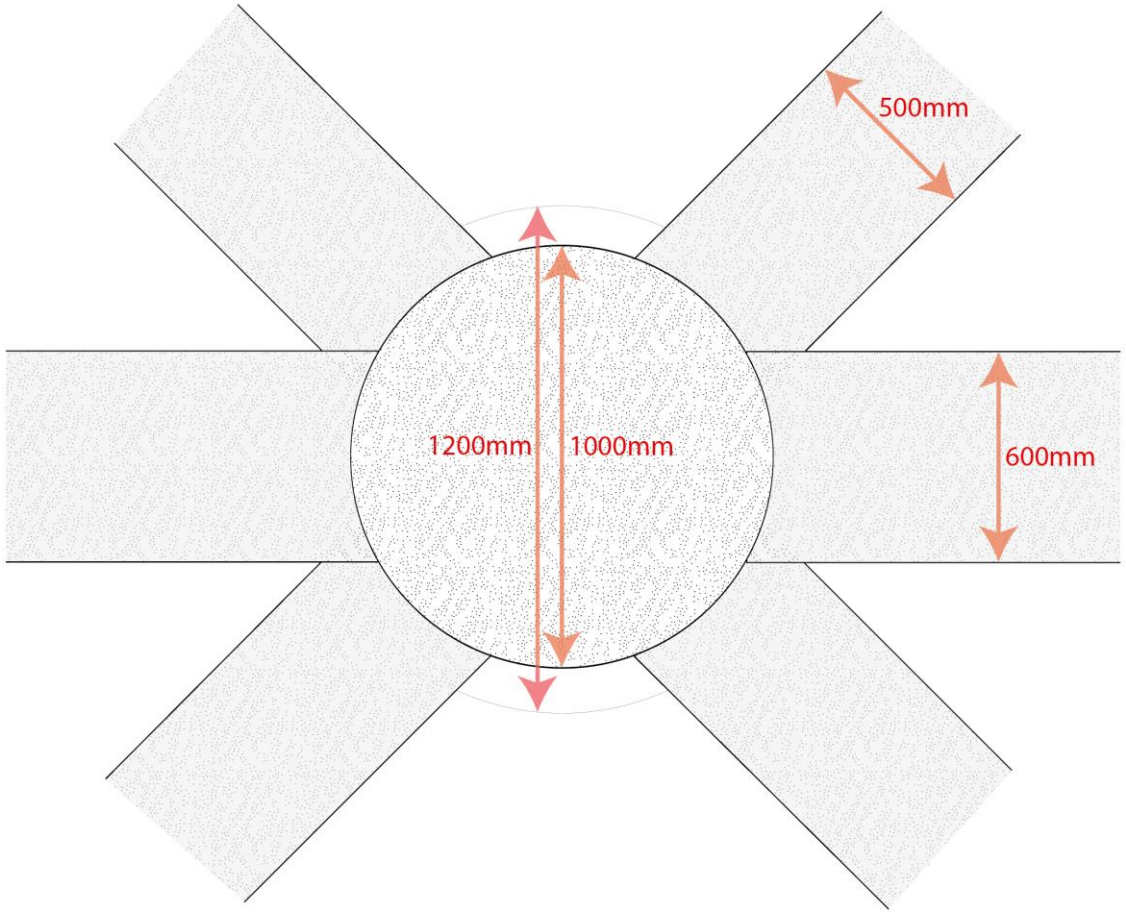
Prototype




Transverse arch
(Glass)
Diagonal arch
(Glass)
Original Transverse arch
(Limestone)
1. Arch optimalization
2. Component design
3. Keystone design
4. Web design
Transverse ridge
Longitudinal ridge
Groin
Window arch
Pier
Springing
5. Connecting

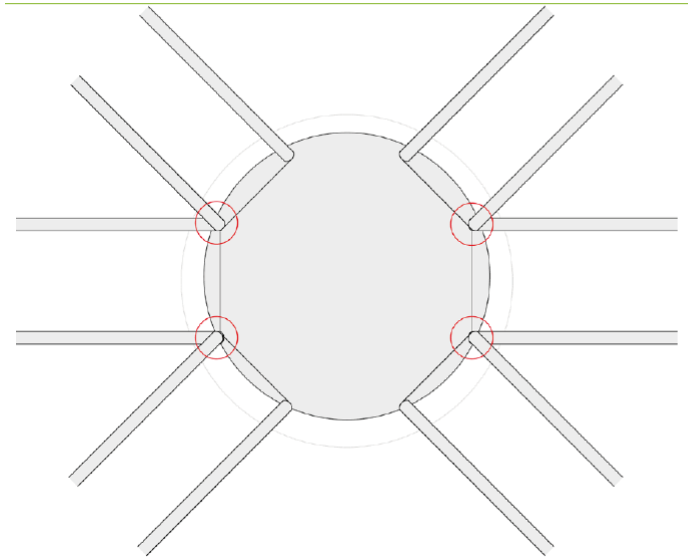
Keystone

Original

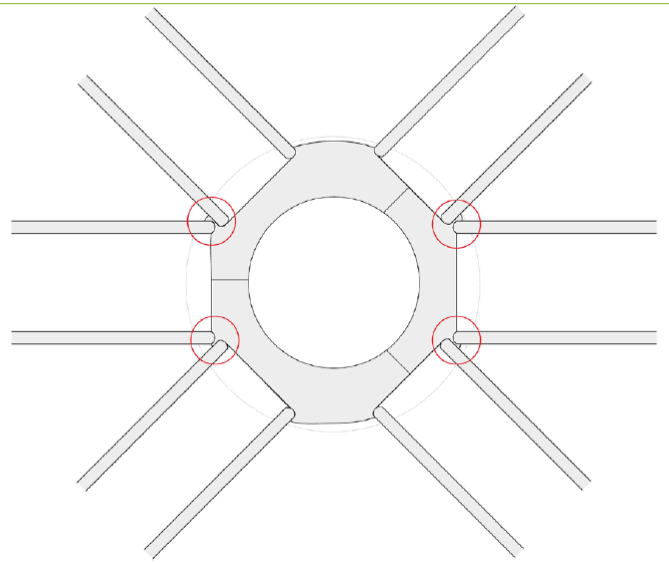


Rib vault of the Notre Dame de Paris. Retrieved from Shaw (2019)

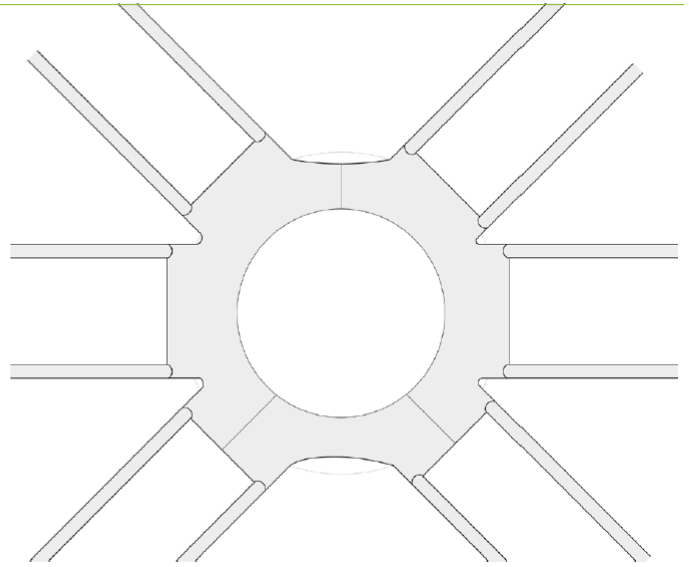
Variant 1 (Follow original)



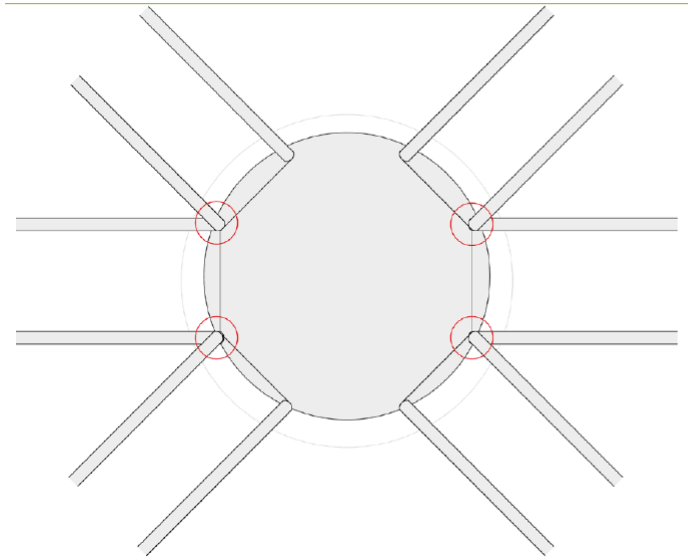
Variant 2 (Original + material saving)



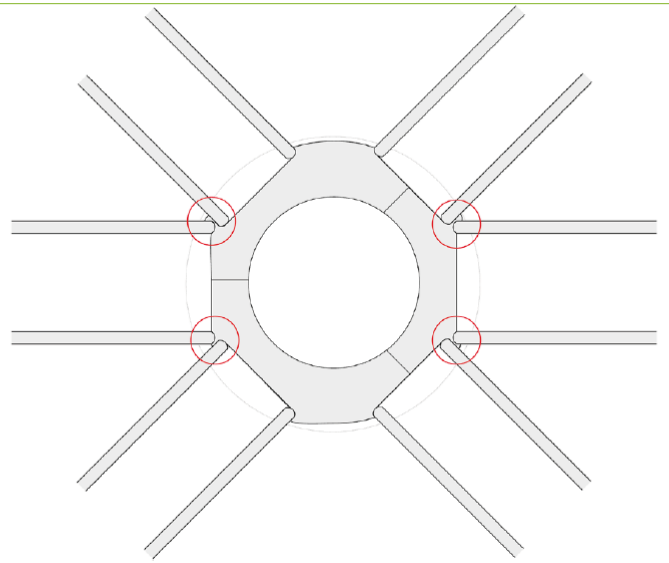
Variant 3 (Extend to arches)



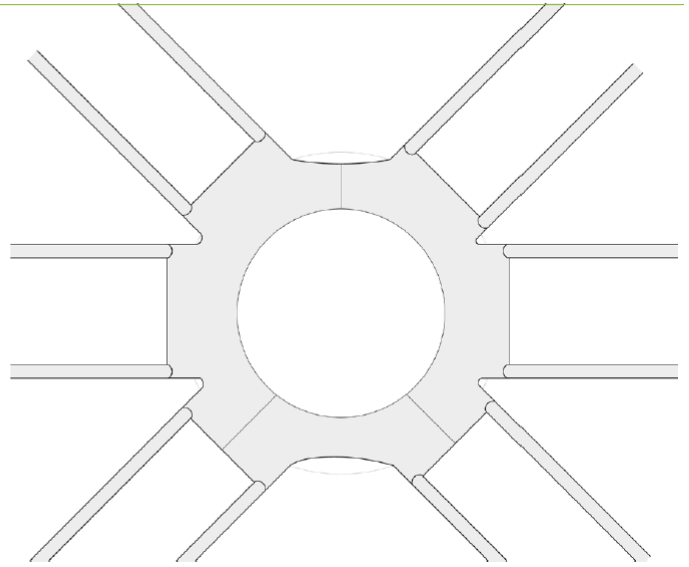
Variant 1 (Follow original)

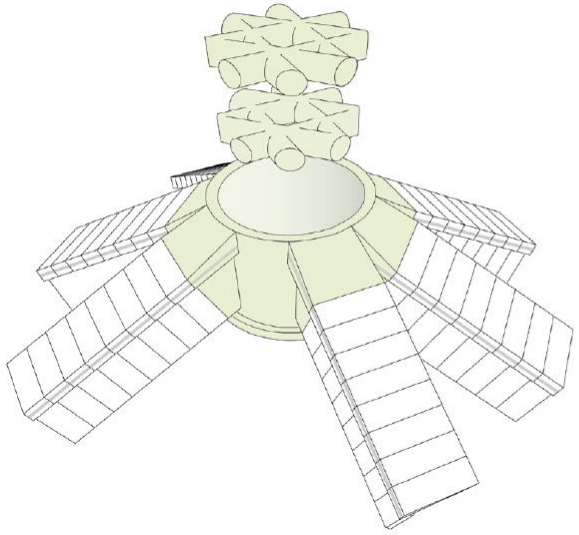
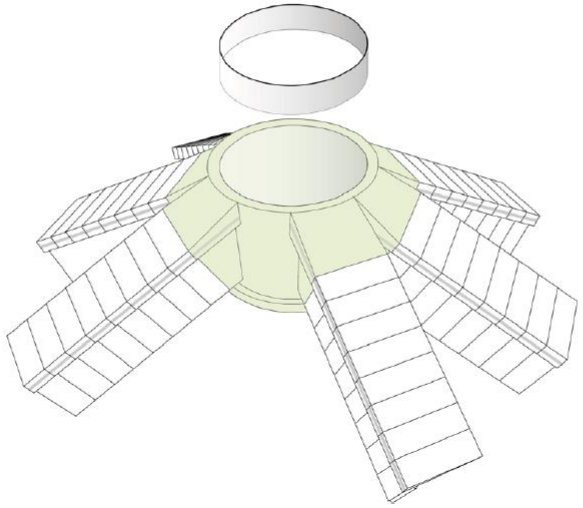
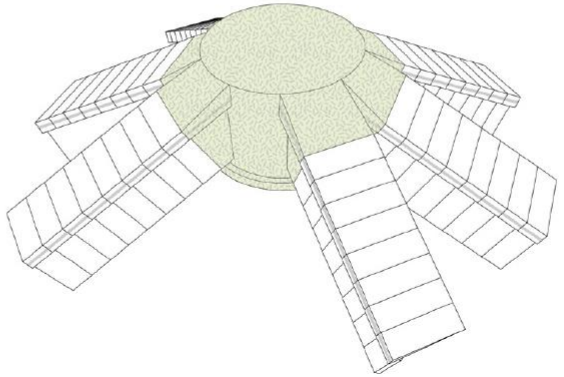
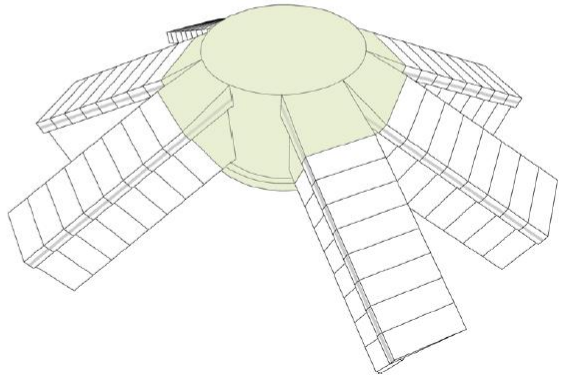


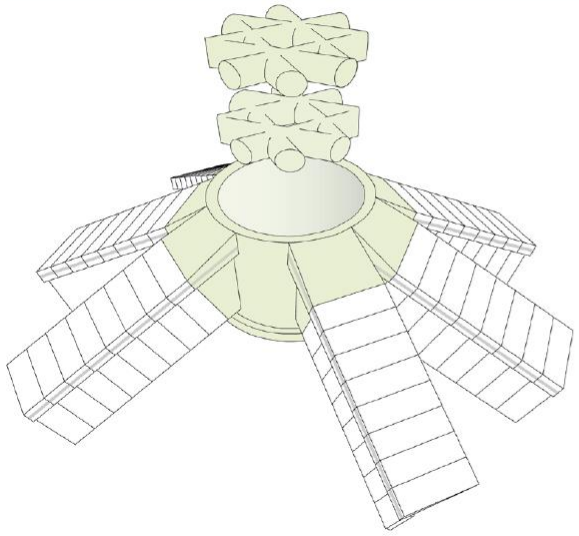
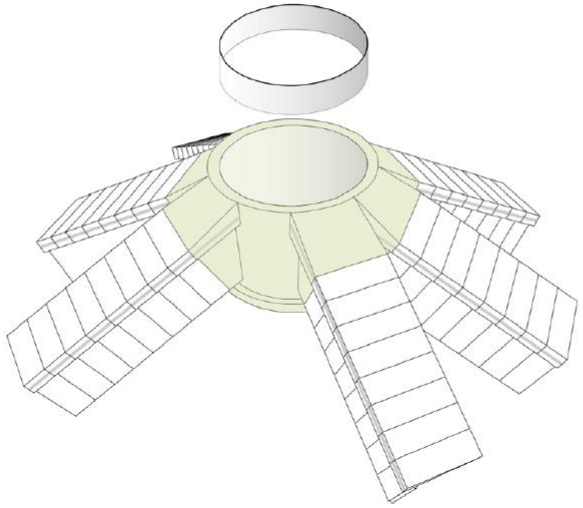
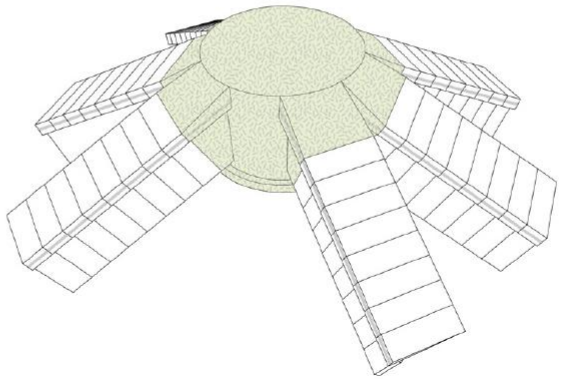
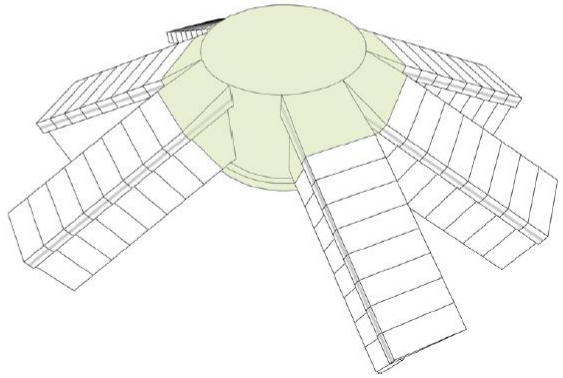
Variant 2 (Original + material saving)



Variant 3 (Extend to arches)



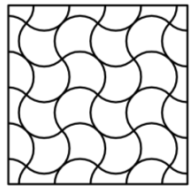
Variant 1 (Complete glass)	Variant 2 (Glass + Steel reinforcement)	Variant 3 (Traditional limestone)	Variant 4 (Modern materials)
			

Variant 1 (Complete glass)	Variant 2 (Glass + Steel reinforcement)	Variant 3 (Traditional limestone)	Variant 4 (Modern materials)
			

Tessellation required

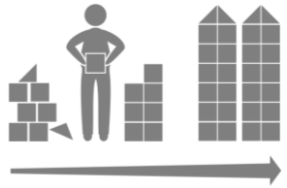
Reduce annealing time

Increase safety

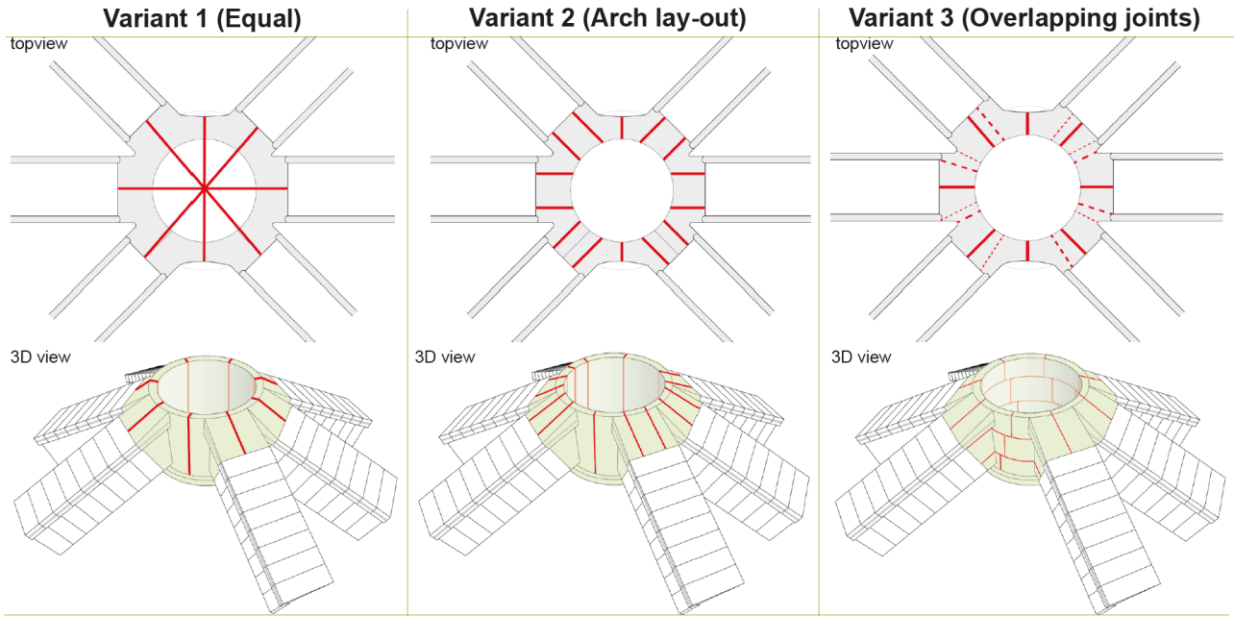


Tolerances

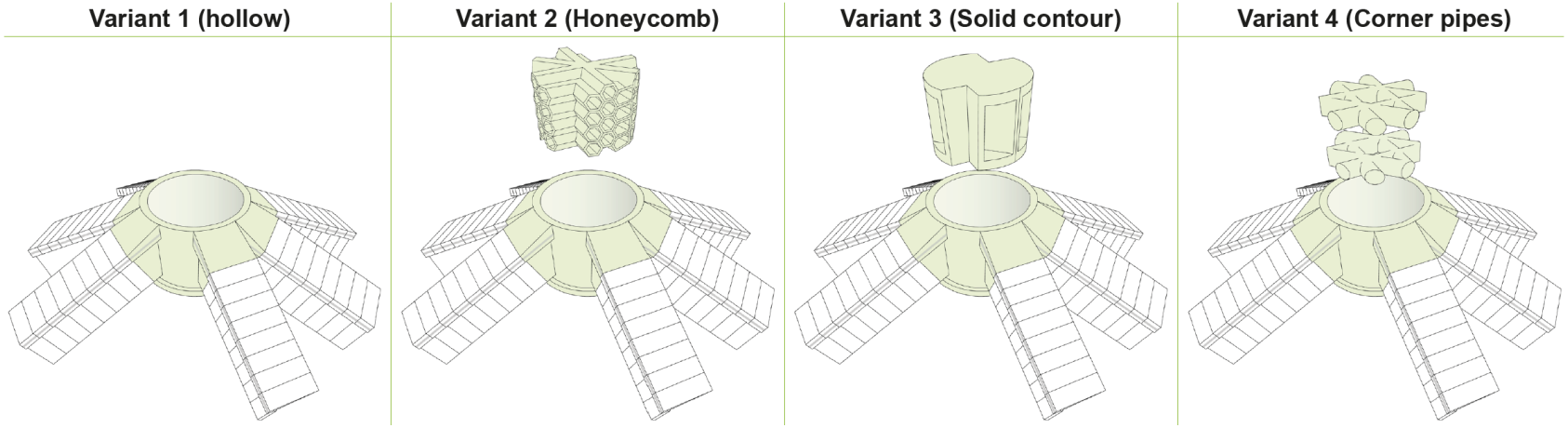
Assembly



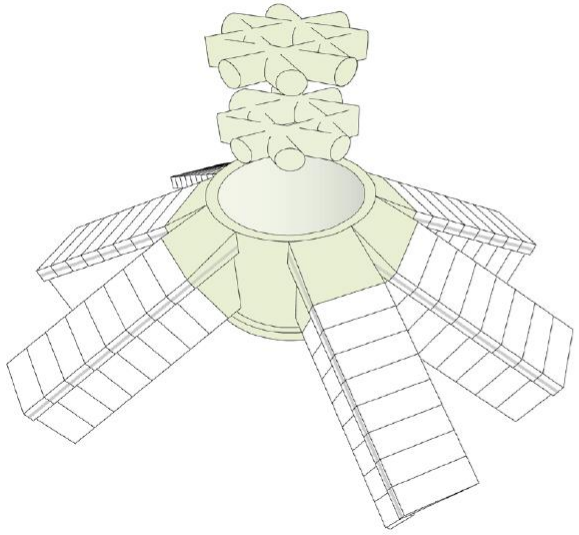
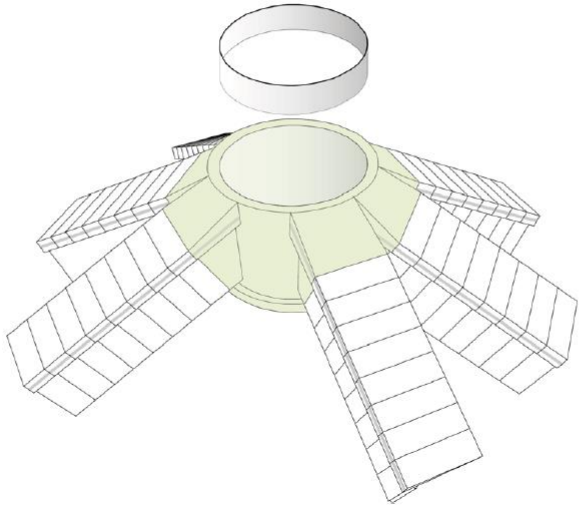
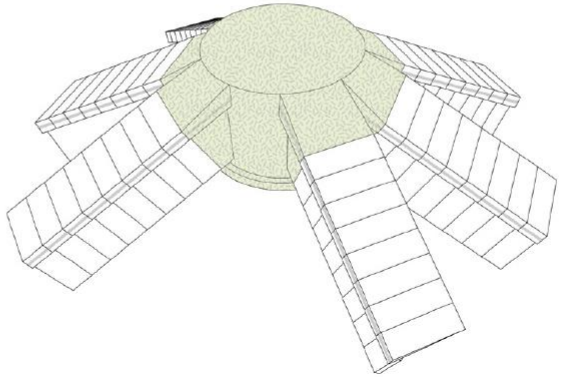
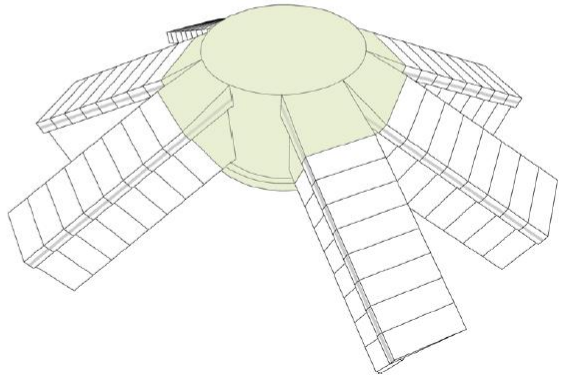
Tessellation

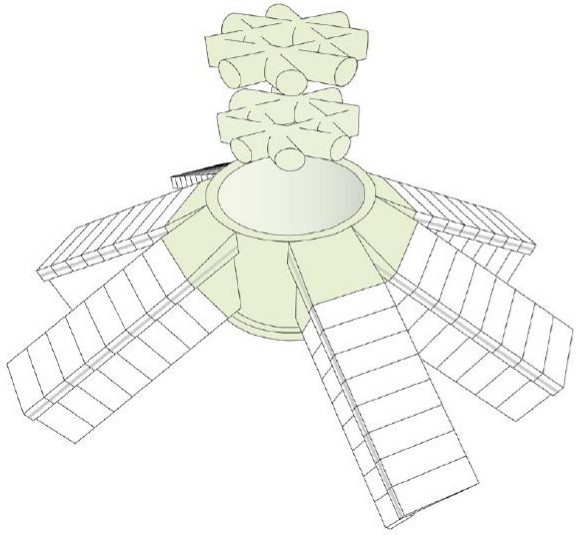
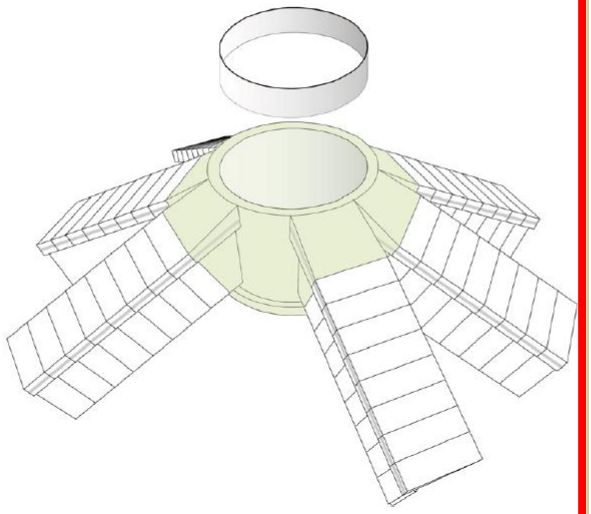
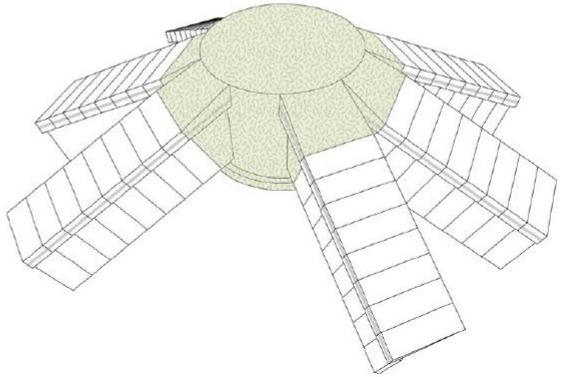
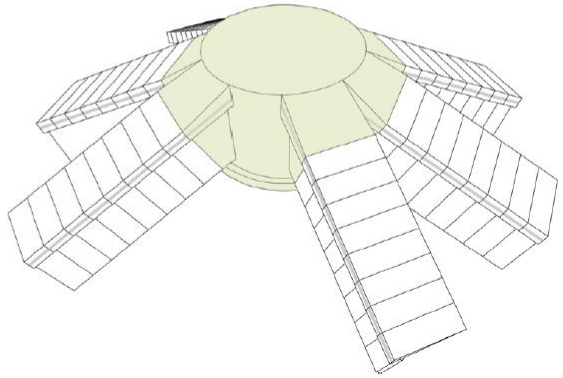


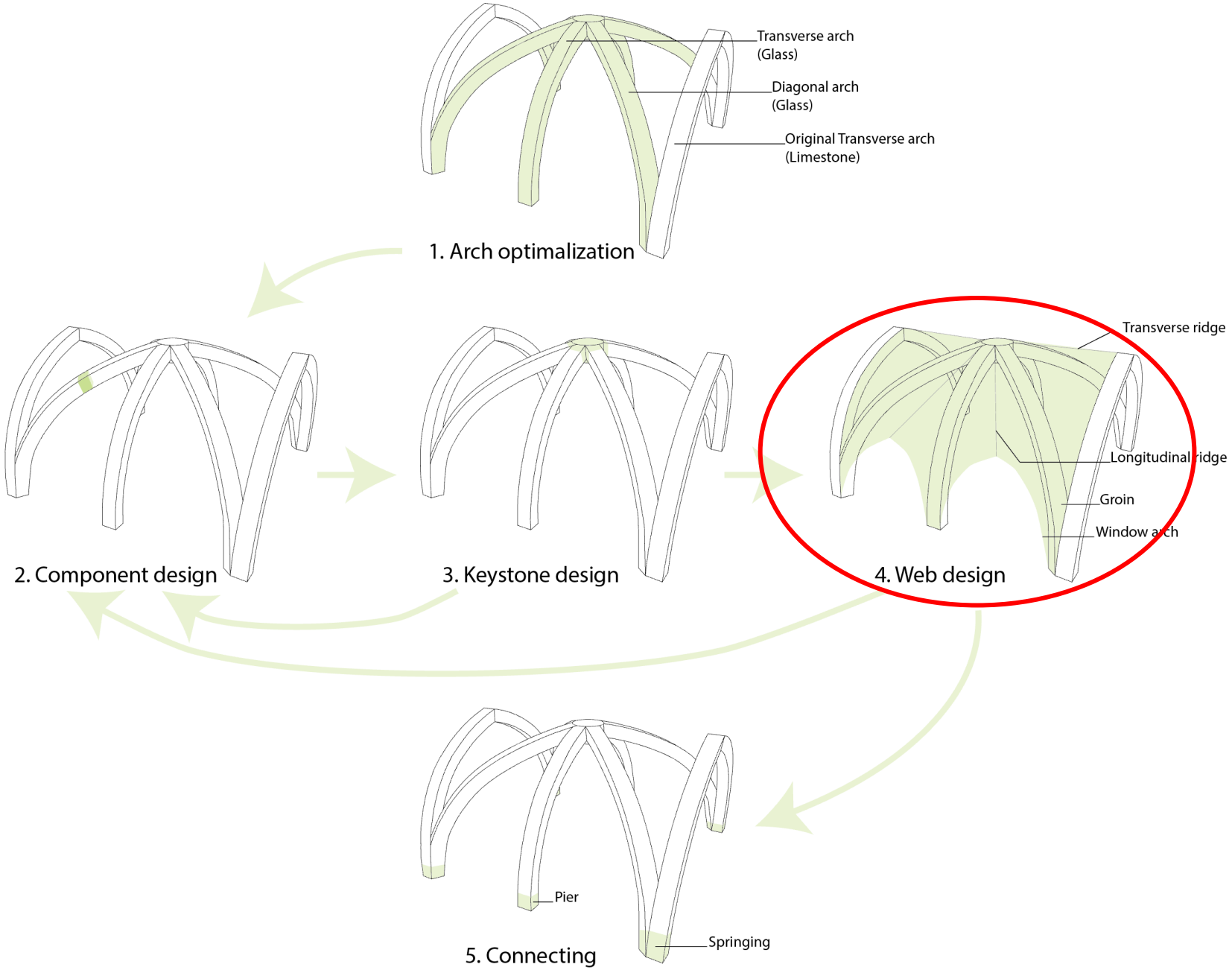
Reinforcement



Is this the best solution?

Variant 1 (Complete glass)	Variant 2 (Glass + Steel reinforcement)	Variant 3 (Traditional limestone)	Variant 4 (Modern materials)
			

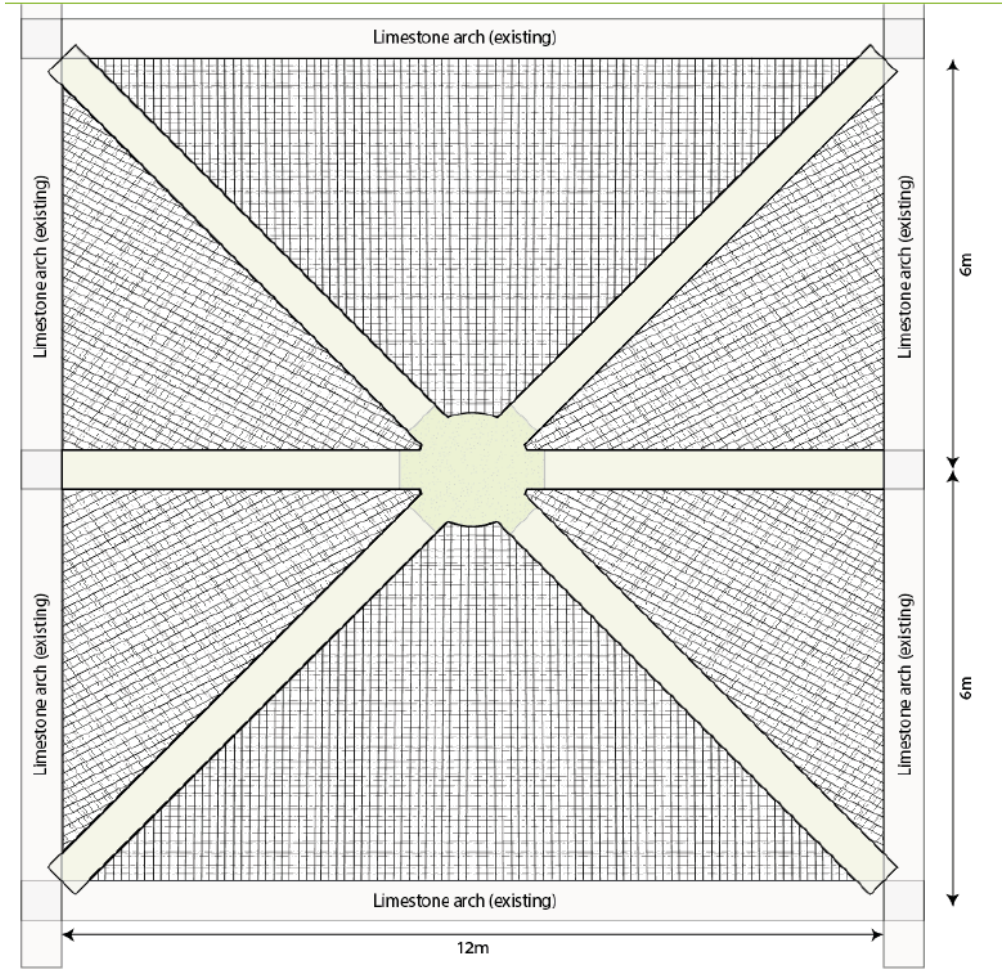
Variant 1 (Complete glass)	Variant 2 (Glass + Steel reinforcement)	Variant 3 (Traditional limestone)	Variant 4 (Modern materials)
			

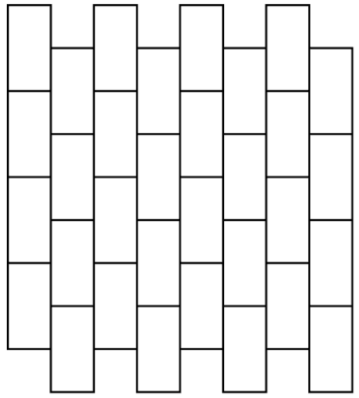

Transverse arch
(Glass)
Diagonal arch
(Glass)
Original Transverse arch
(Limestone)
1. Arch optimalization
2. Component design
3. Keystone design
Transverse ridge
Longitudinal ridge
Groin
Window arch
4. Web design
Pier
Springing
5. Connecting

Top view

Web

Variant 1 (per component)



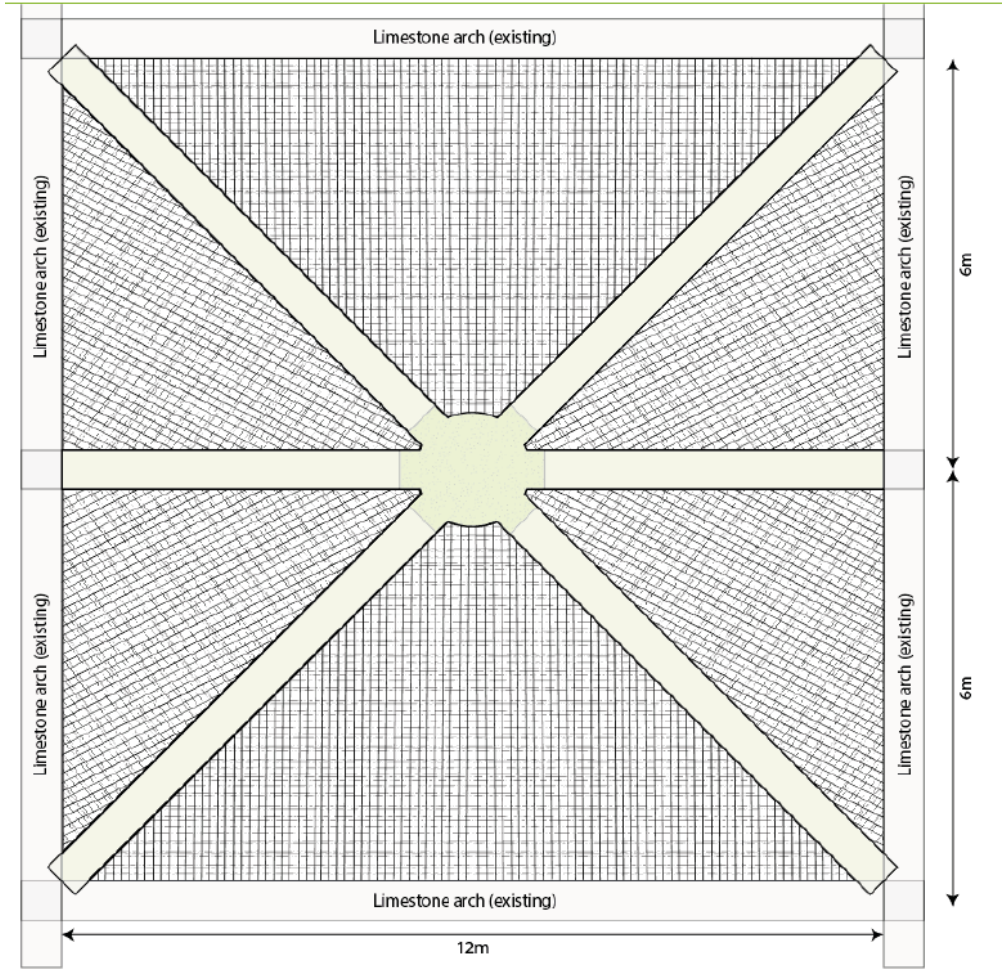


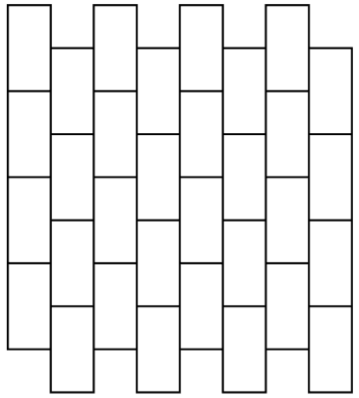
Running bond

Top view

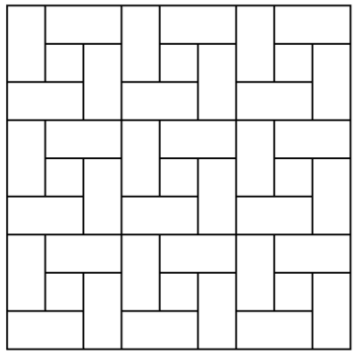
Web

Variant 1 (per component)

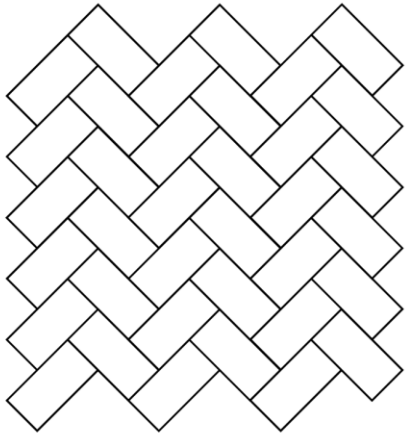




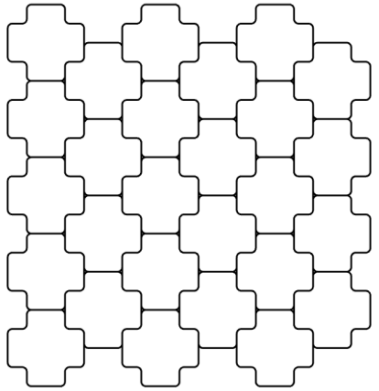
Running bond



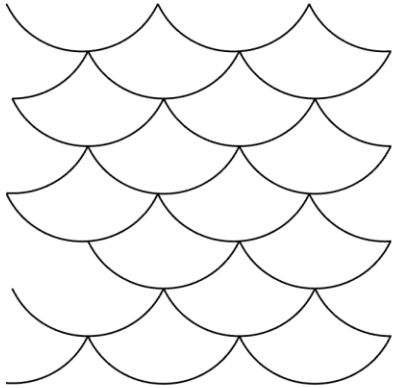
Basketweave bond



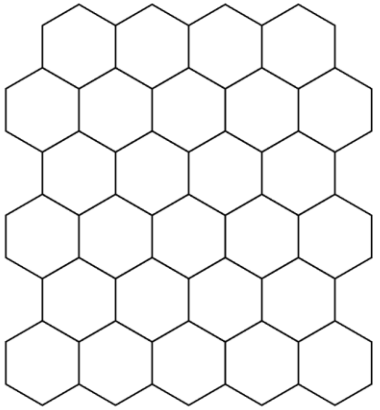
Herringbone bond



Moroccan Cross



Fish scales



Hexagon

Cast glass plate vs float glass plate

Cast glass:

- Custom made
- Single plate → No safety
- Big mould

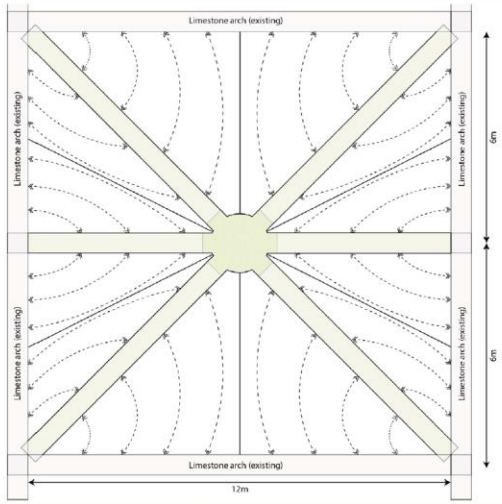
Retrieved from https://www.nathanallan.com/our-products/willow-architectural-cast-glass/

Float glass:

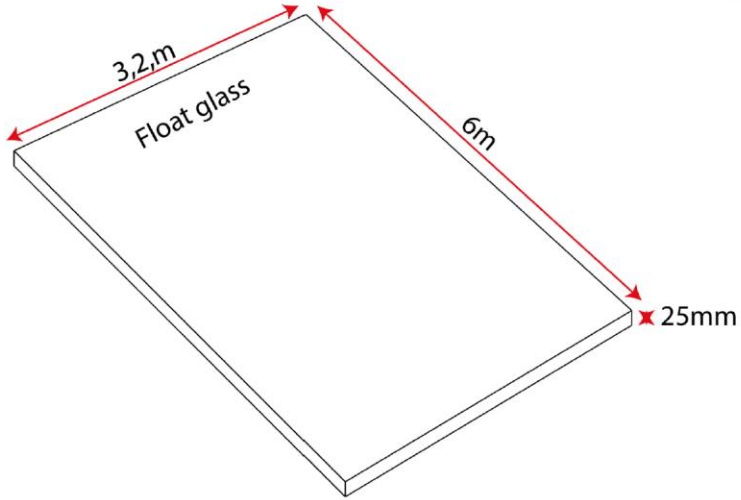
- Standardized process
- Lamination → increase safety factor
- Engraved patterns

Retrieved from Un Studio (2020).

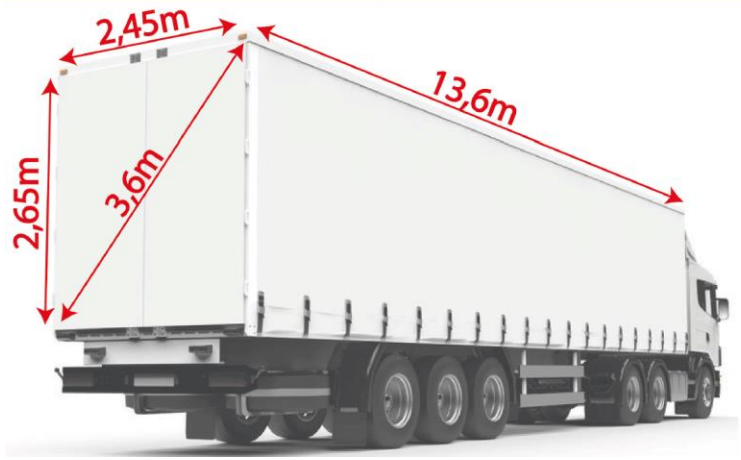
Curvature original web



Float glass dimentions



Transport



Crane

Fixed crane

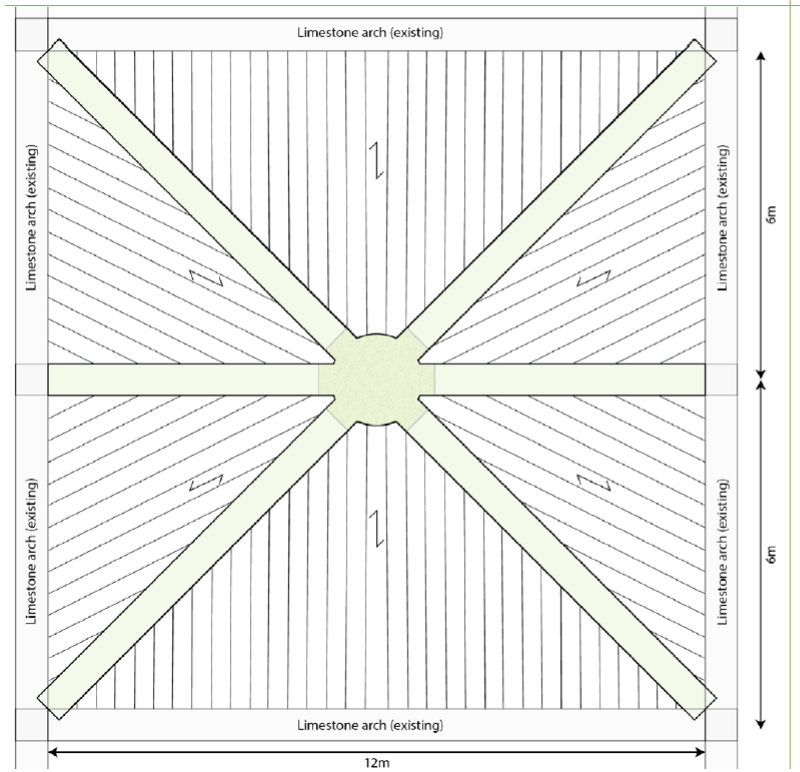
Max. lifting weight: 10.000kg
Lifting height: 60m or more
Location on site: Outside

Flexible mini crane

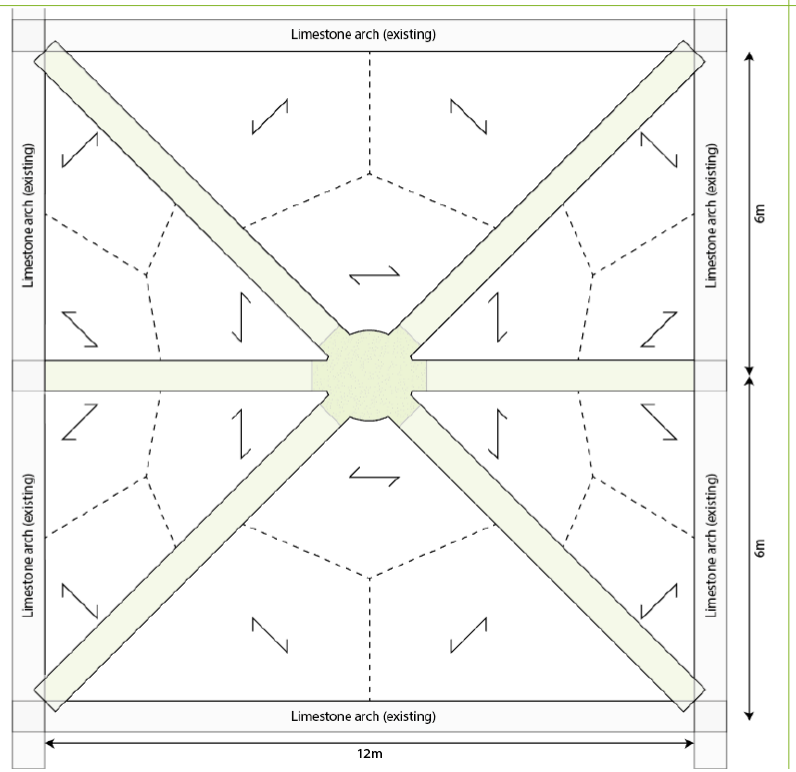
Max. lifting weight: 2.500kg
Lifting height: 15m
Location on site: Inside

Top view

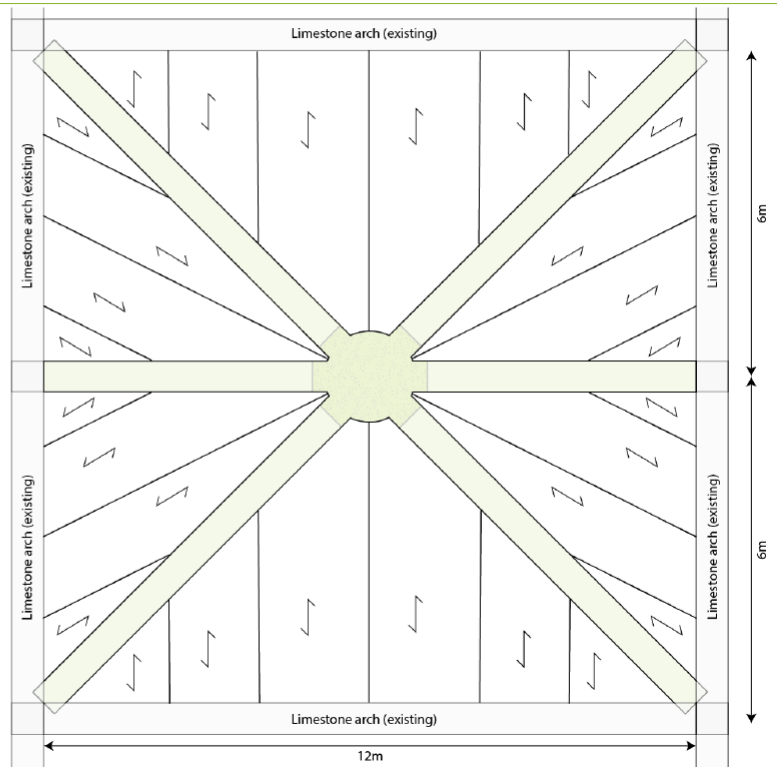
Variant 2 (Strips)



Variant 3 (Plate)

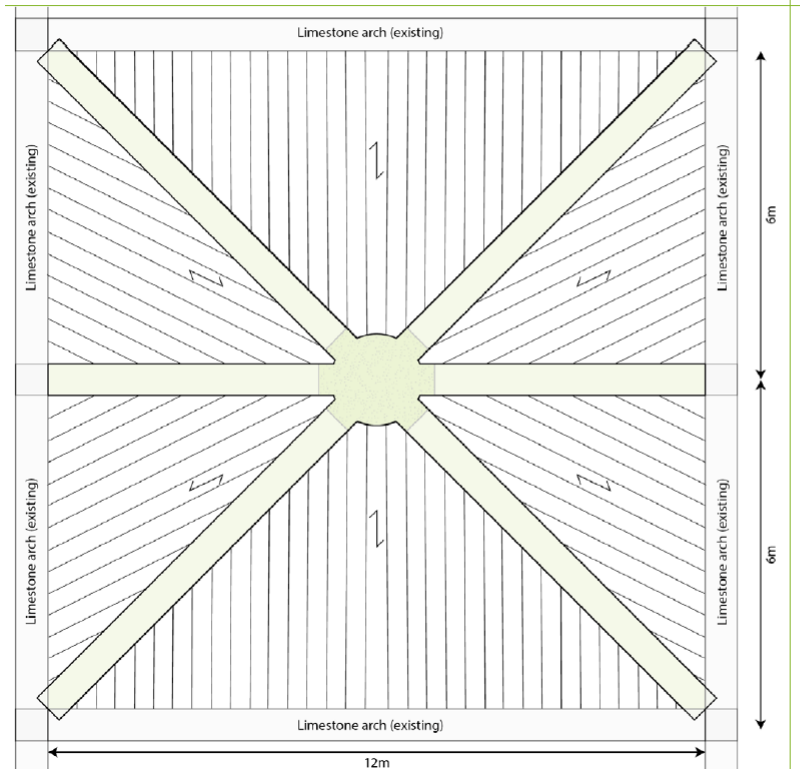


Variant 4 (Plate)

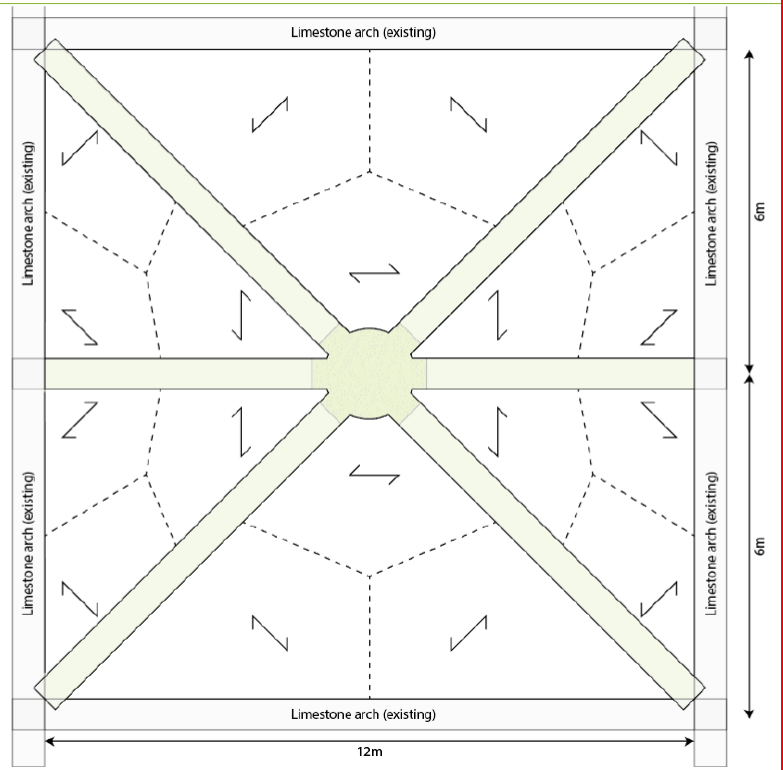


Top view

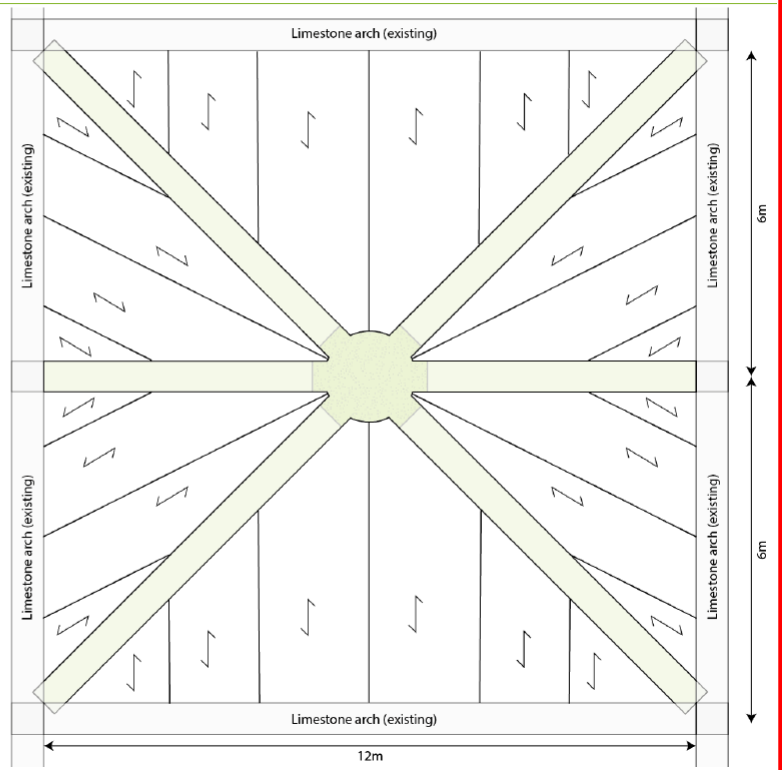
Variant 2 (Strips)

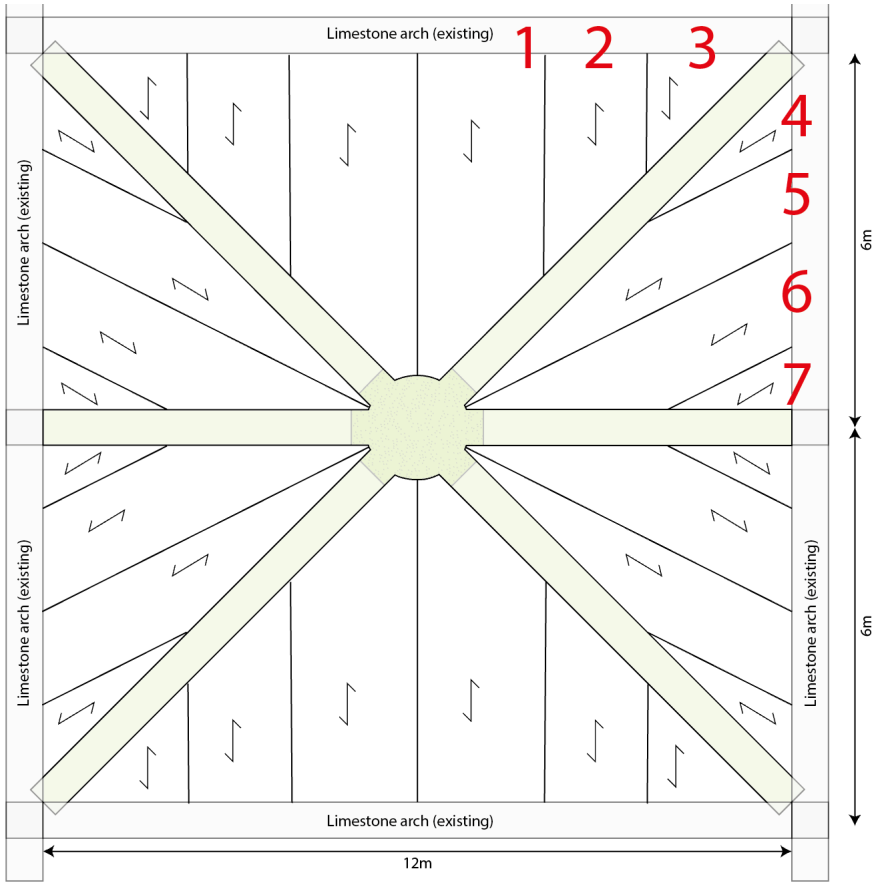


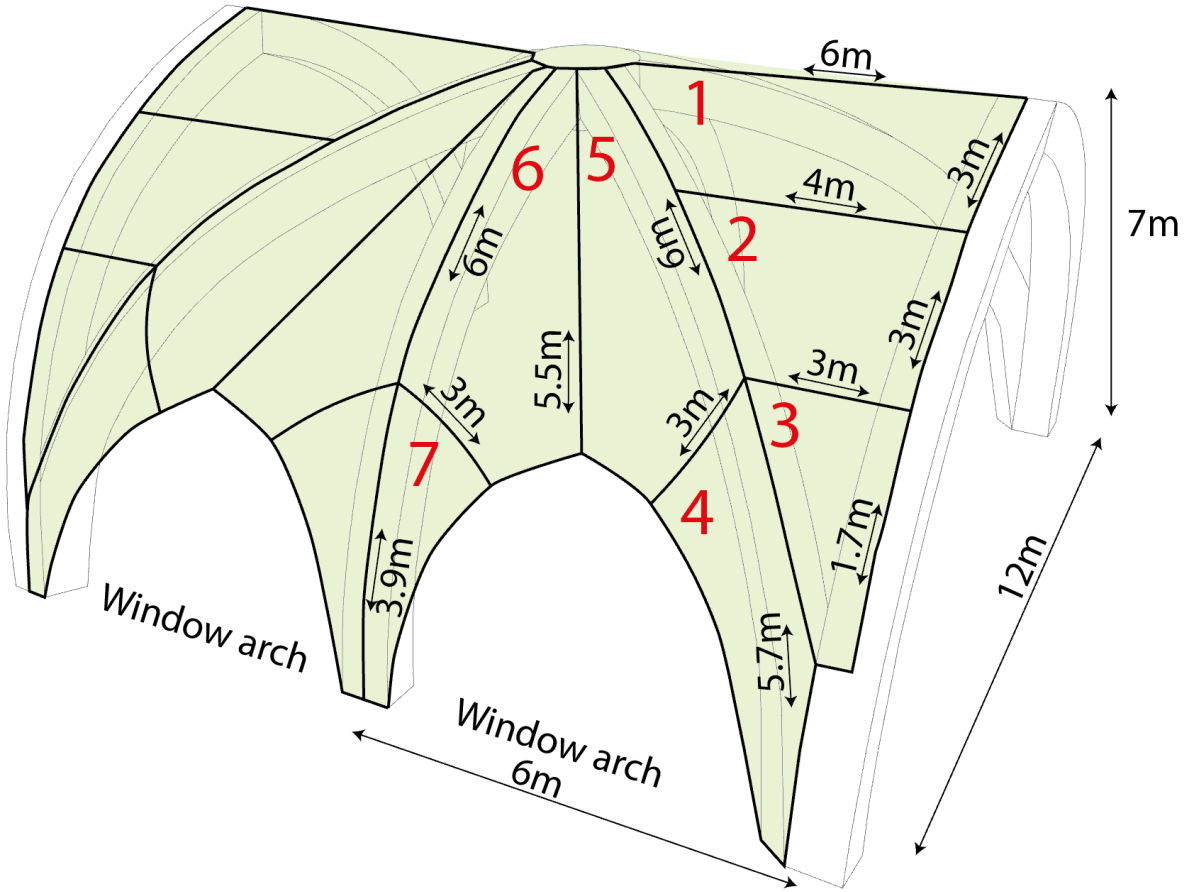
Variant 3 (Plate)



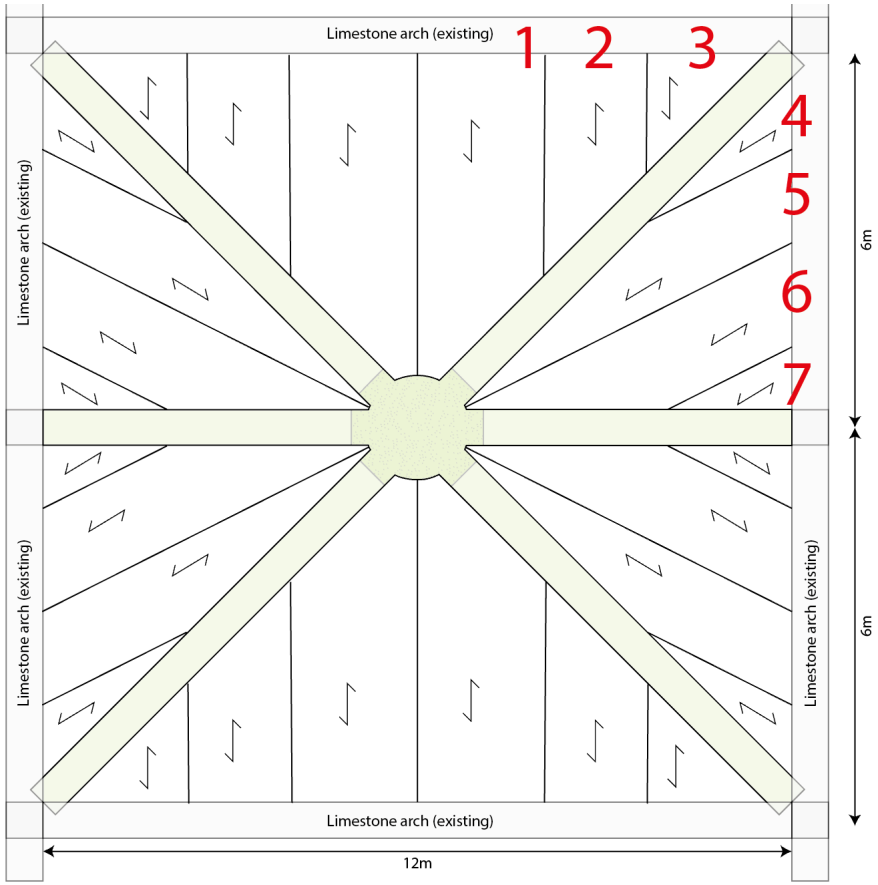
Variant 4 (Plate)

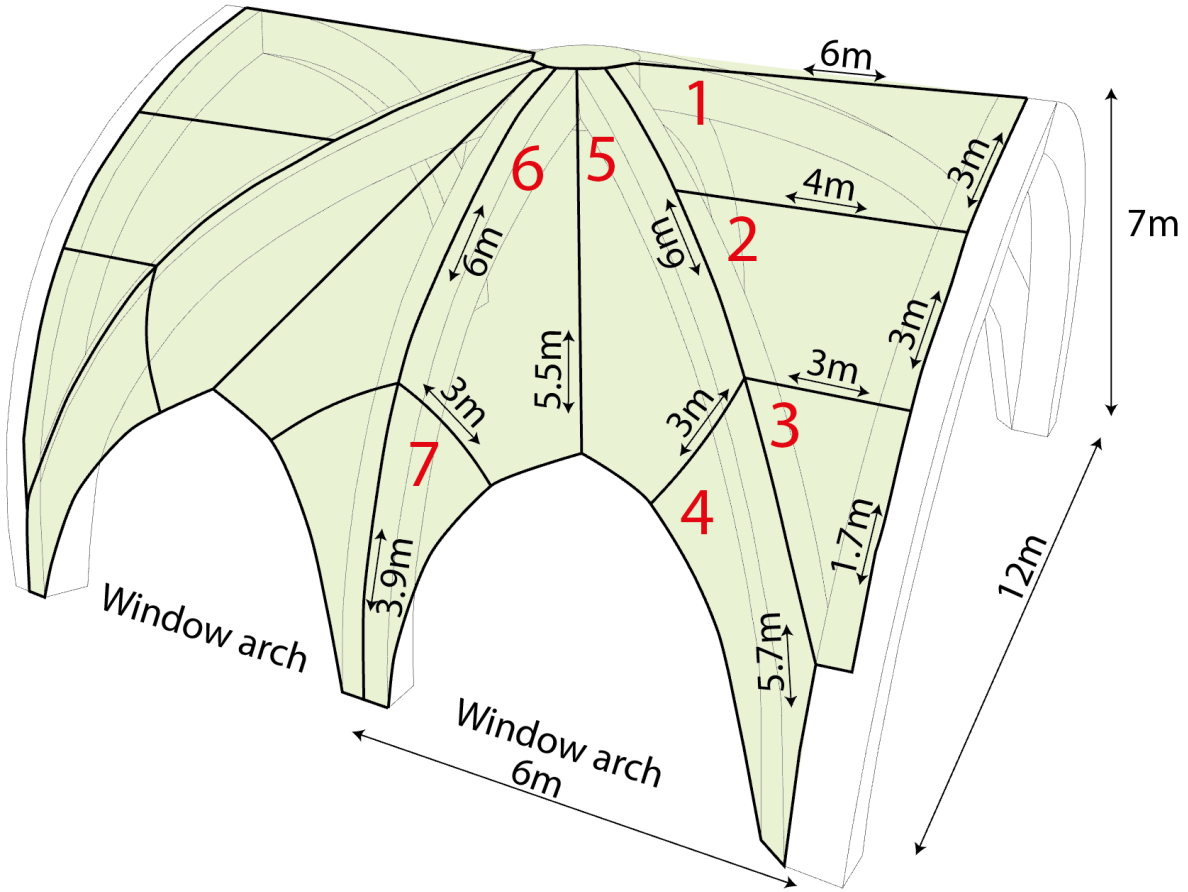






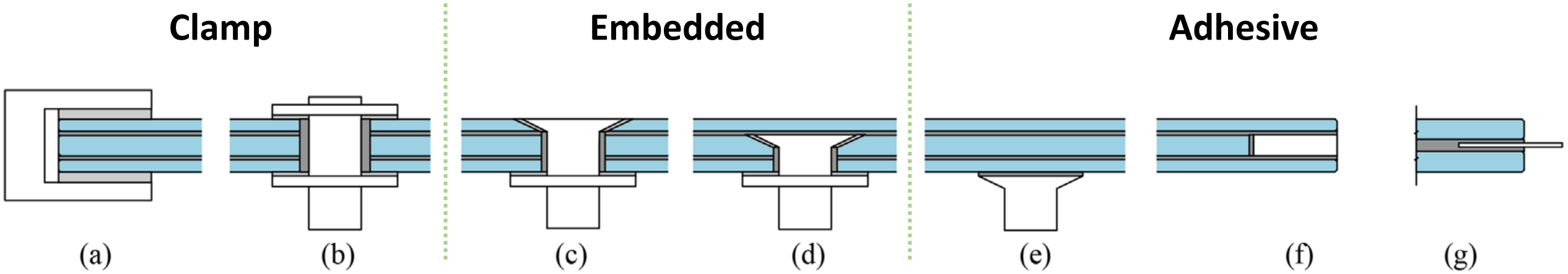
	Dimension section (mm)		Deflection (mm)		Stress (N/mm²)							
Variant	Thickness	Plates	Allowed	Simulated$_{max}$	Glass Compres. $_{max}$	Glass Tensile $_{max}$	S1		S2		S3	
							Compres. $_{Max}$	Tensile $_{max}$	Compres. $_{Max}$	Tensile $_{max}$	Compres. $_{Max}$	Tensile $_{max}$
1	30	10-10-10	5,00	2,39	300	30	0,00	4,38	0,15	0,89	1,43	0,00
2	24	8-8-8	4,00	3,25	300	30	0,00	5,06	0,23	1,04	1,68	0,00
3	20	6-8-6	3,33	4,17	300	30	0,00	5,64	0,30	1,16	1,95	0,00
4	22	8-6-8	3,67	3,66	300	30	0,00	5,34	0,26	1,09	1,81	0,00





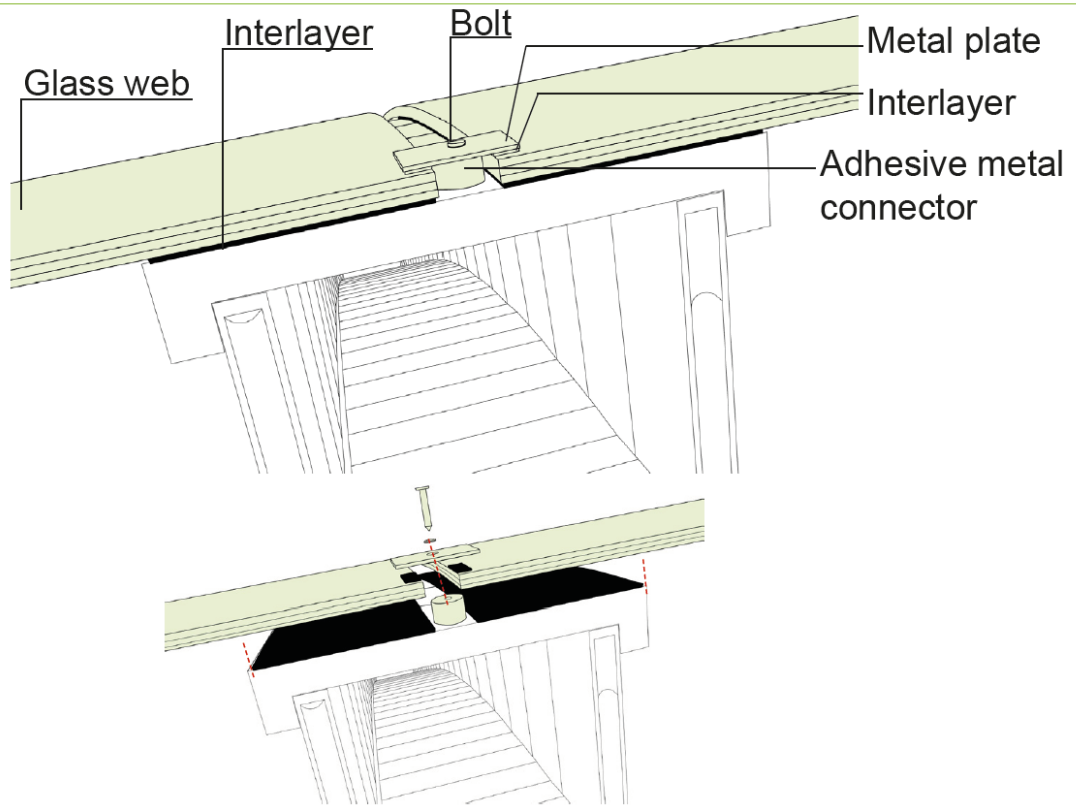
	Dimension section (mm)		Deflection (mm)				Stress (N/mm²)					
Variant	Thickness	Plates	Allowed	Simulated$_{max}$	Glass Compres. $_{max}$	Glass Tensile $_{max}$	S1		S2		S3	
							Compres. $_{Max}$	Tensile $_{max}$	Compres. $_{Max}$	Tensile $_{max}$	Compres. $_{Max}$	Tensile $_{max}$
1	30	10-10-10	5,00	2,39	300	30	0,00	4,38	0,15	0,89	1,43	0,00
2	24	8-8-8	4,00	3,25	300	30	0,00	5,06	0,23	1,04	1,68	0,00
3	20	6-8-6	3,33	4,17	300	30	0,00	5,64	0,30	1,16	1,95	0,00
4	22	8-6-8	3,67	3,66	300	30	0,00	5,34	0,26	1,09	1,81	0,00

Connection web - arch

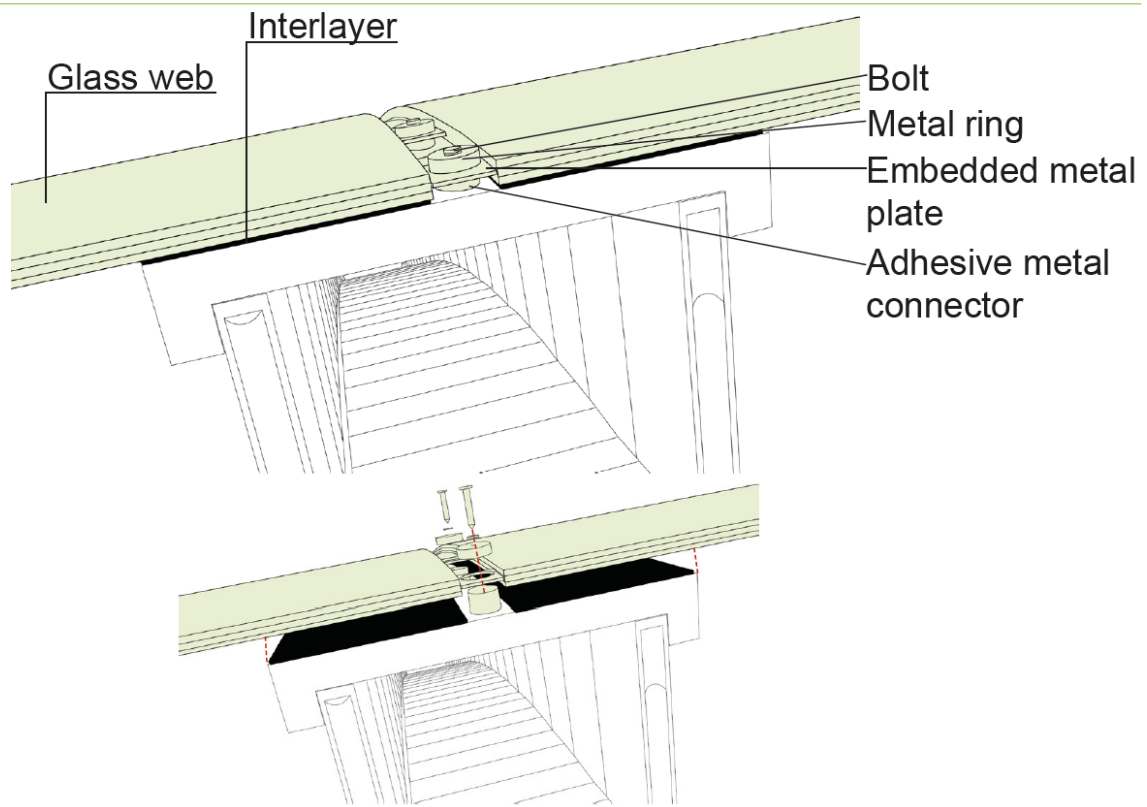


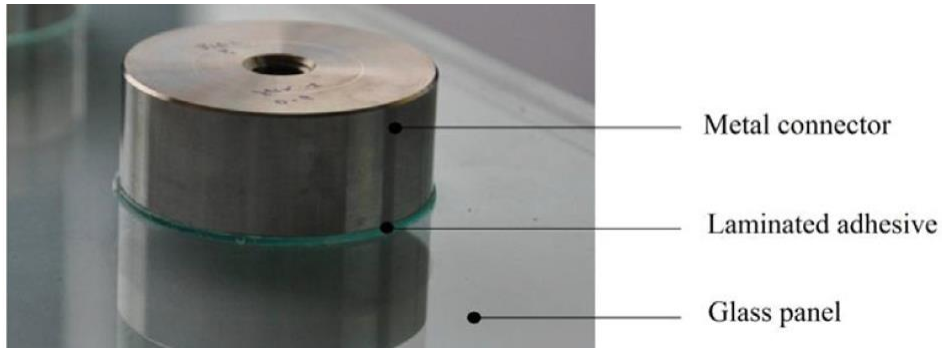
Scheme of connection used in structural glass applications - clamped (a), bolted (b), bolted with countersunk bolt (c), hybrid with countersunk bolt (d), adhesive (e), embedded with thick insert (f) and embedded with thin insert (g). Retrieved from Bedon and Santarsiero (2018).

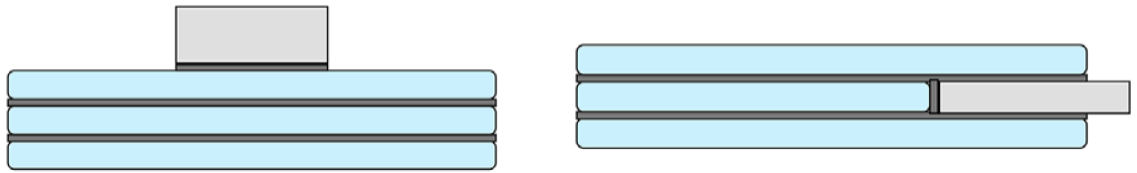
Variant 5 (adhesive)



Variant 6 (adhesive)

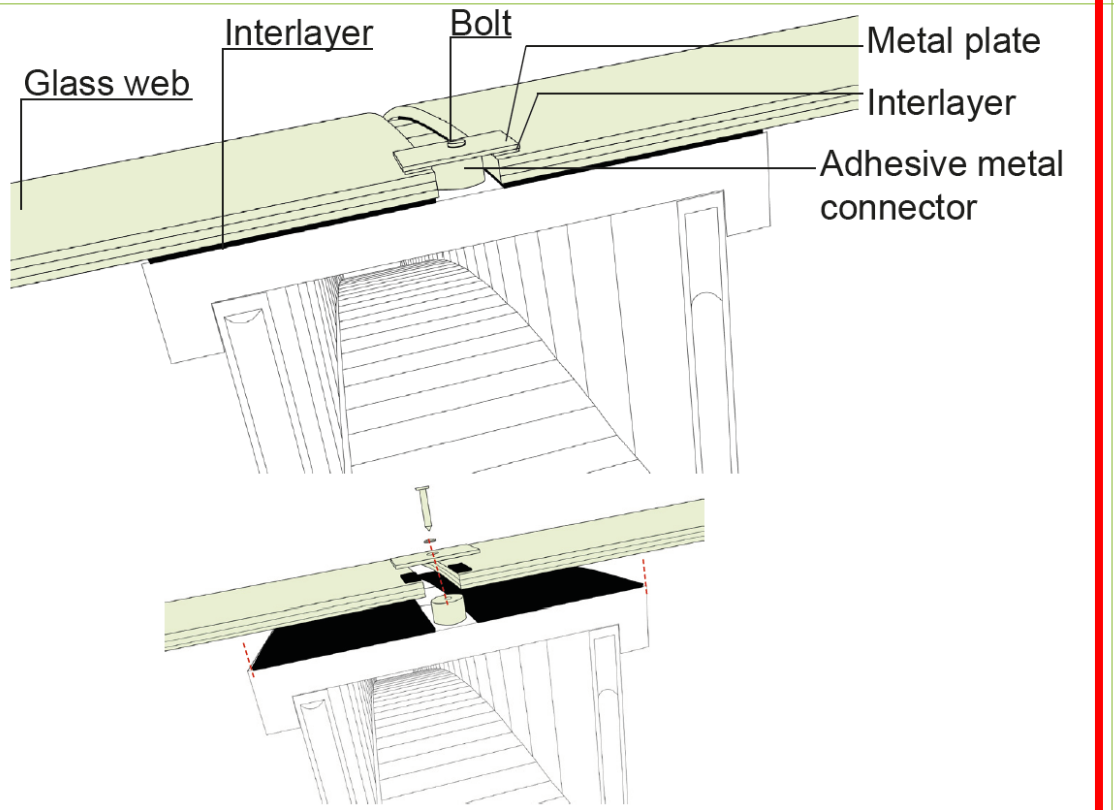




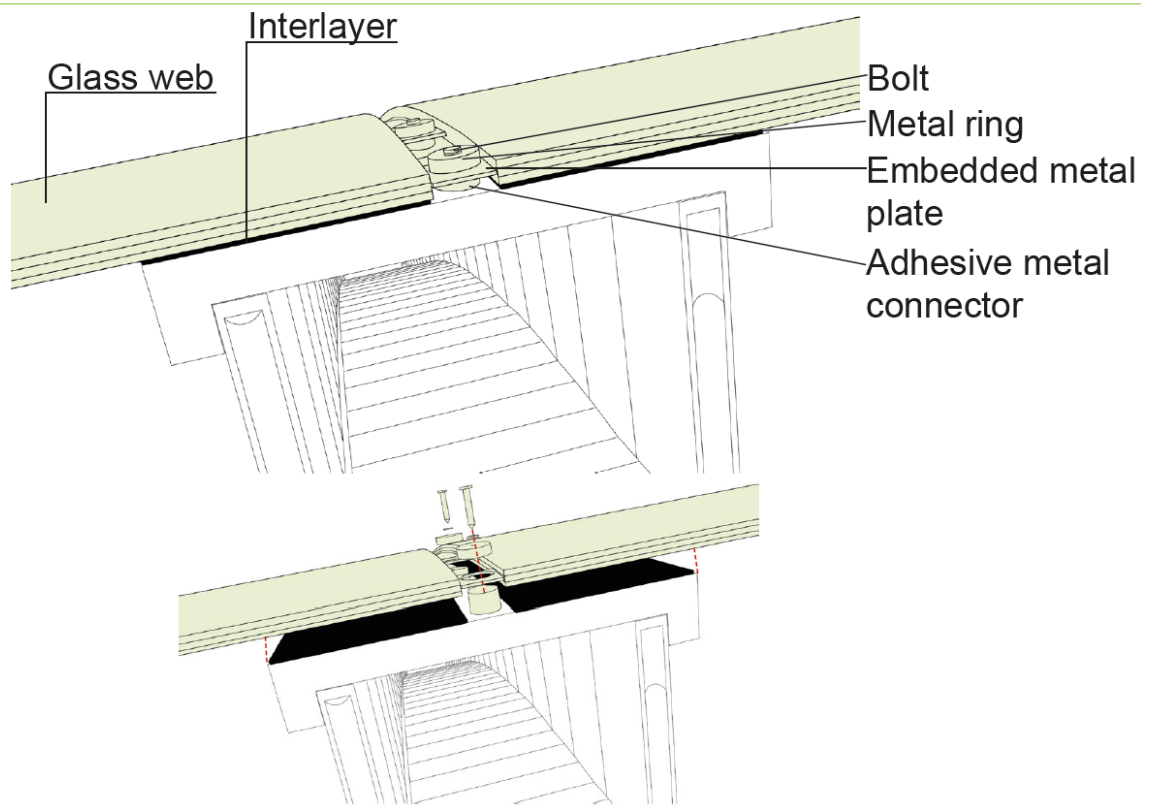


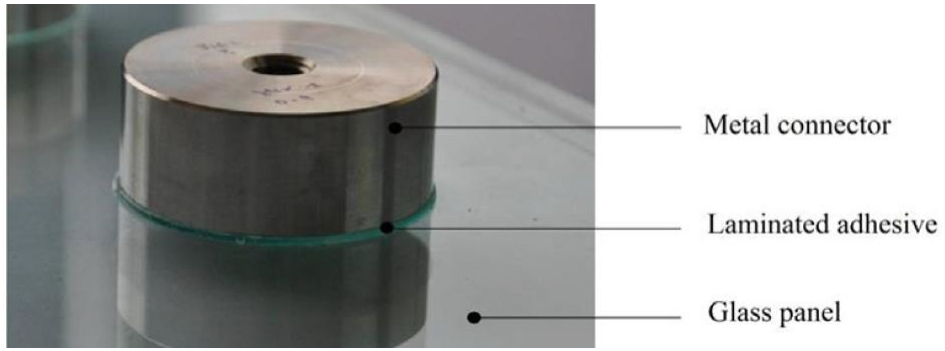
Adhesive connection. Retrieved from Bedon and Santarsiero (2018).

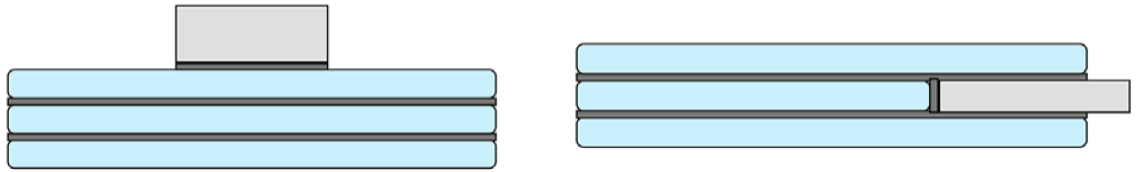
Variant 5 (adhesive)



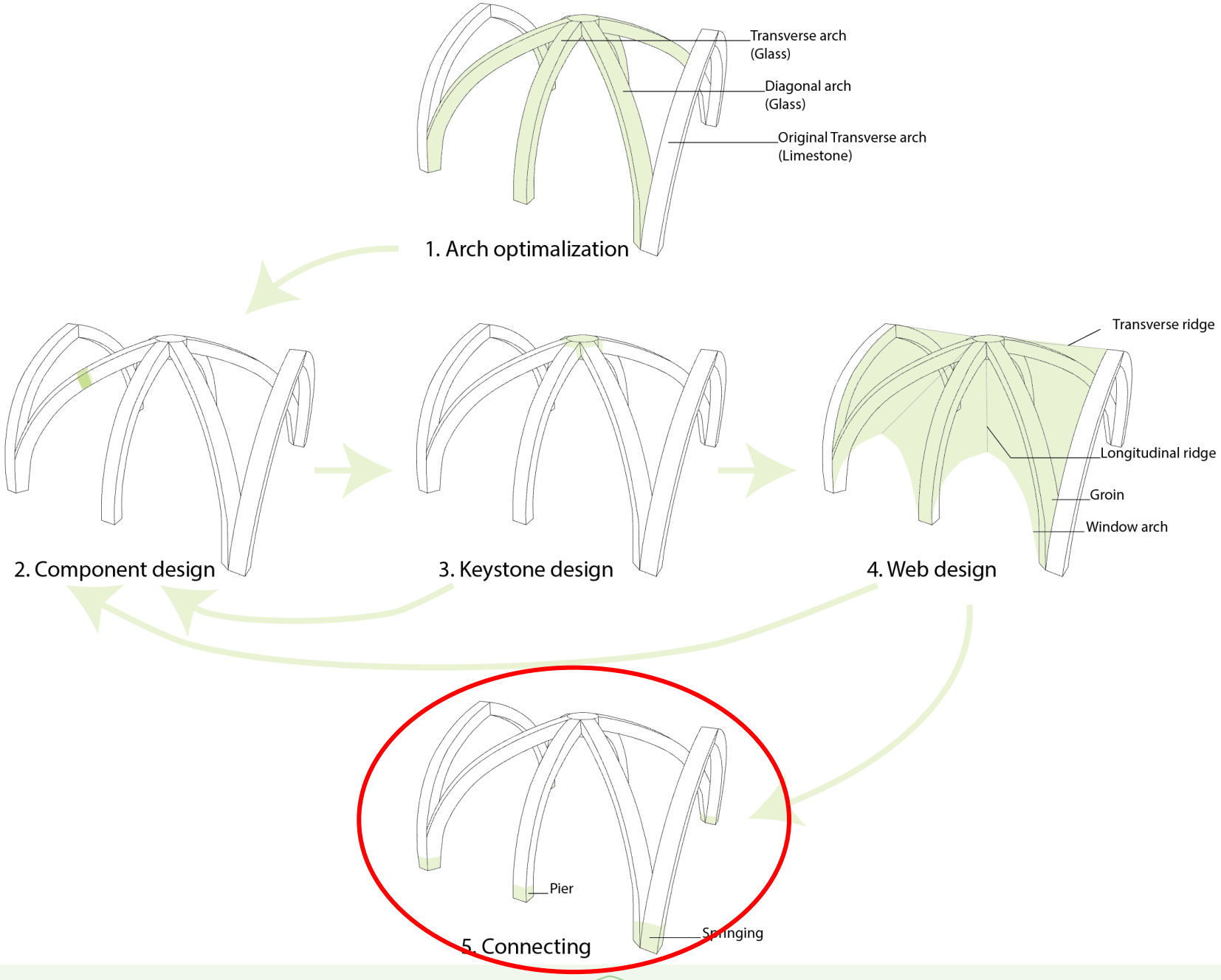
Variant 6 (adhesive)







Adhesive connection. Retrieved from Bedon and Santarsiero (2018).


Transverse arch
(Glass)
Diagonal arch
(Glass)
Original Transverse arch
(Limestone)
1. Arch optimalization
2. Component design
3. Keystone design
Transverse ridge
Longitudinal ridge
Groin
Window arch
4. Web design
Pier
Springing
5. Connecting

Assembly assessment

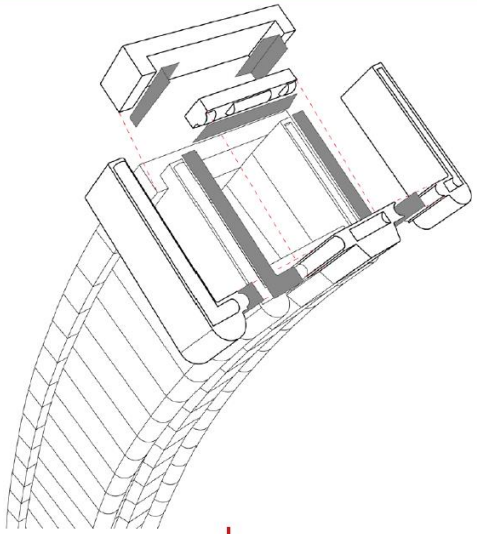
Interlayer possibility

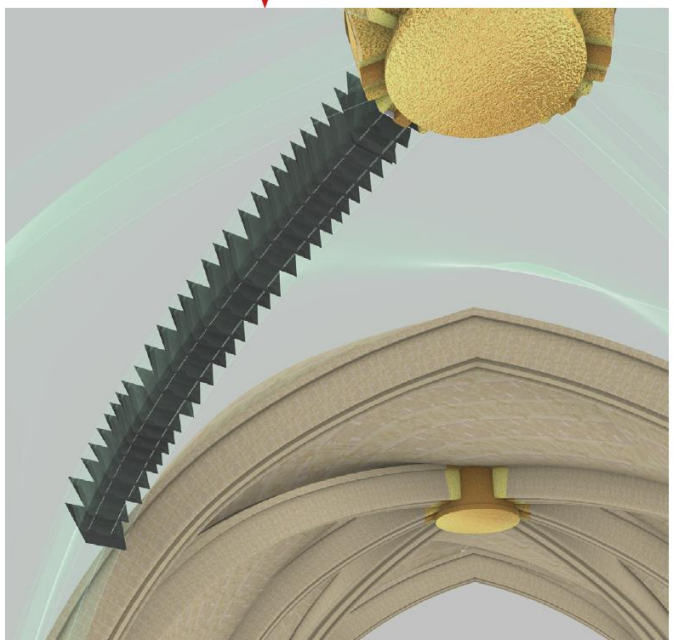
Visual effect

Labor intensity

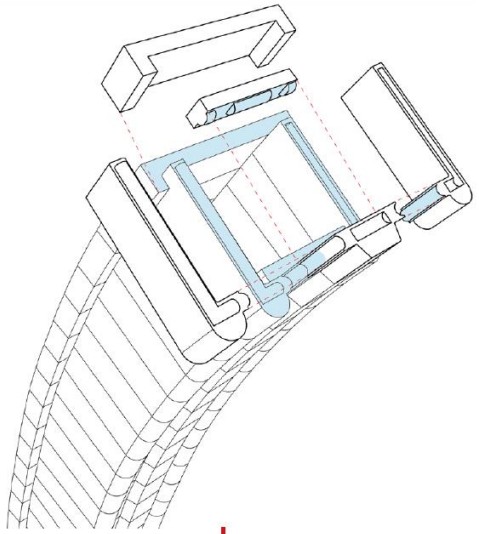
Quality Control

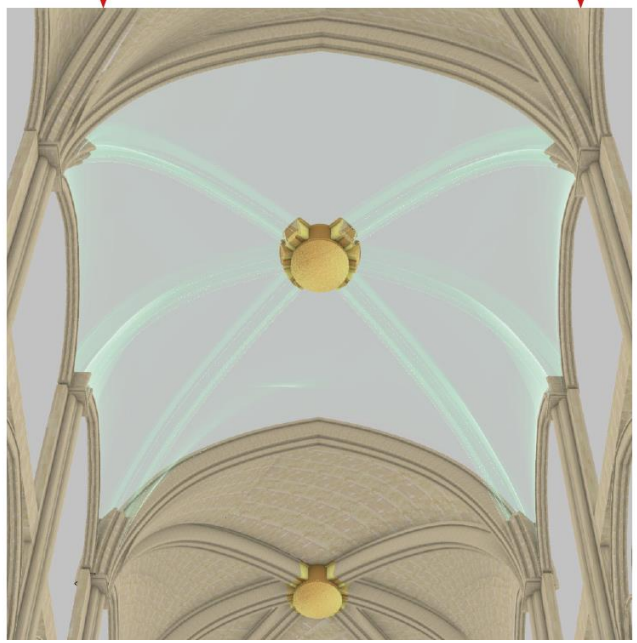
Variant 1
(Dry-assembly per component on location)



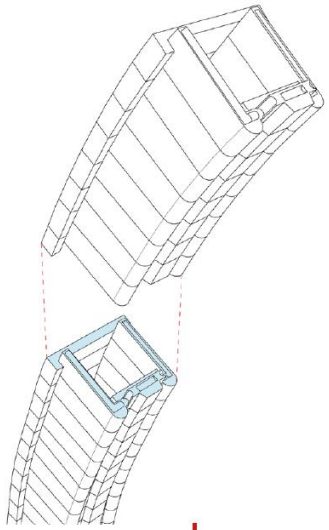


Variant 2
(Adhesive bonding per component on location)

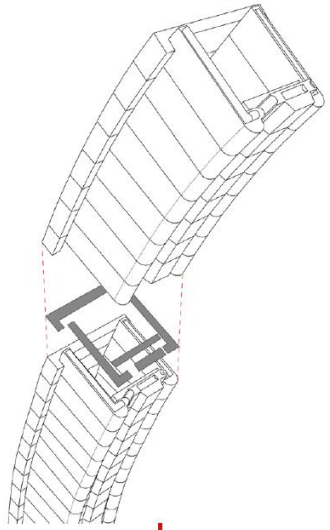


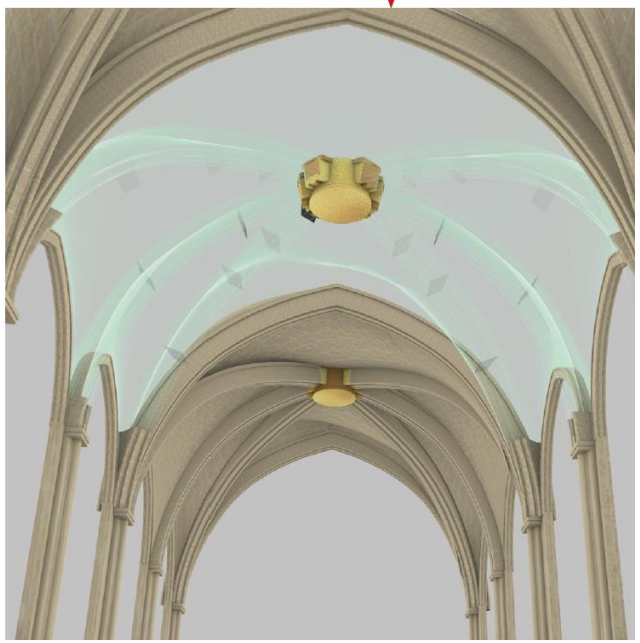


Variant 3
esive bonding at manufacture + on location)

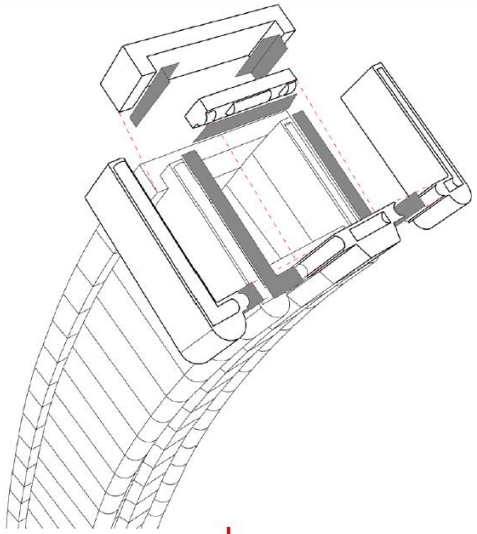


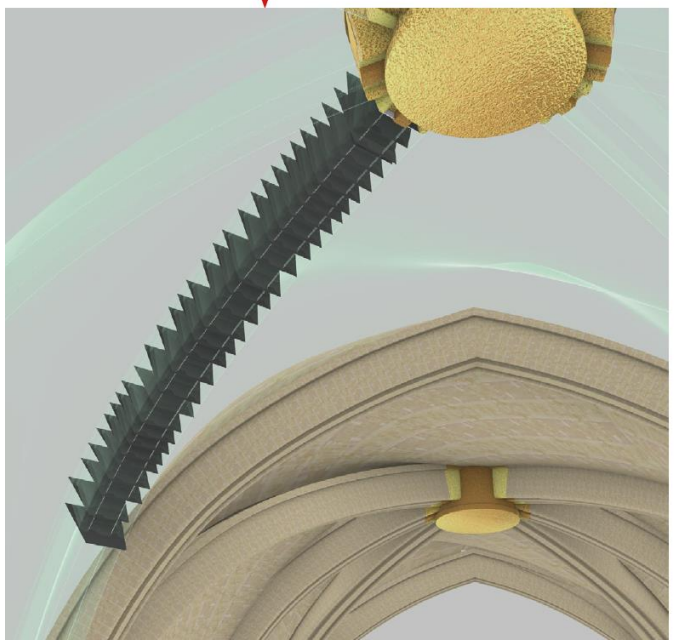
Variant 4
(Adhesive bonding at manufacture + dry-assembly on location)



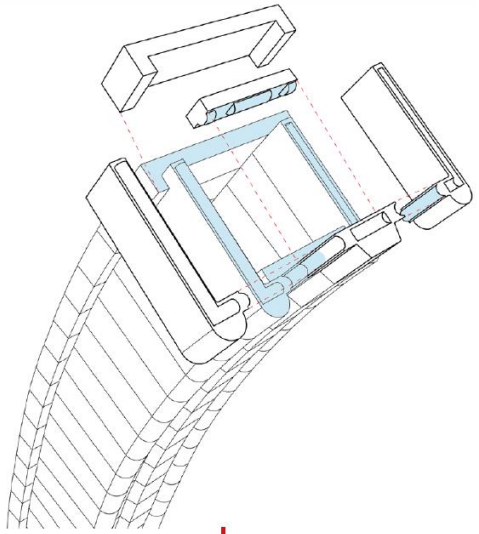


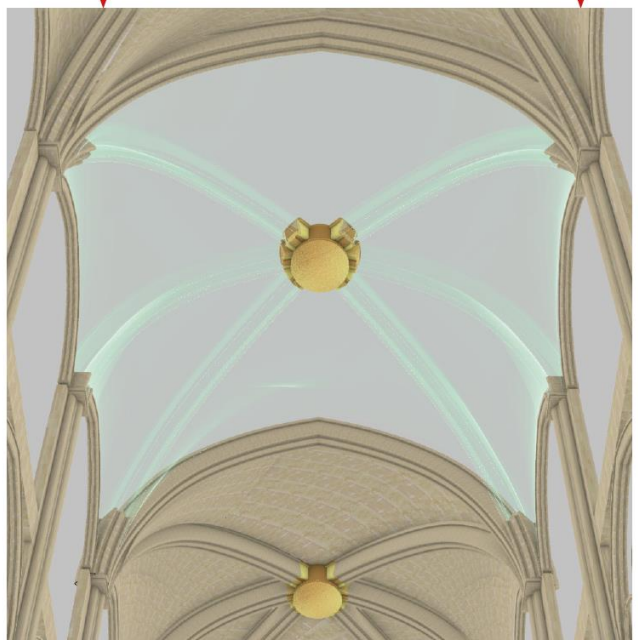
Variant 1
(Dry-assembly per component on location)



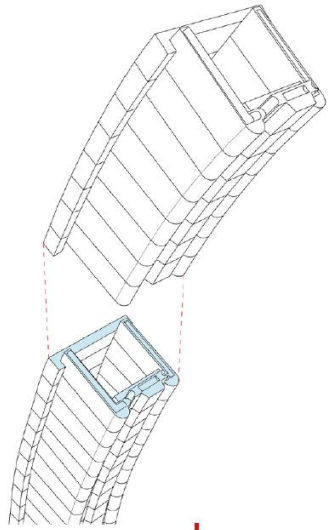


Variant 2
(Adhesive bonding per component on location)

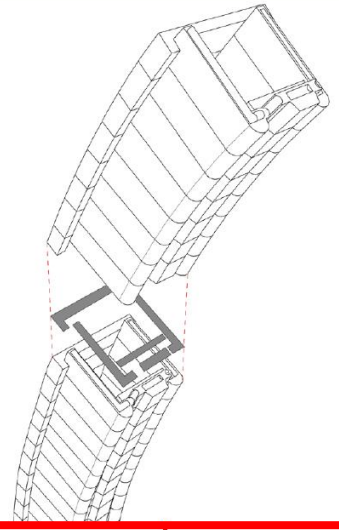


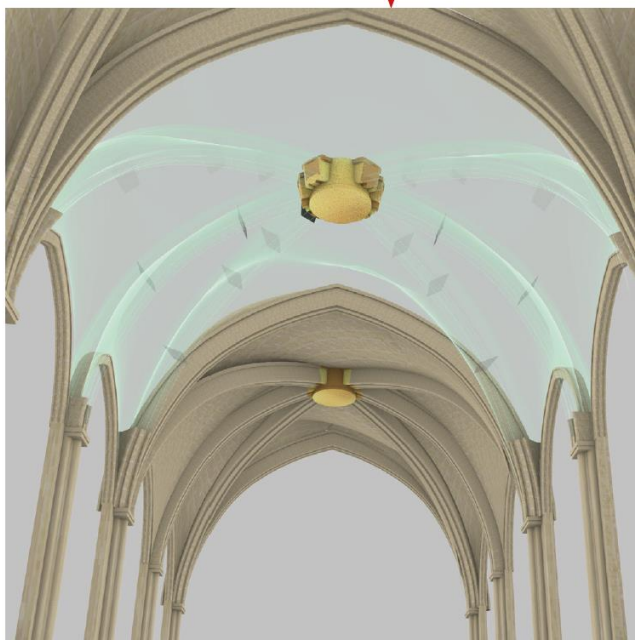


Variant 3
esive bonding at manufacture + on location)

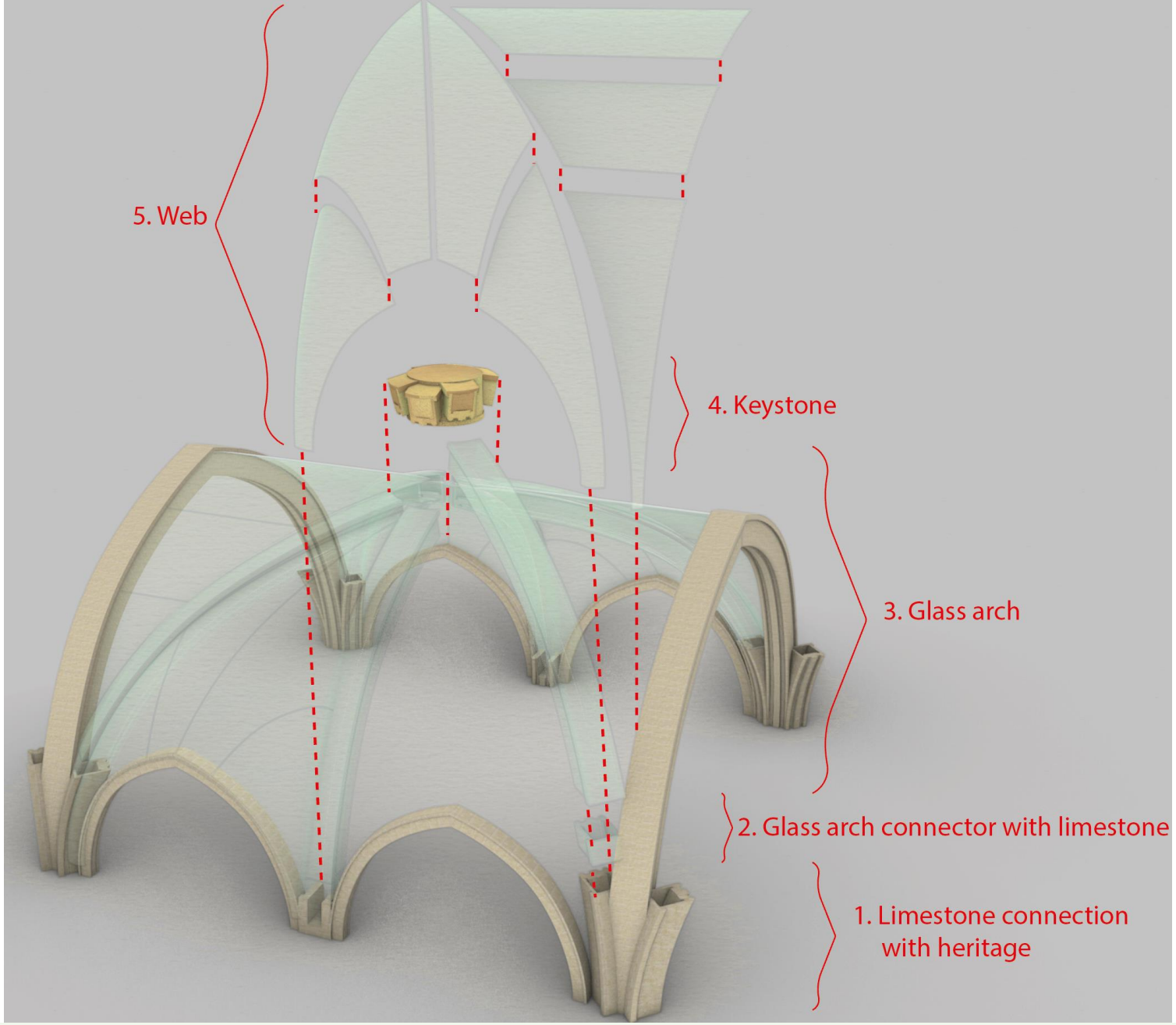


Variant 4
(Adhesive bonding at manufacture + dry-assembly on location)

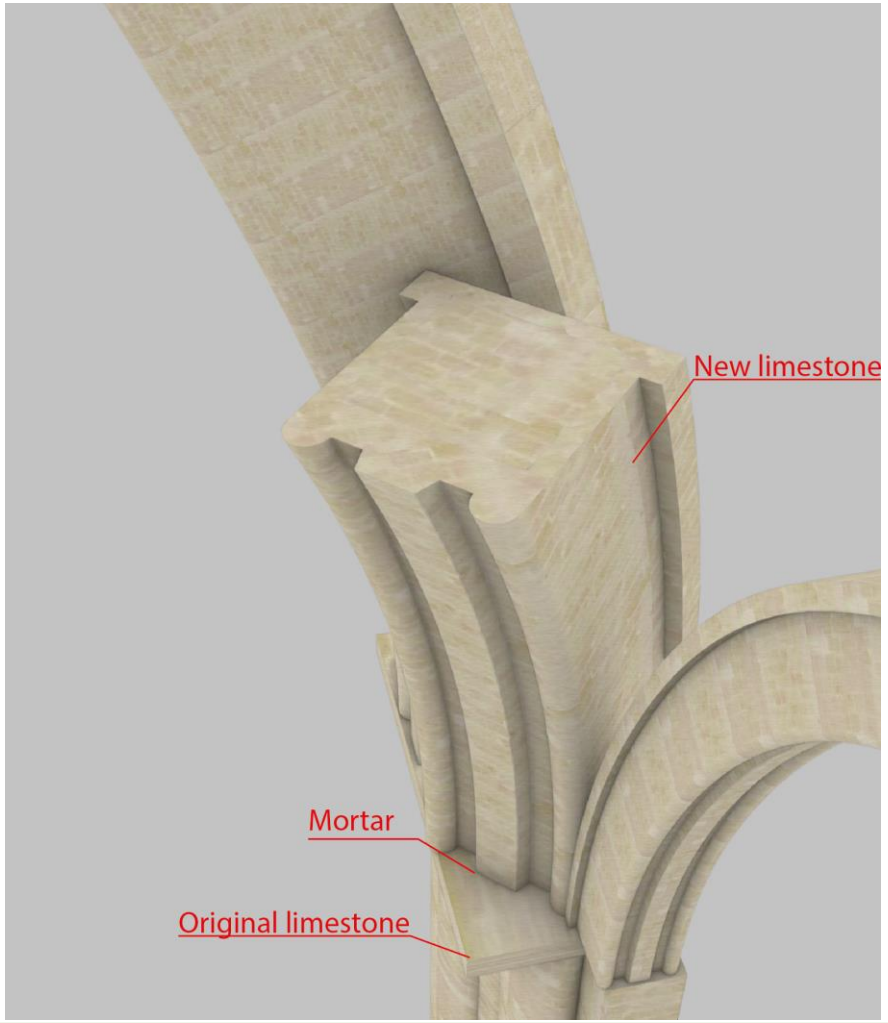




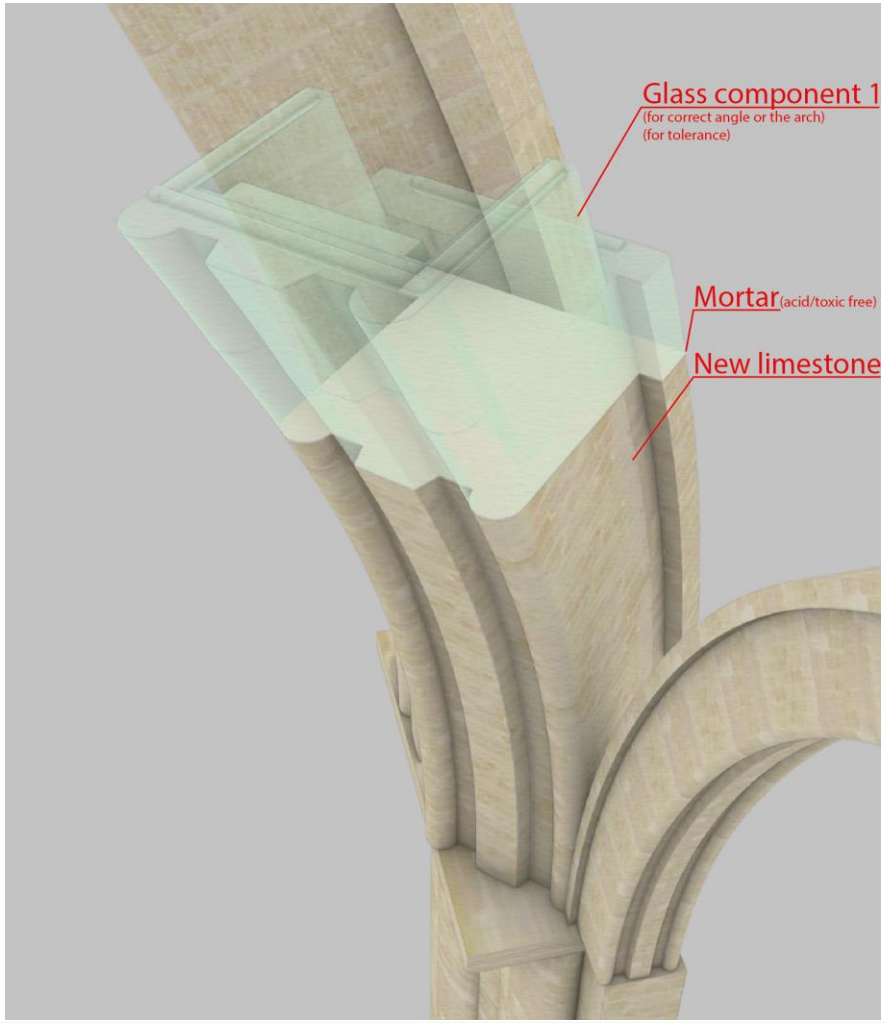
Final design


5. Web
4. Keystone
3. Glass arch
2. Glass arch connector with limestone
1. Limestone connection with heritage

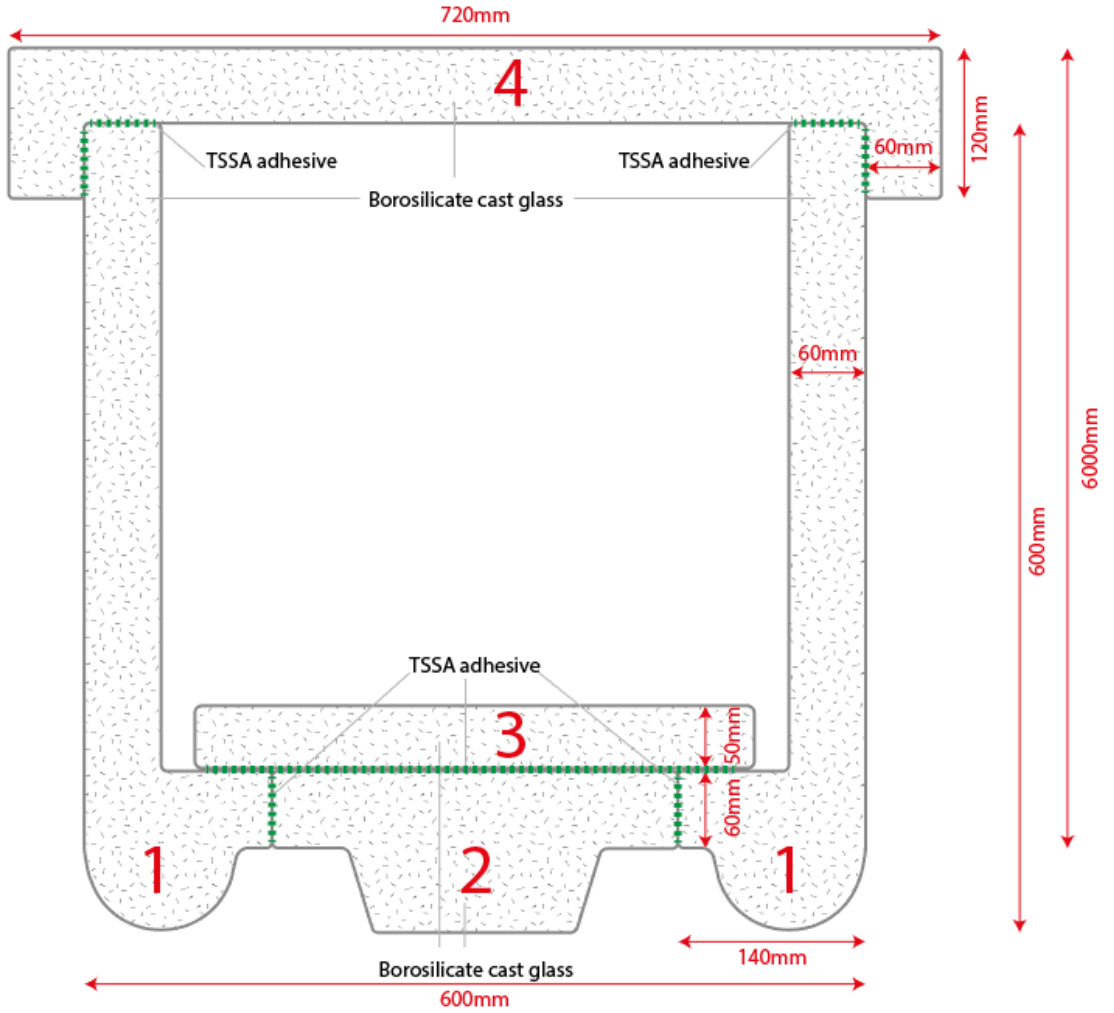
Limestone connection with the heritage

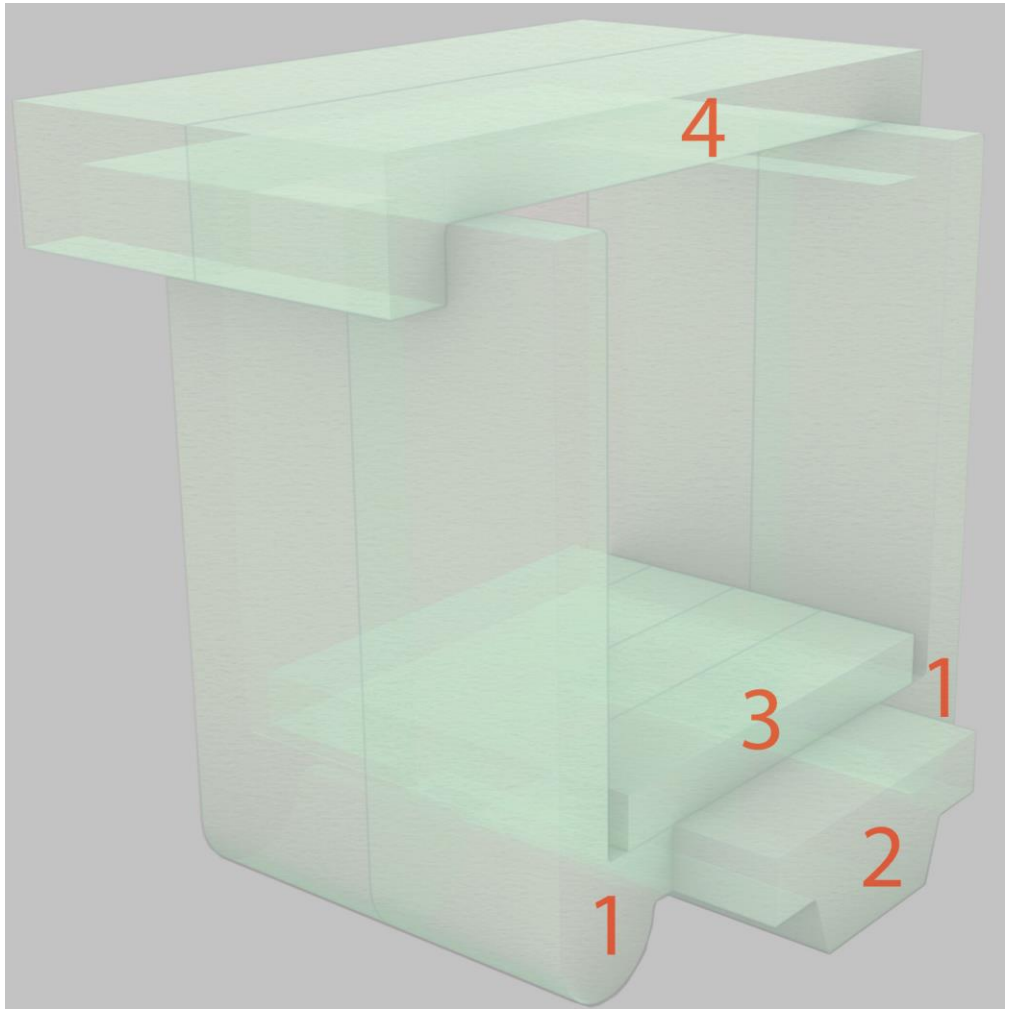


Glass arch connector with limestone

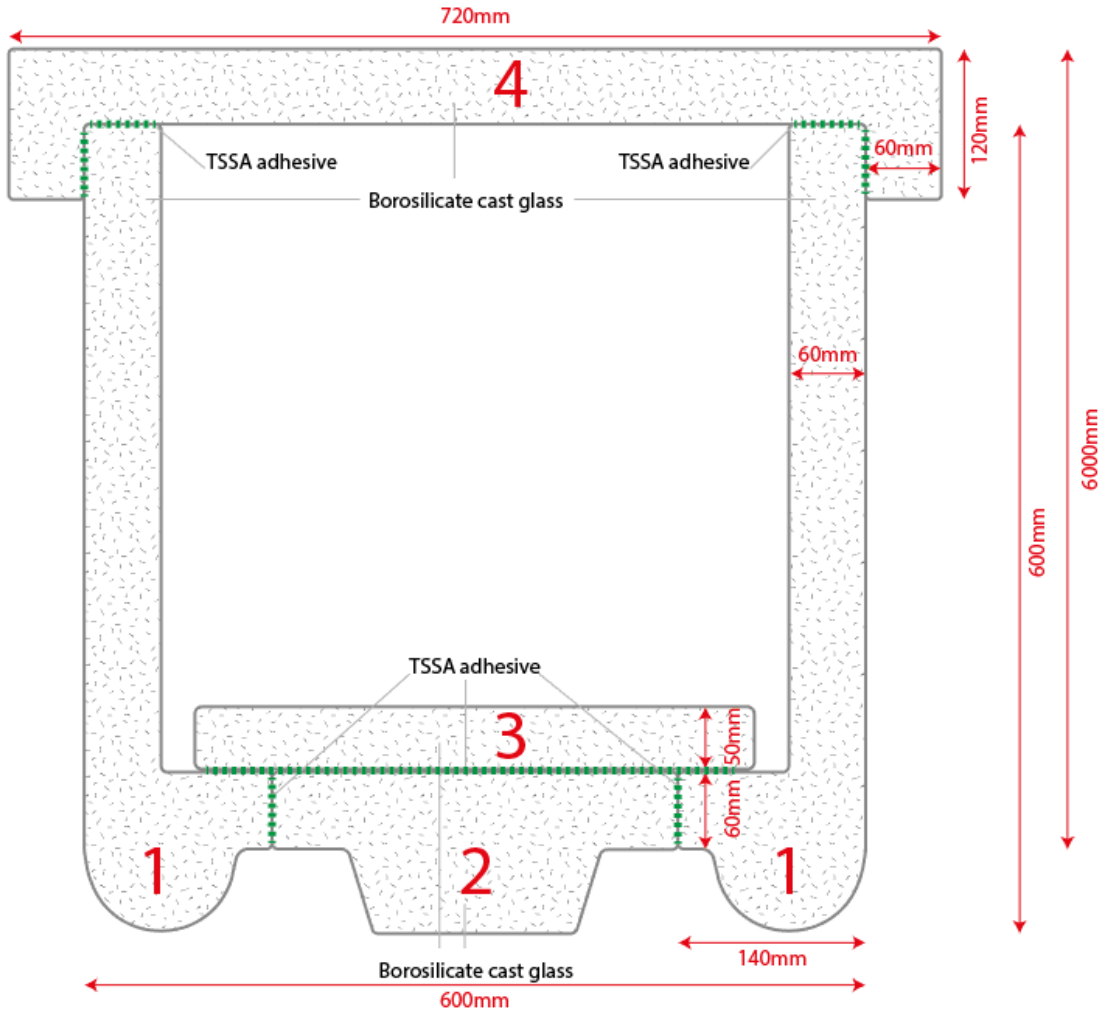


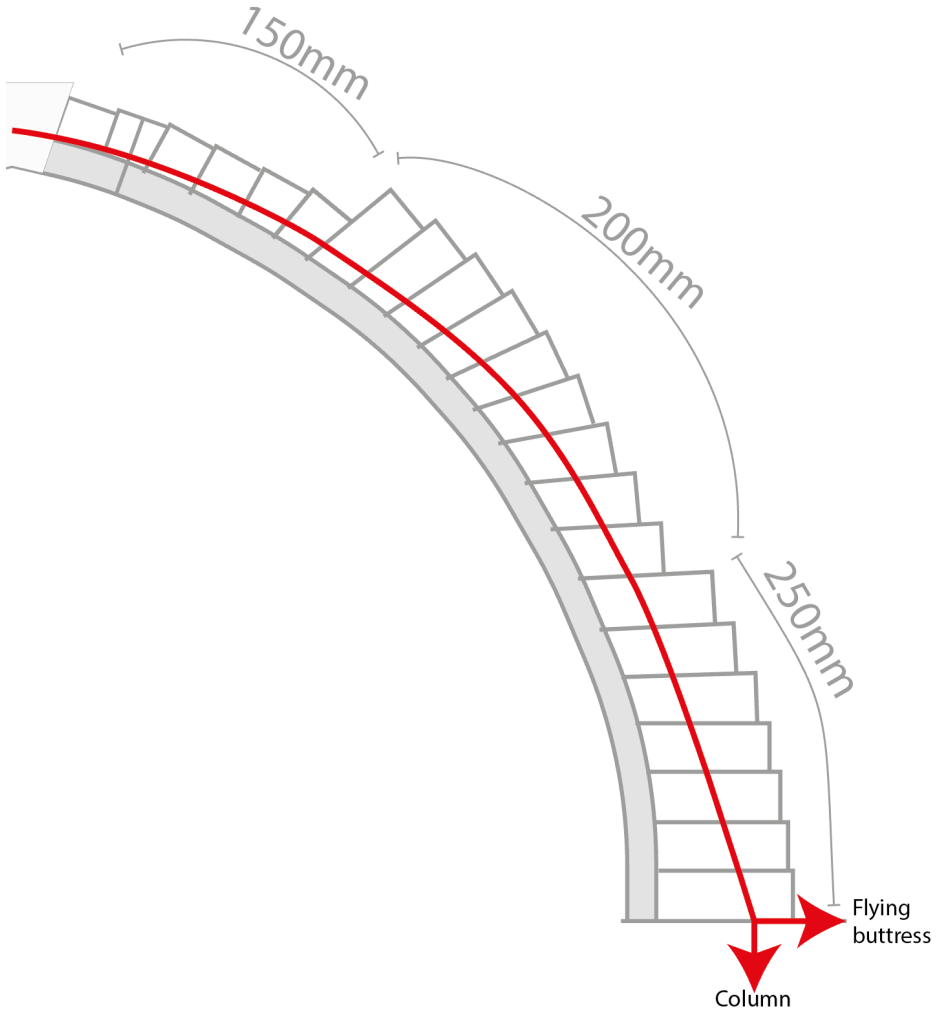
Glass component 1

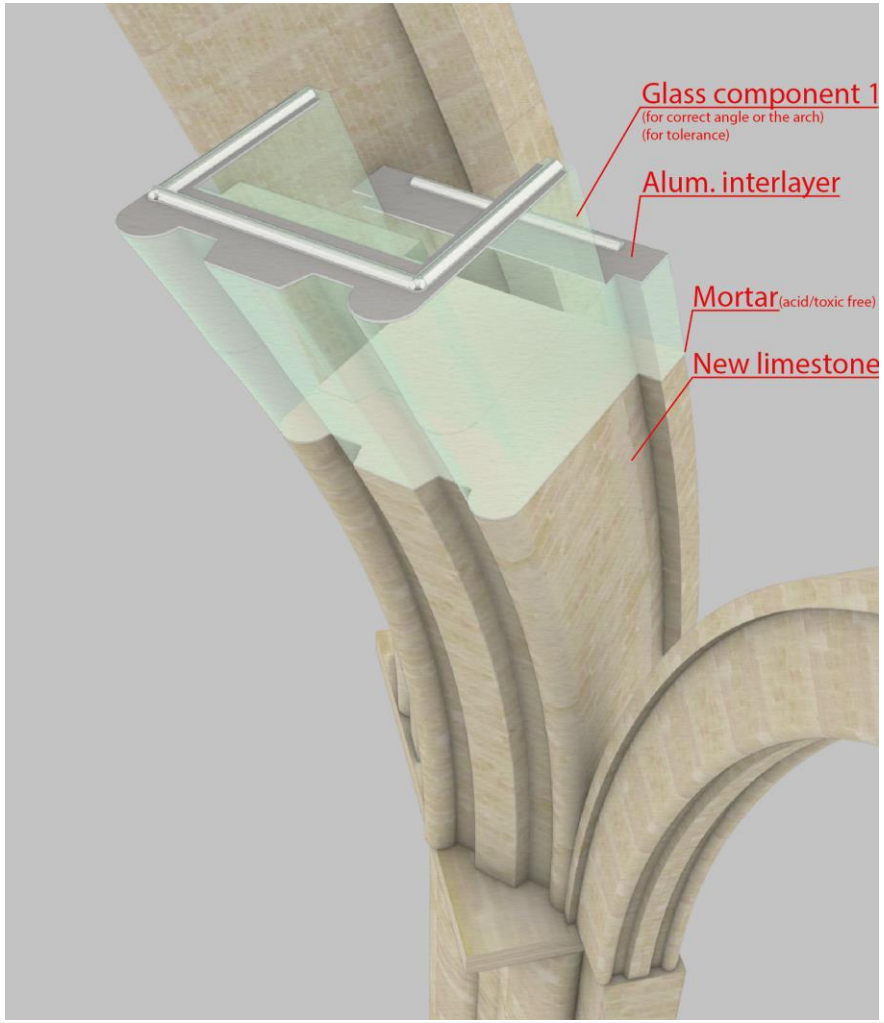




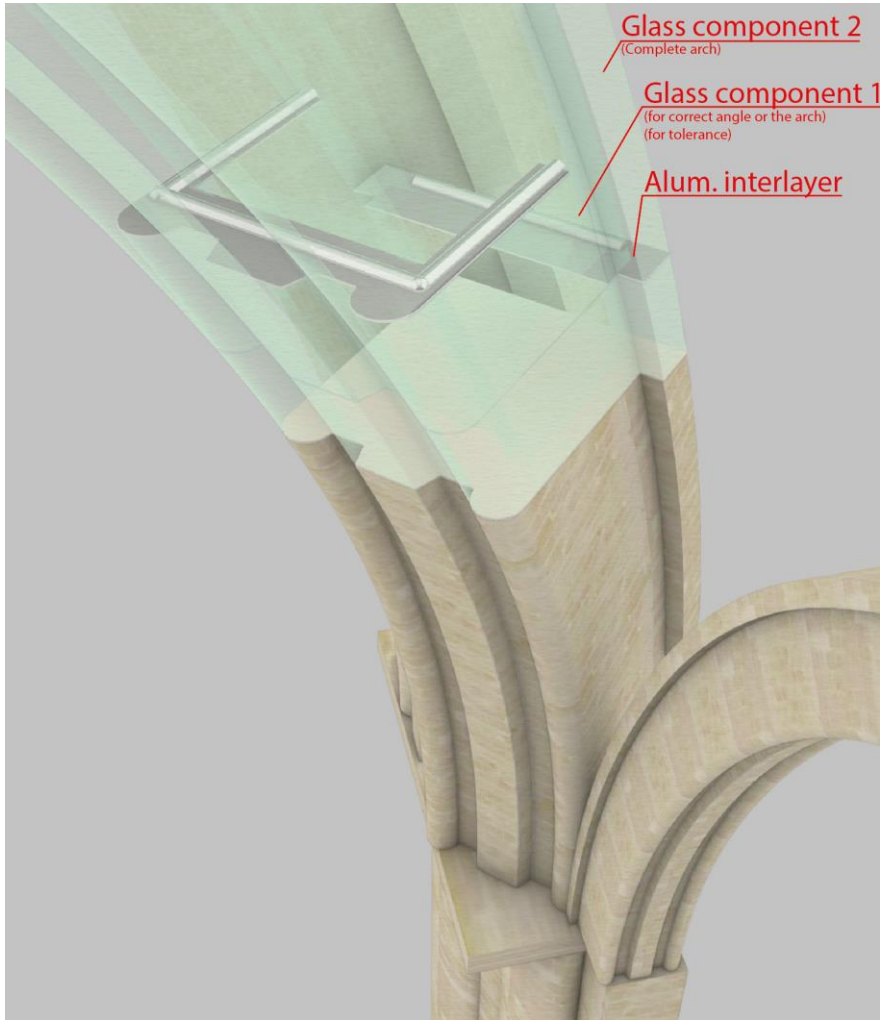
Glass component 1



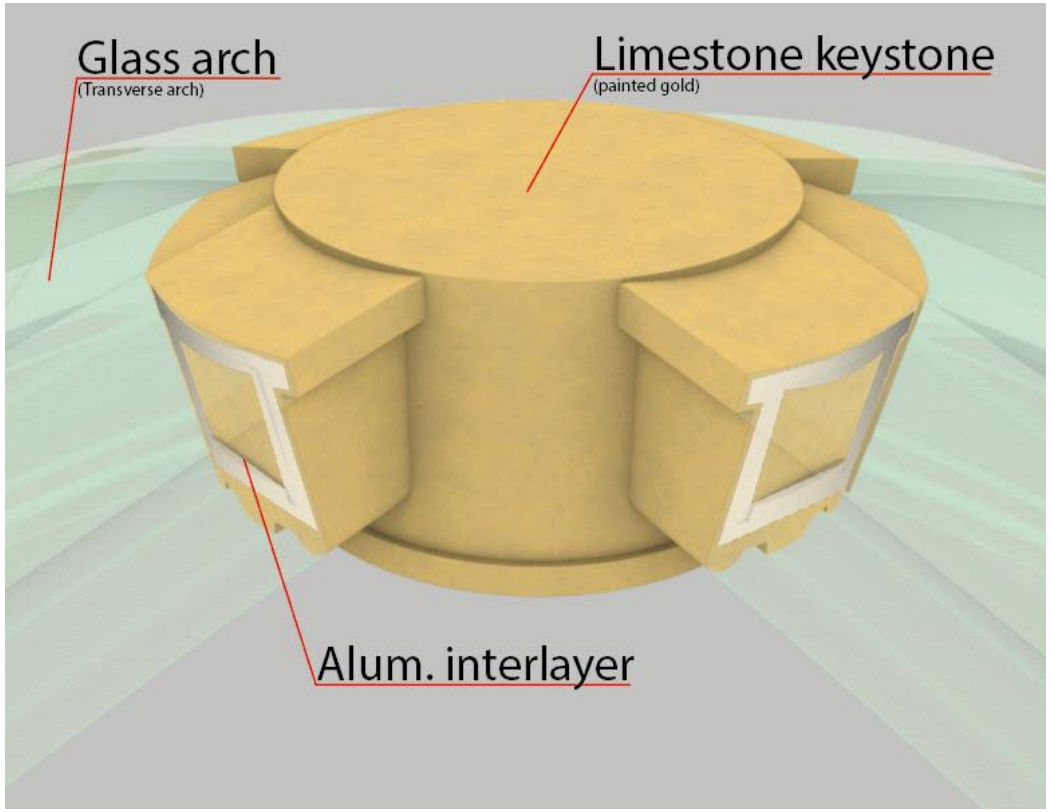


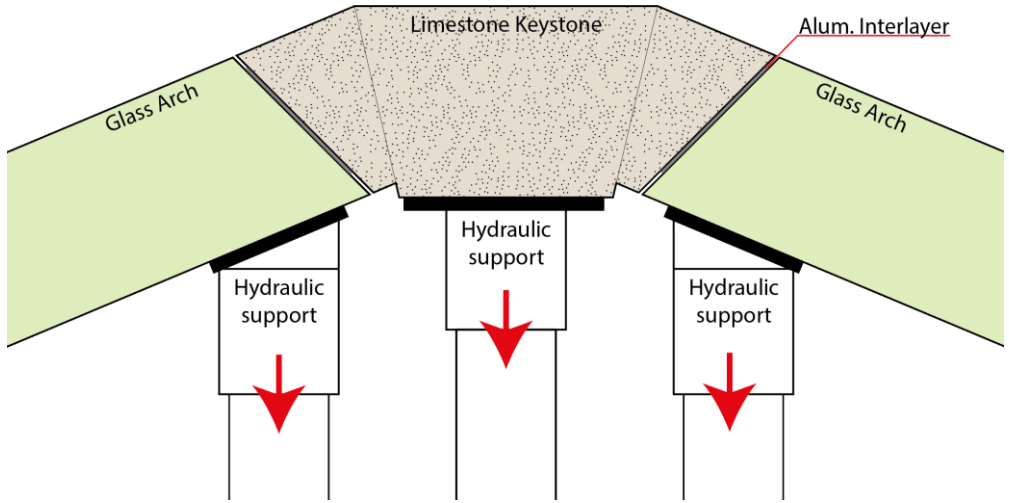

Glass component 1
(for correct angle or the arch)
(for tolerance)
Alum. interlayer
Mortar (acid/toxic free)
New limestone

Glass component 1 & 2



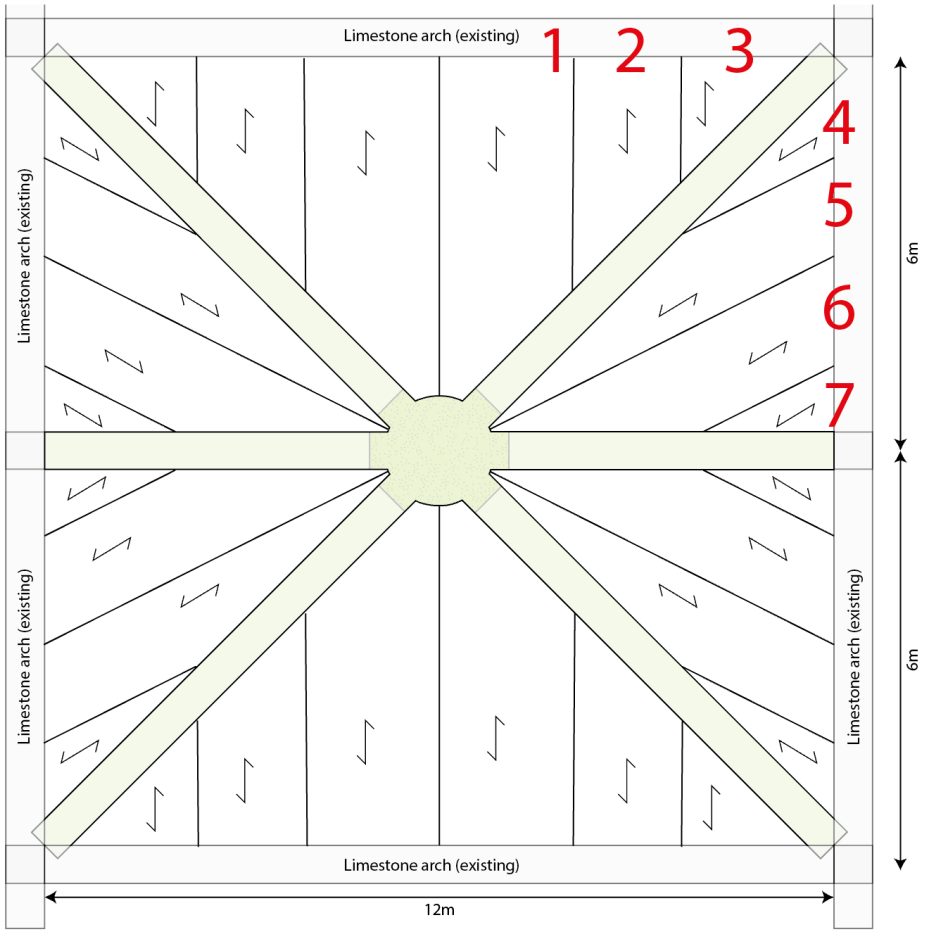
Keystone

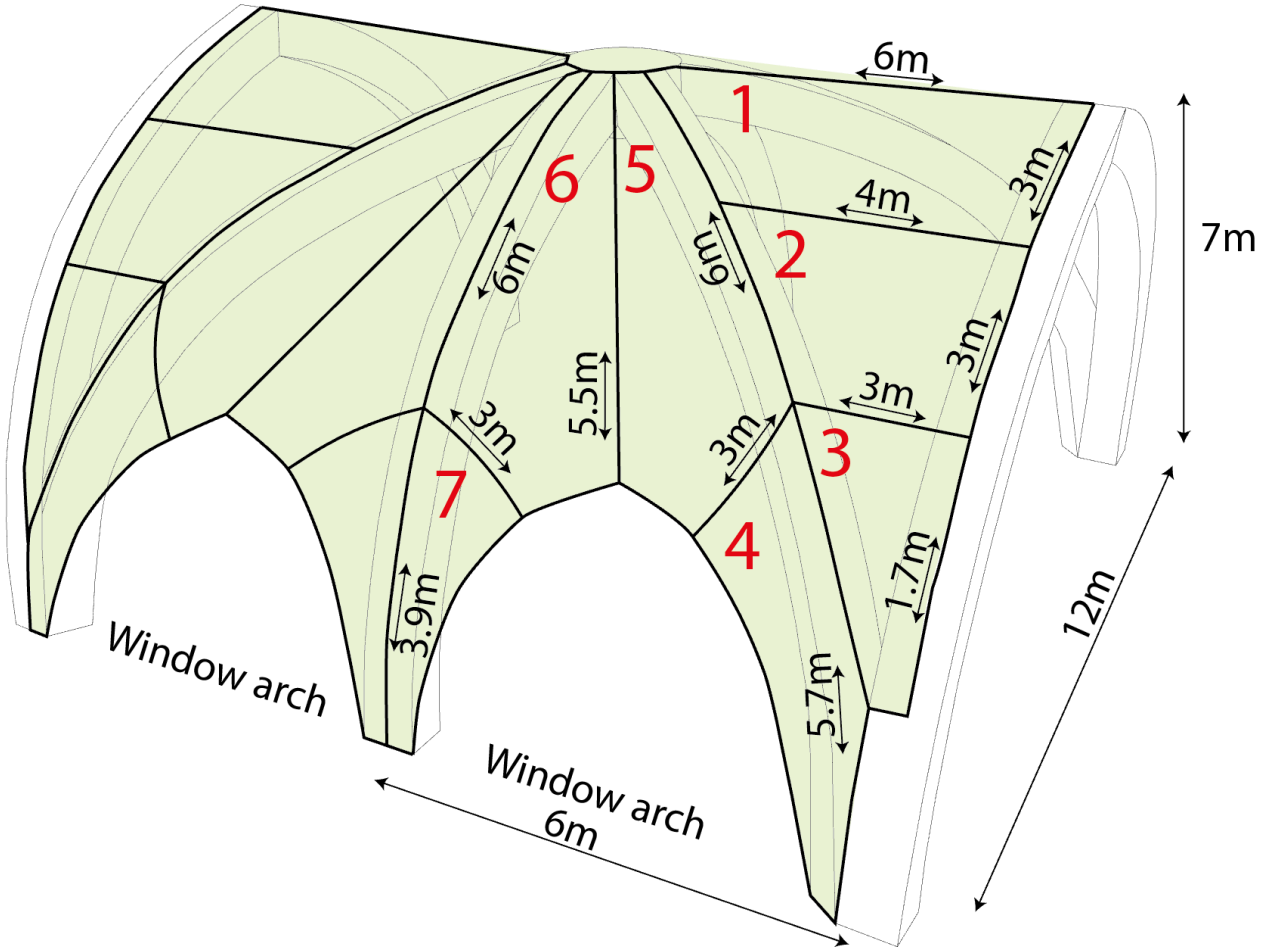


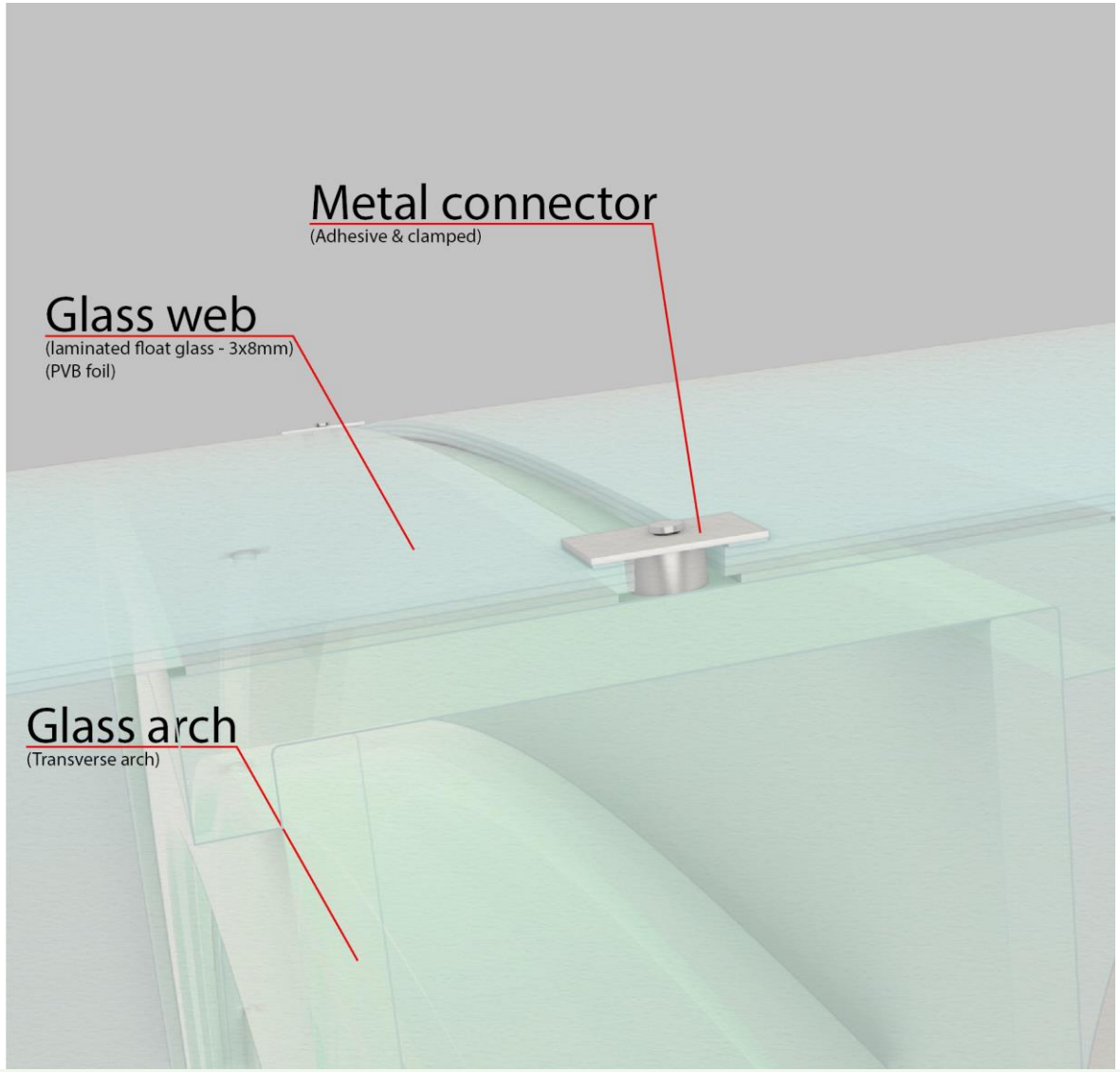


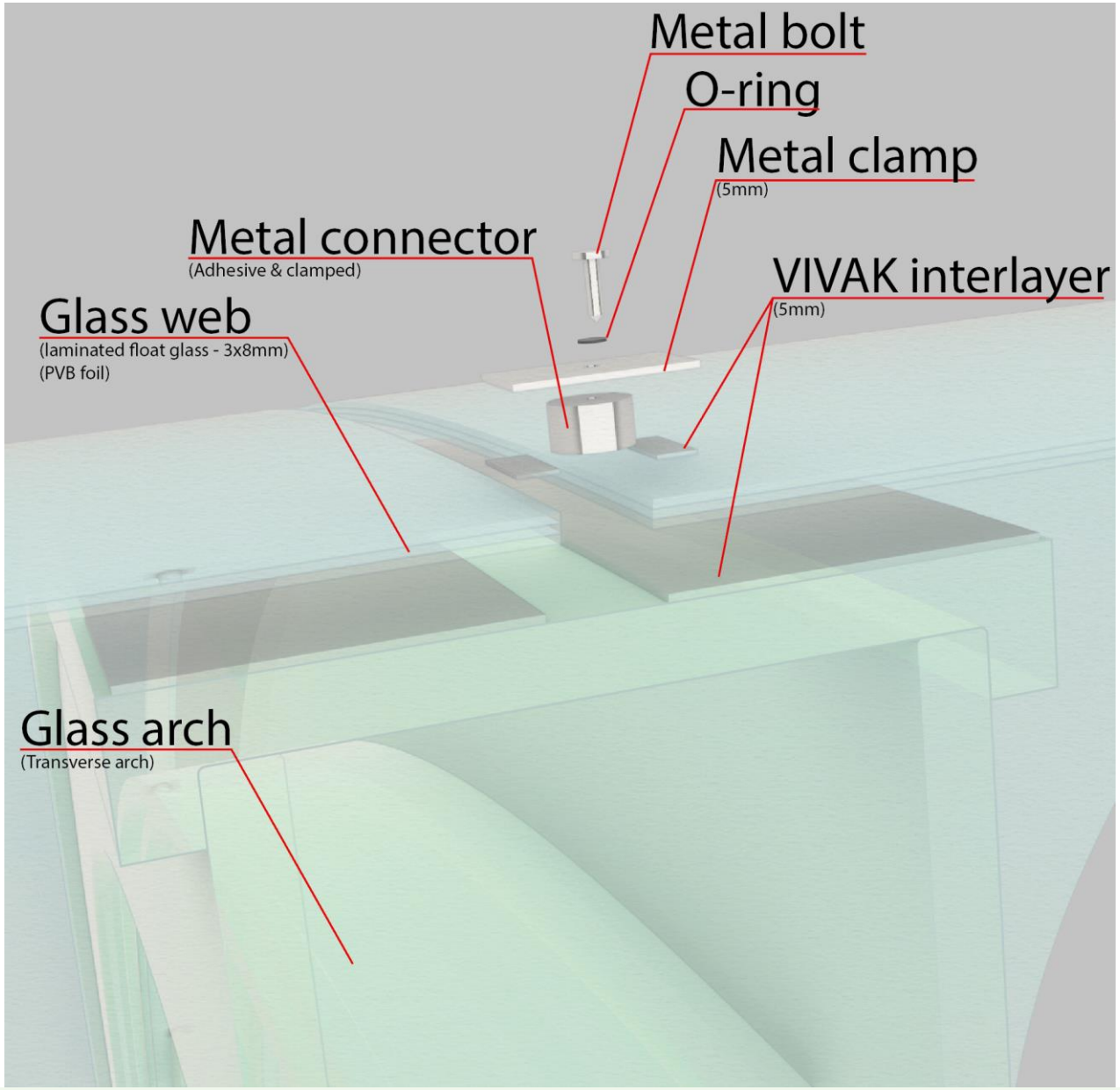
Abstract

Web

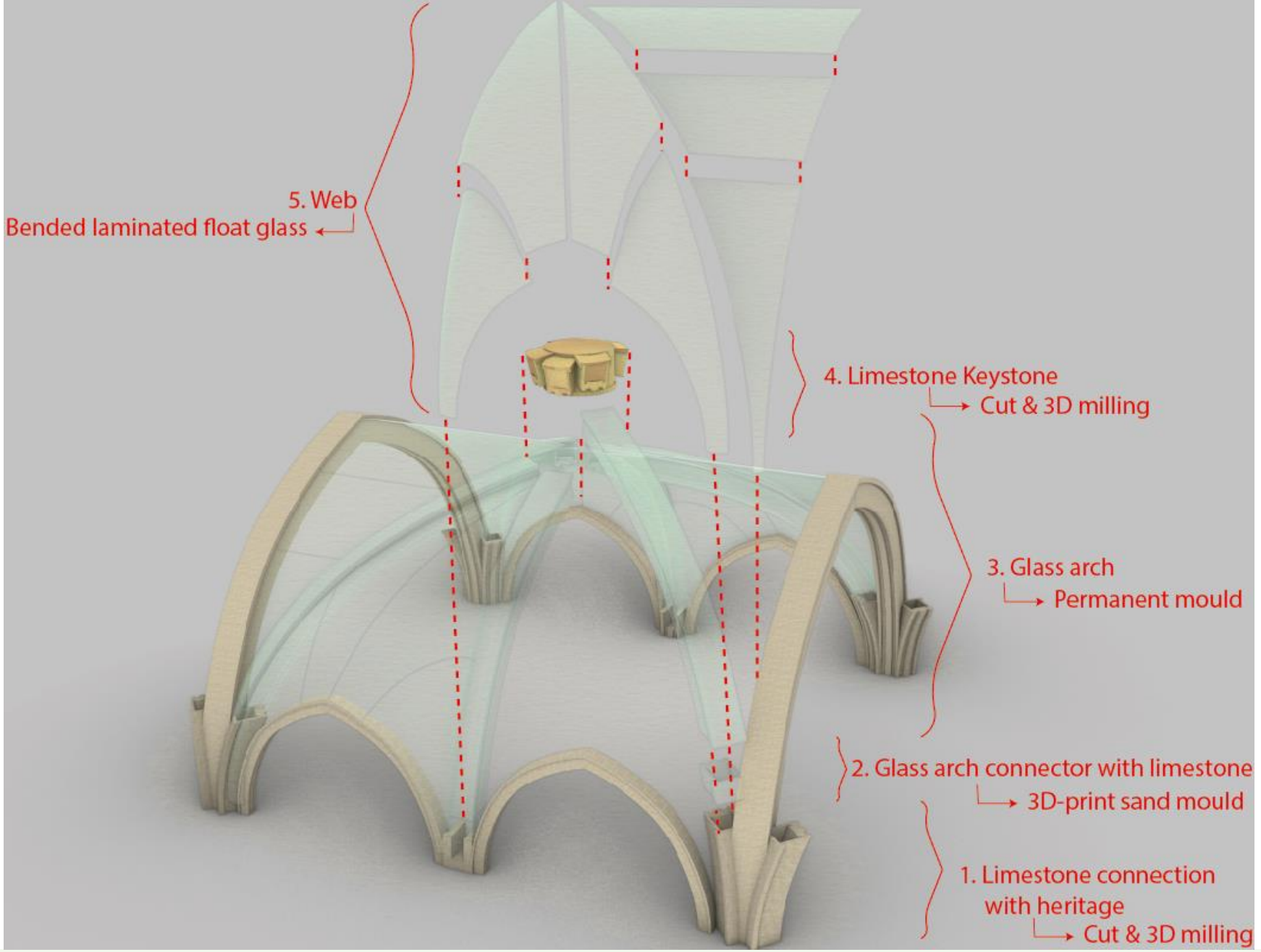

Limestone arch (existing)
Limestone arch (existing)
Limestone arch (existing)
Limestone arch (existing)
1
2
3
4
5
6
7
6m
6m
12m


1
2
3
4
5
6
7
6m
4m
3m
6m
6m
5.5m
3m
3m
3m
3m
3.9m
1.7m
5.7m
7m
12m
Window arch
Window arch
6m


Metal connector
(Adhesive & clamped)
Glass web
(laminated float glass - 3x8mm)
(PVB foil)
Glass arch
(Transverse arch)


Metal bolt
O-ring
Metal clamp
(5mm)
Metal connector
(Adhesive & clamped)
VIVAK interlayer
(5mm)
Glass web
(laminated float glass - 3x8mm)
(PVB foil)
Glass arch
(Transverse arch)

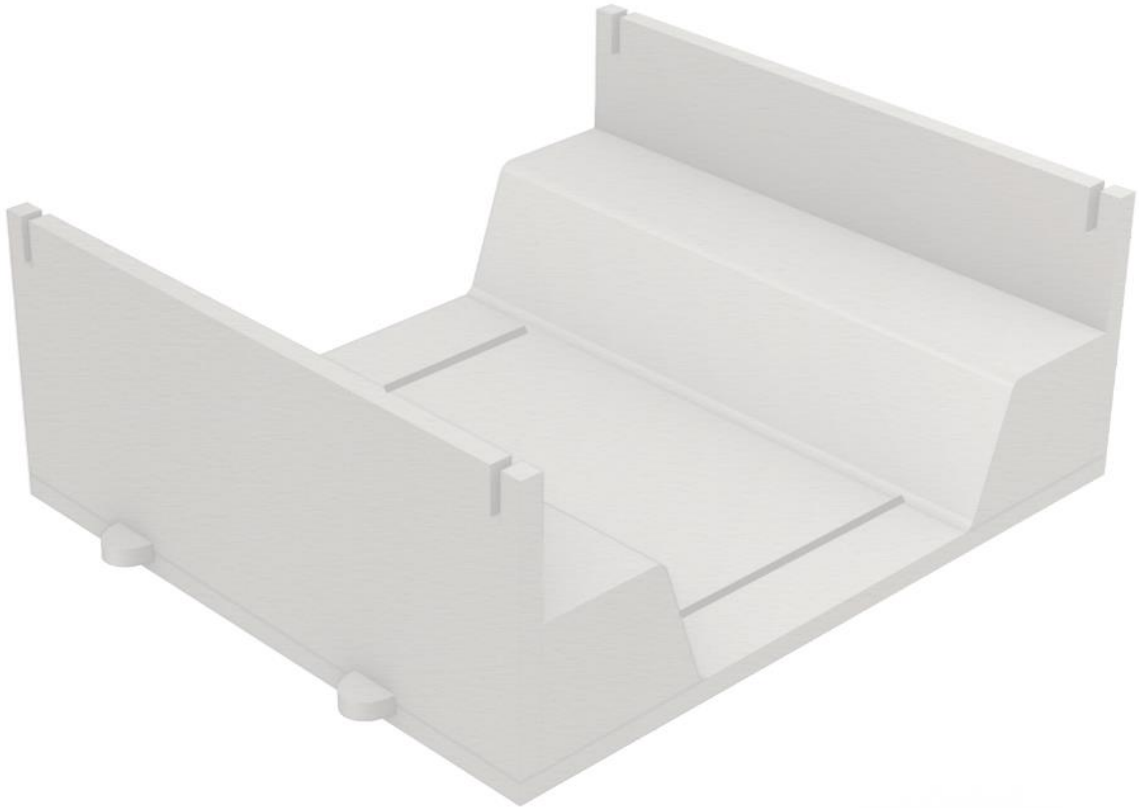
How to produce?


5. Web
Bended laminated float glass
4. Limestone Keystone
Cut & 3D milling
3. Glass arch
Permanent mould
2. Glass arch connector with limestone
3D-print sand mould
1. Limestone connection
with heritage
Cut & 3D milling

Permanent mould

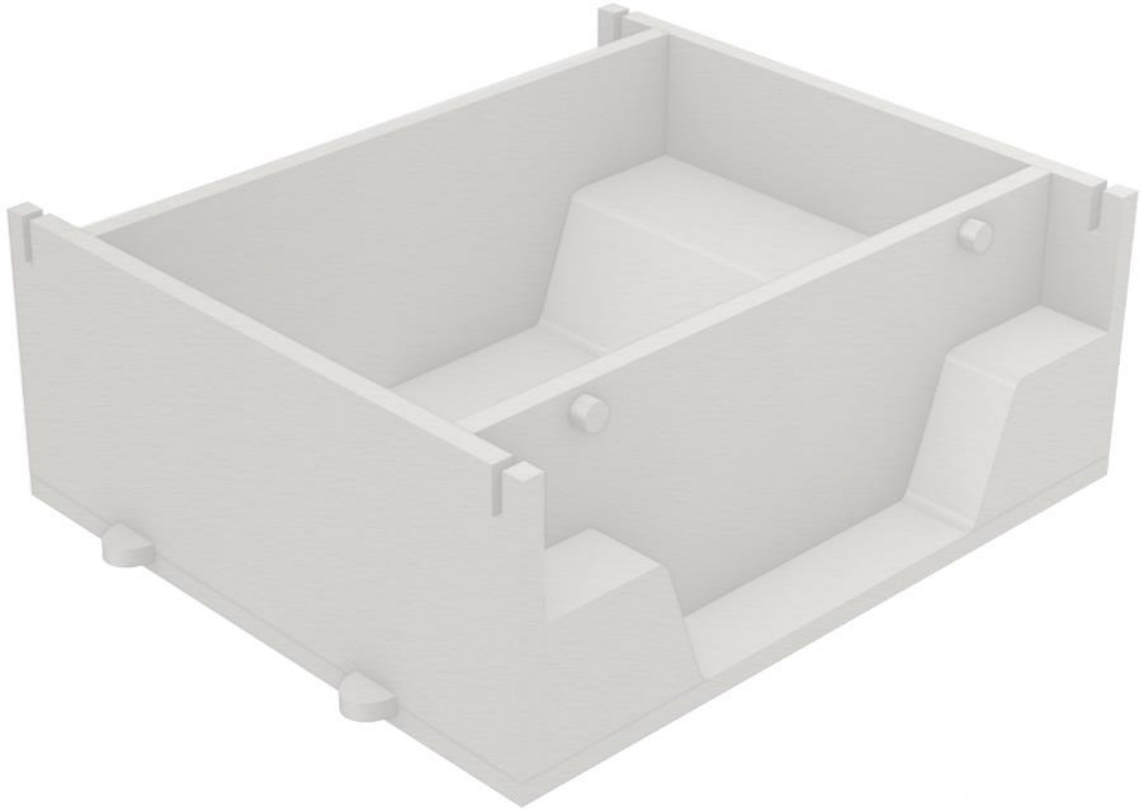
Phase • Base plate

1



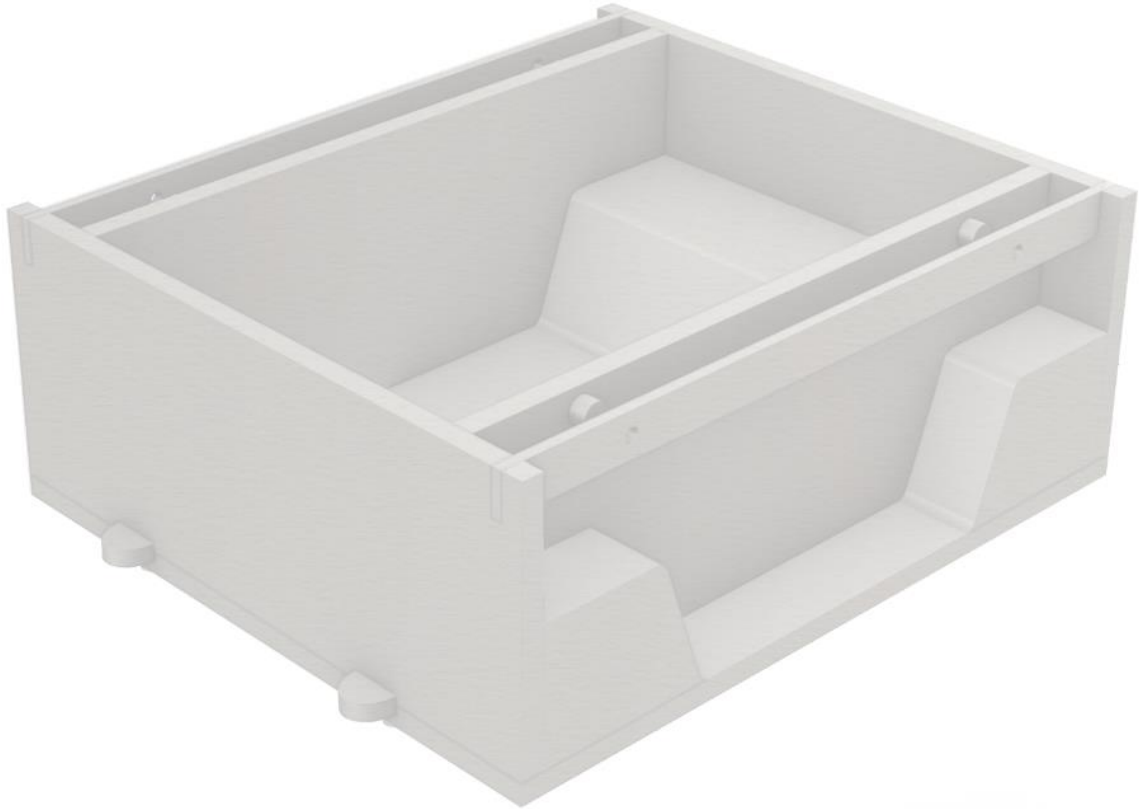
Phase 2

- Slide in the fixed walls based on the guides.
- Fixate the walls with screws from below.



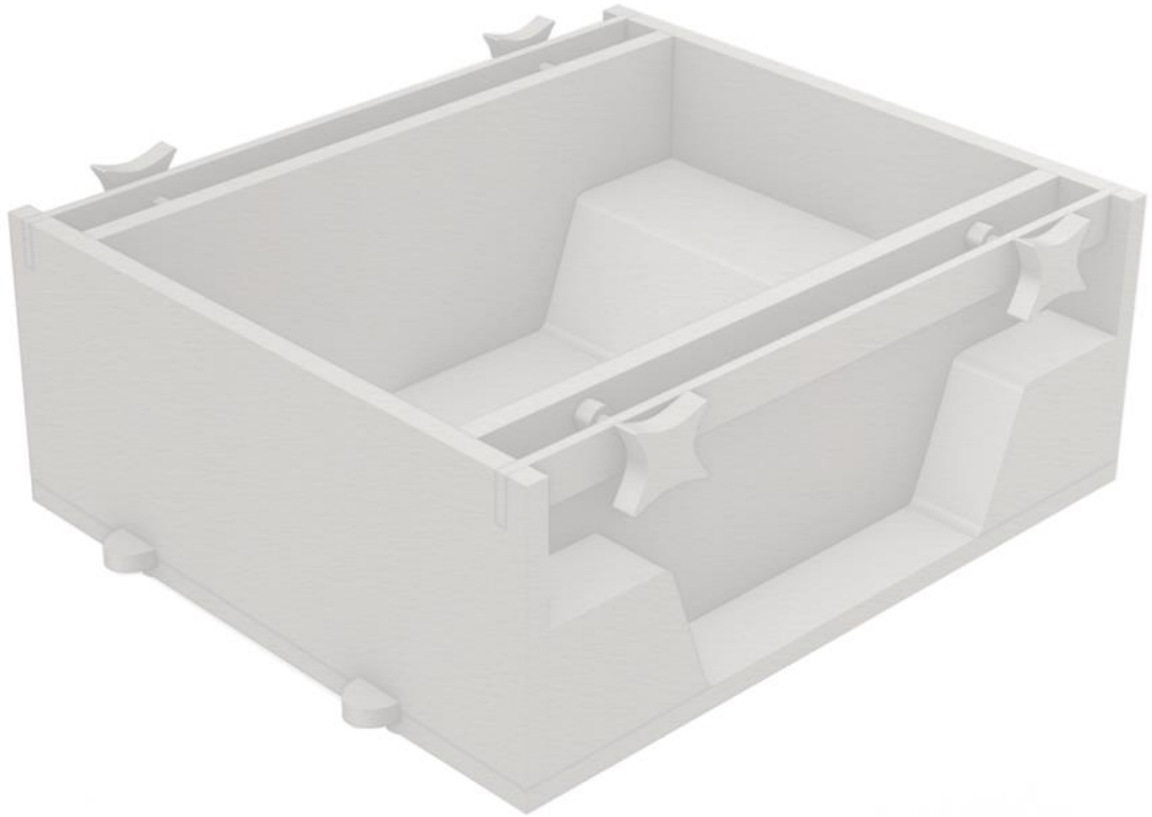
Phase 3

- Place the adjustable walls.



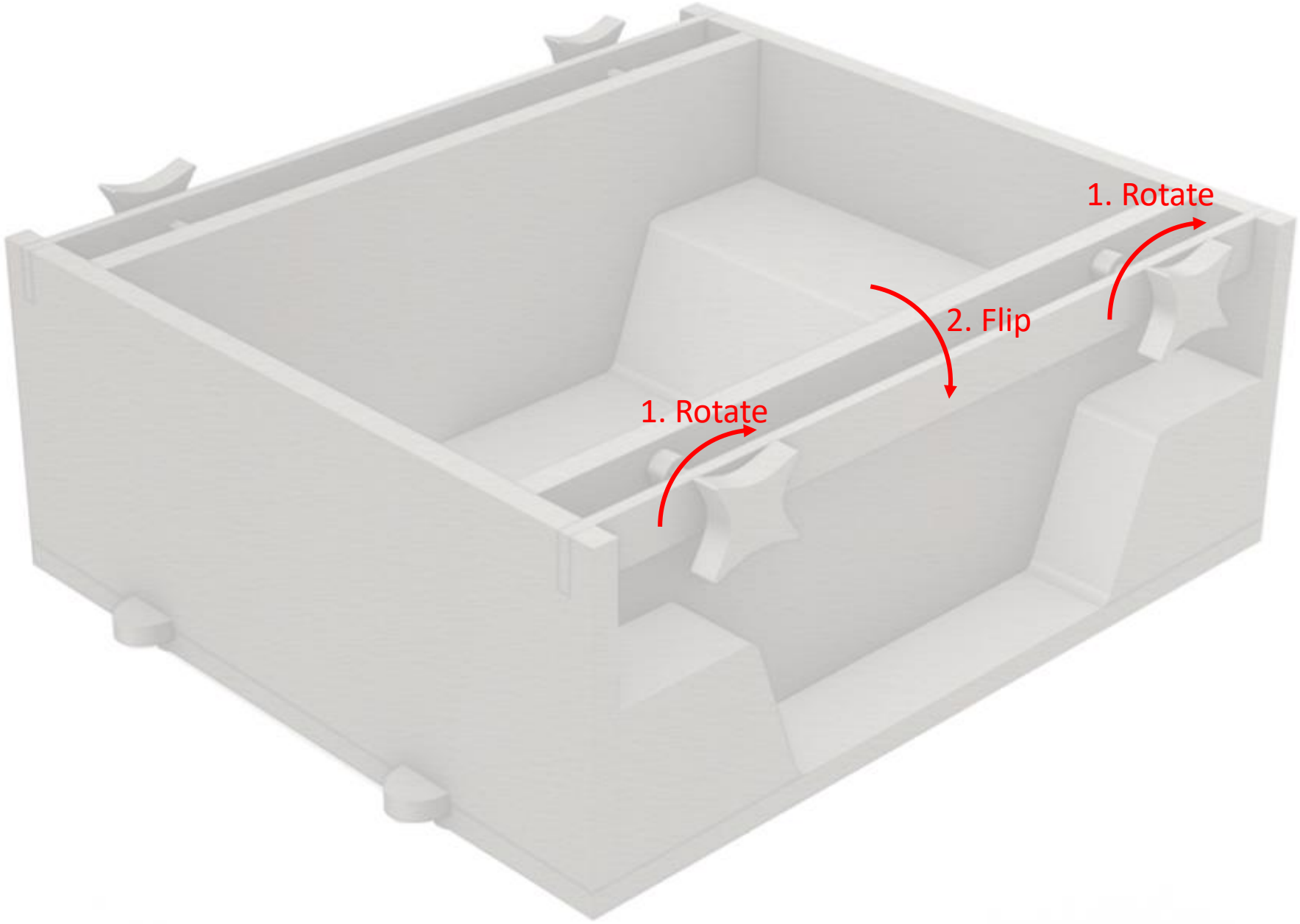
Phase 4

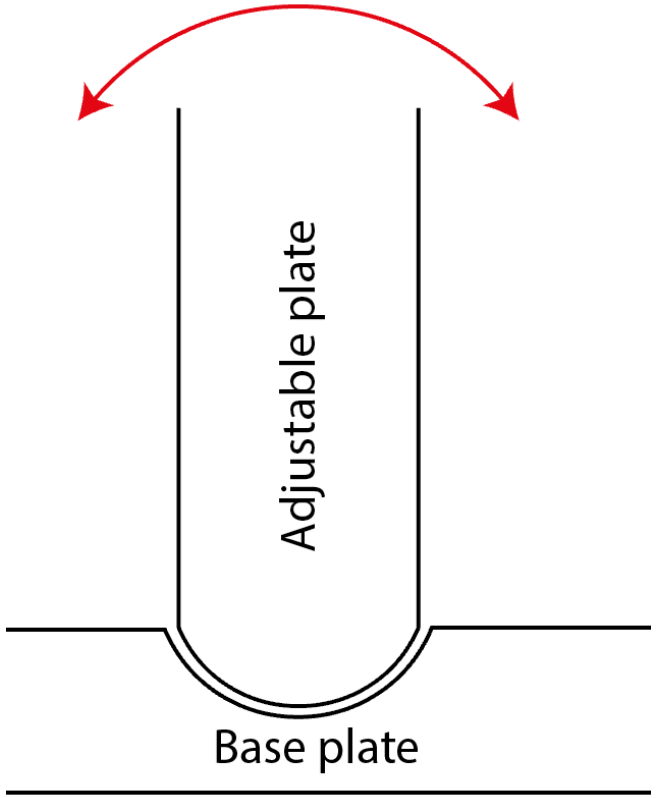
- Place the rails where the adjustable parts are connected with the fixed wall.



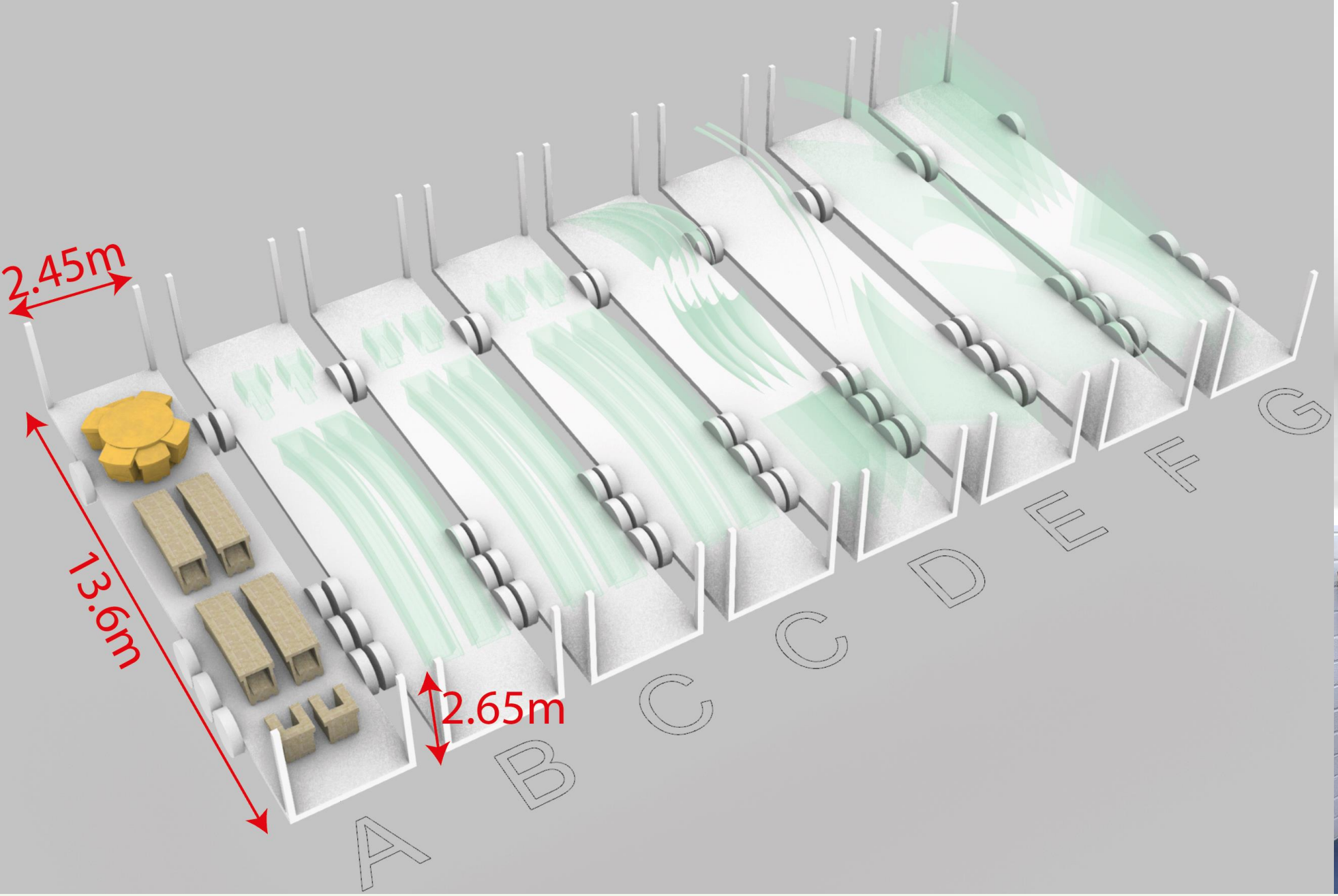
Phase 5

- Install the adjustable wall with the rotating elements on both sides required on the angle of the arch.
- Apply powder in the mould.
- Mould is ready for casting glass.


1. Rotate
2. Flip
1. Rotate


Adjustable plate
Base plate

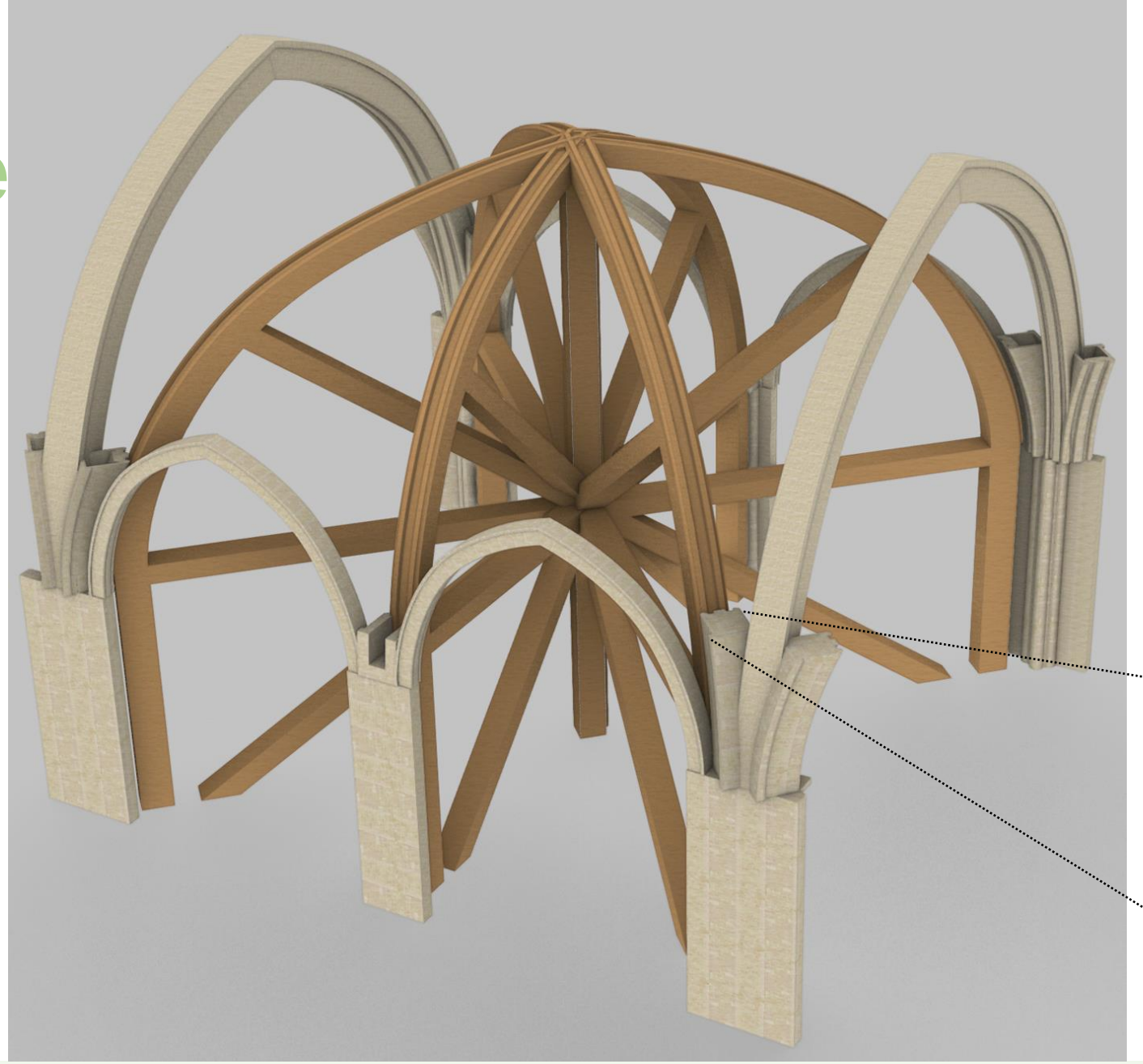
How to transport?

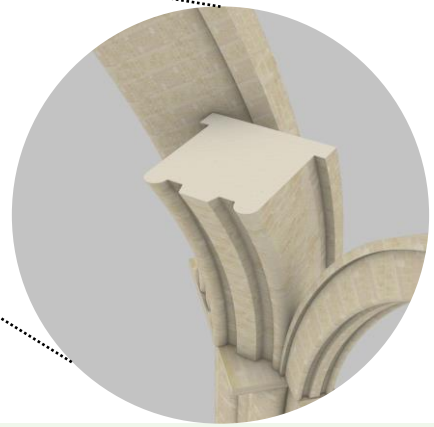

2.45m
13.6m
2.65m
A
B
C
D
E
F
G

How to assemble?

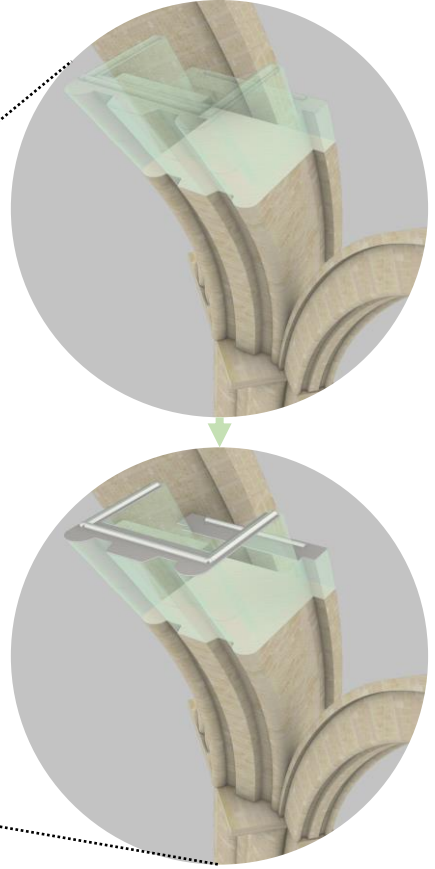
Temp. support

Limestone

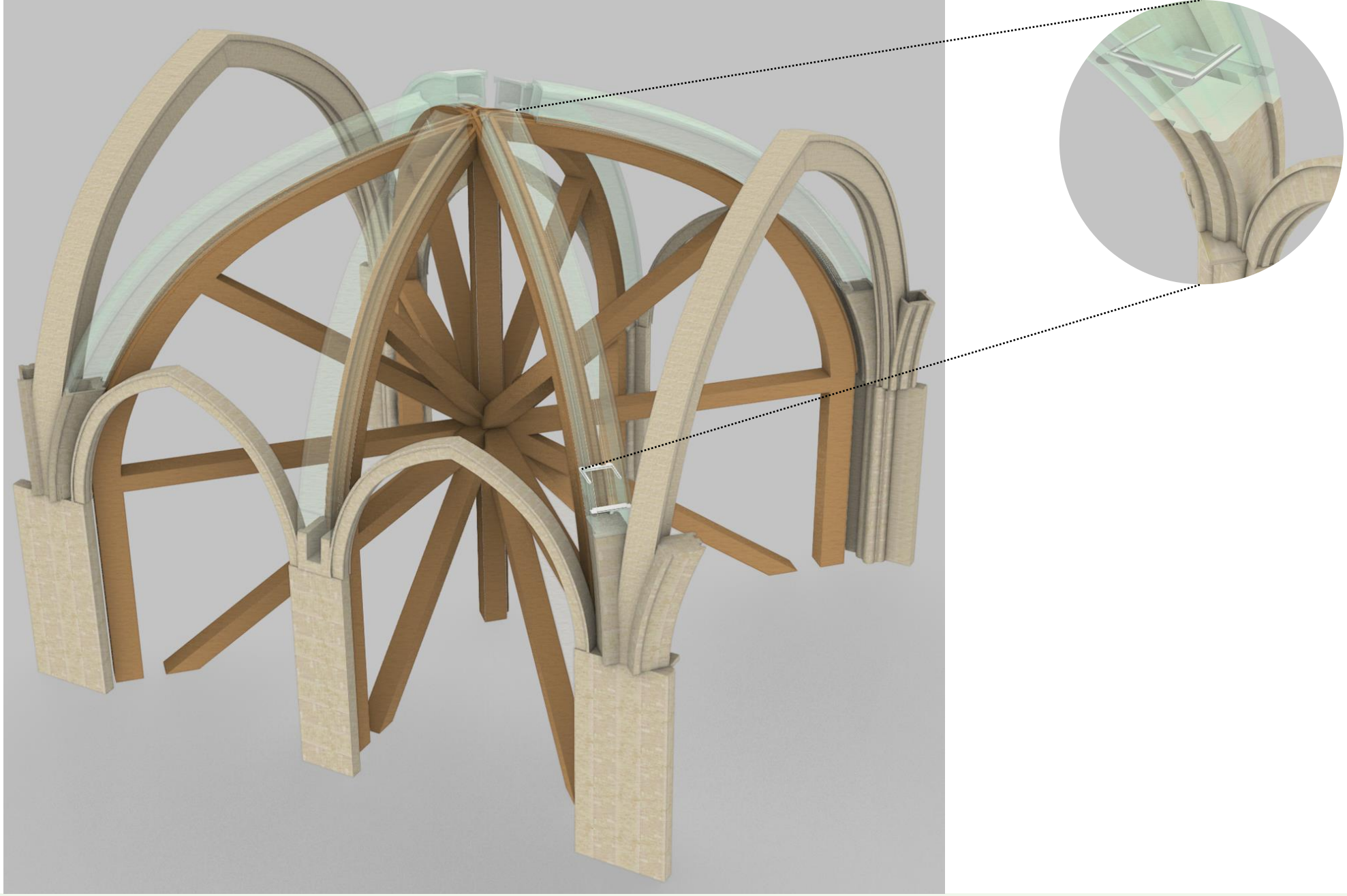




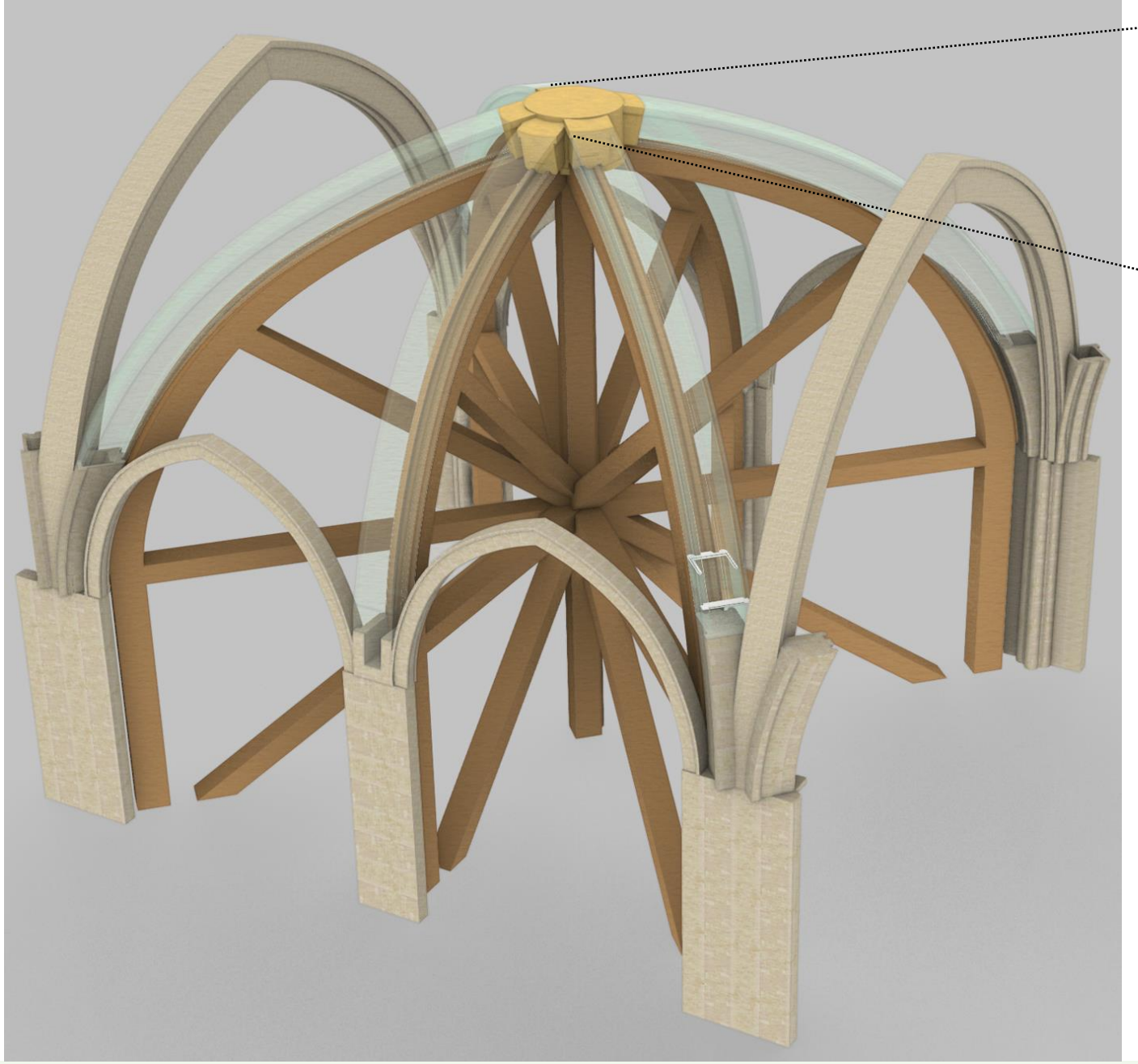
Glass comp. 1

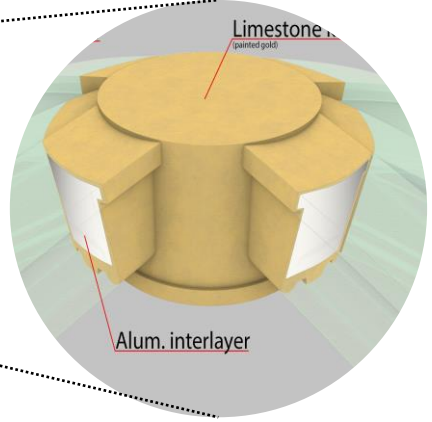


Glass comp. 2

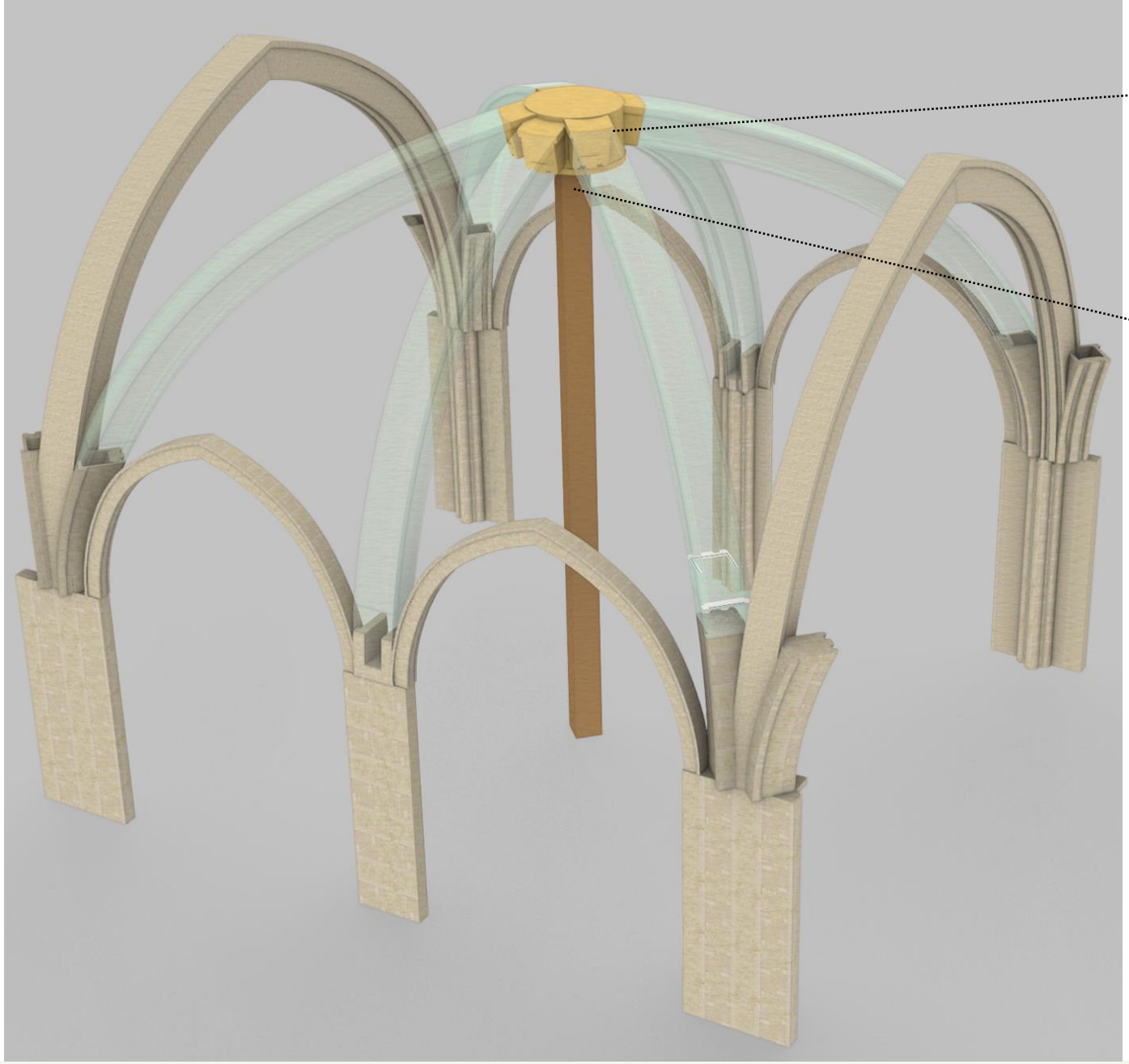


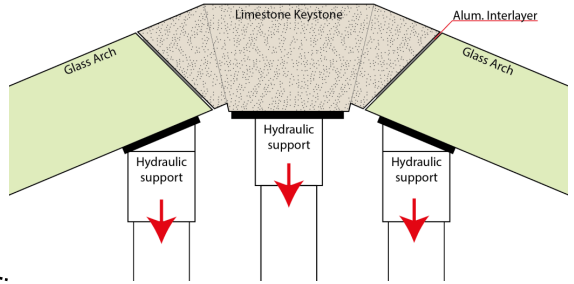
Keystone



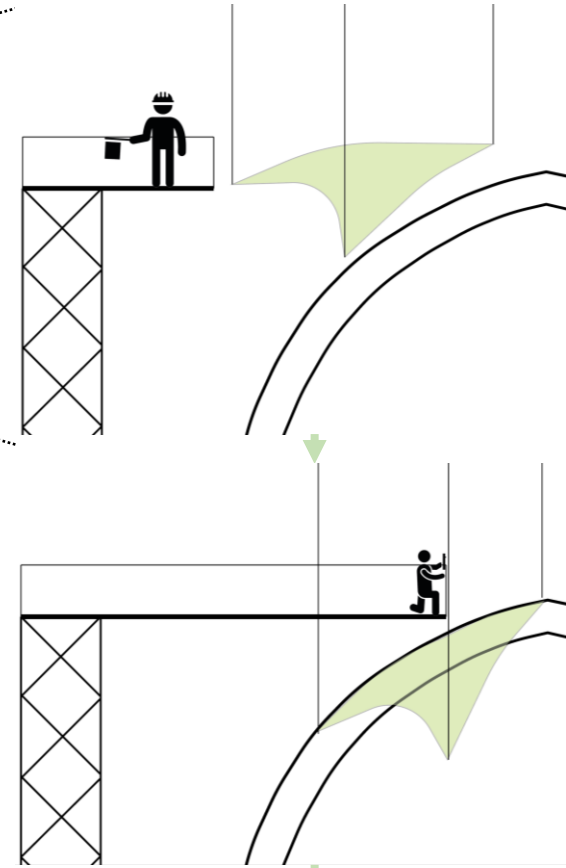


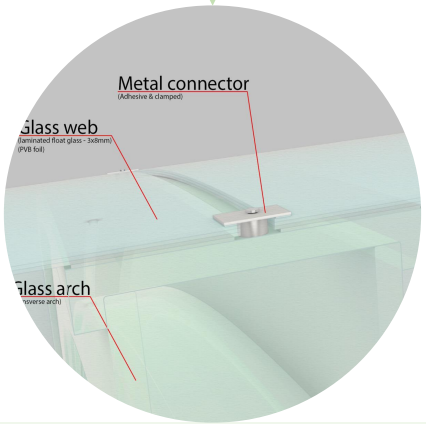
Connect




Limestone Keystone
Alum. Interlayer
Glass Arch
Glass Arch
Hydraulic support
Hydraulic support
Hydraulic support

Web




Metal connector
(Adhesive & clamped)
Glass web
(laminated float glass - 3x8mm)
(PVB foil)
Glass arch

Done

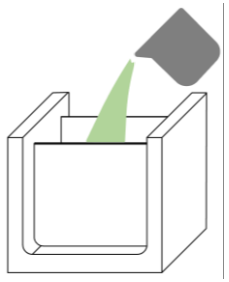
Conclusion

To what extent can a historical masonry arch vault be reconstructed by using cast glass components?

Full cast glass vault structure…

…at what cost?

Complex production



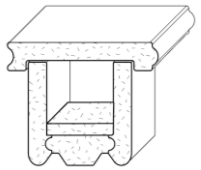
Assembly risks

Labor intensity

Budget

Another option…

Permanent/ temporary



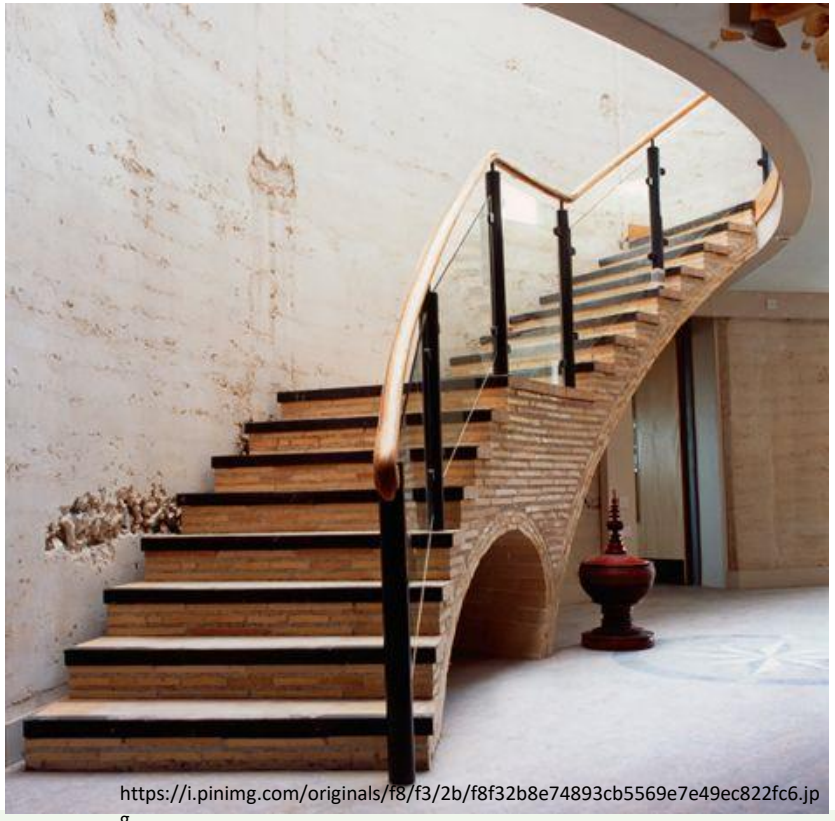
Prefab

Combine materials/ manufacturing process

Mimic patterns

Other applications

https://en.clipdealer.com/photo/media/A:72087141



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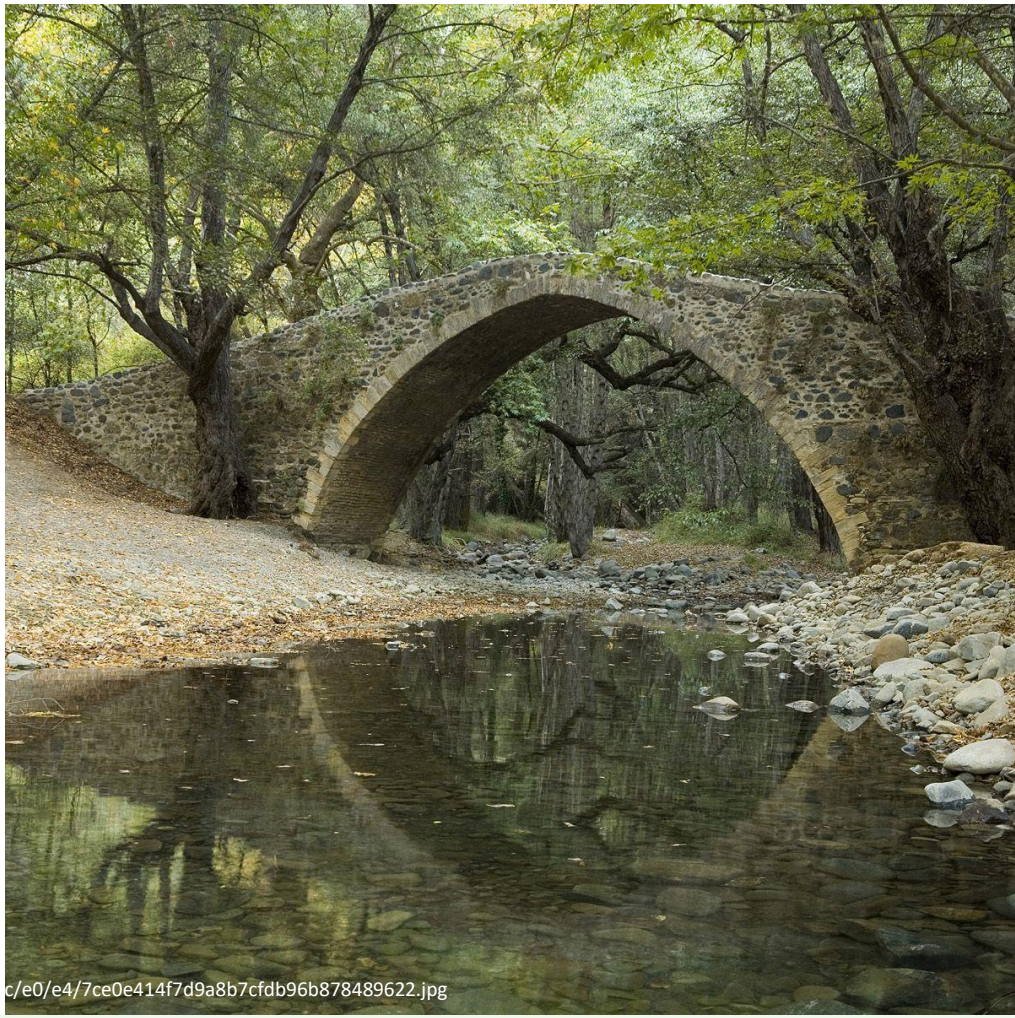


c/e0/e4/7ce0e414f7d9a8b7cfdb96b878489622.jpg

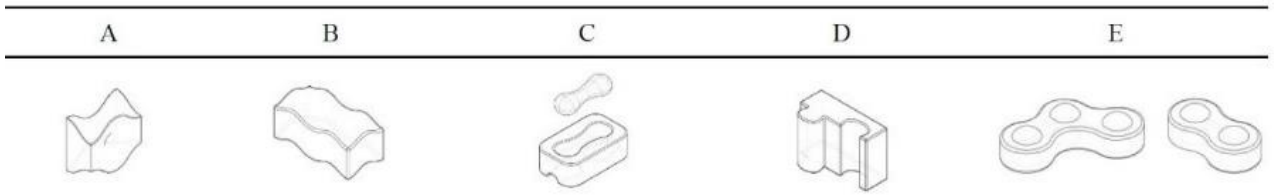
Discussion & Limitations

- Time & Software
  - Interlocking
  - Parametric design
  - Covid-19

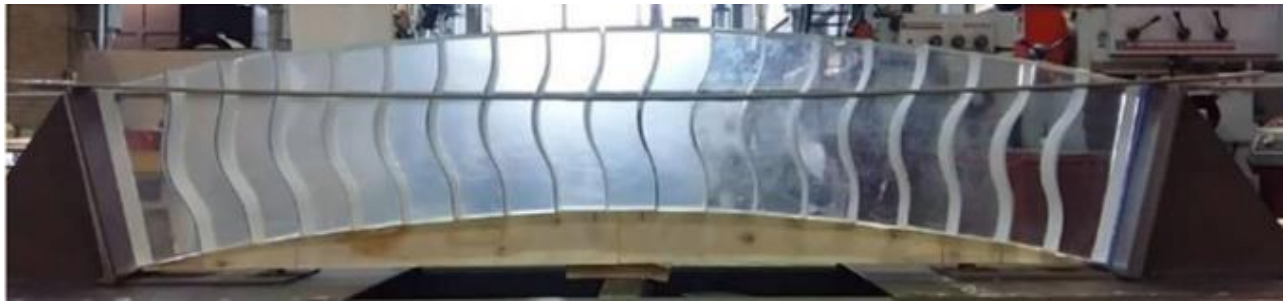
- Future research
  - Interlocking system simulations (different forces)
  - Keystone
  - 3D printed glass for interlocking elements


Thank you

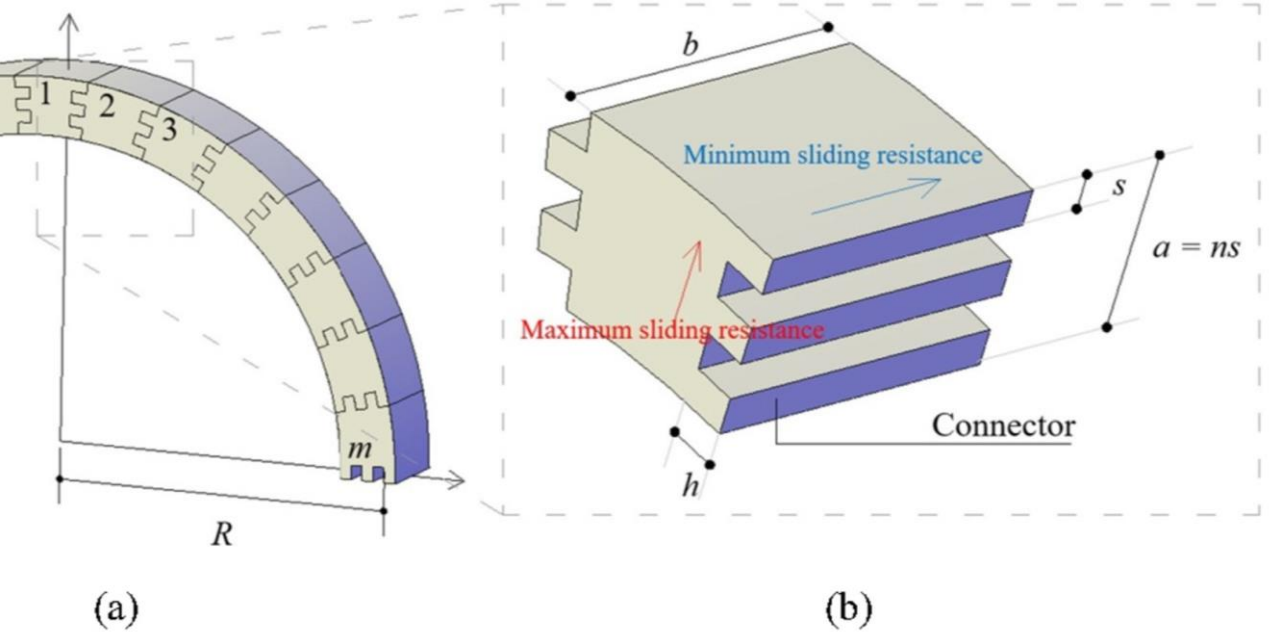
Interlocking



Researched interlocking systems by Oikonomopoulou. Retrieved from Oikonomopoulou (2019).



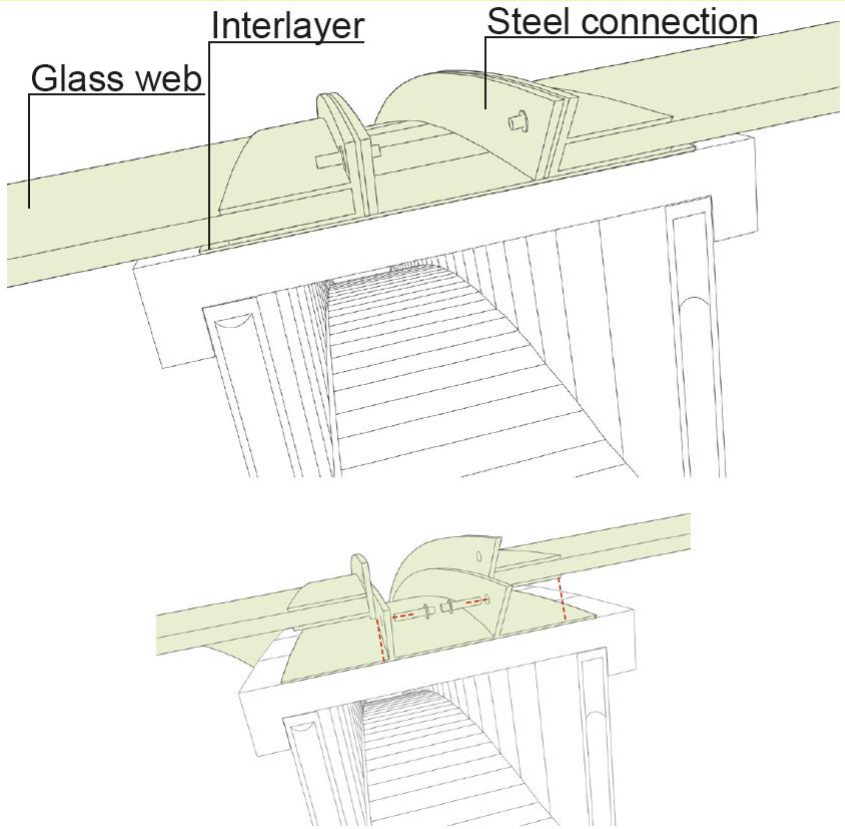
Dry-assembly interlocking glass bridge structure. Retrieved from Aurik, Snijder, Noteboom, Nijsse, & Louter (2018).



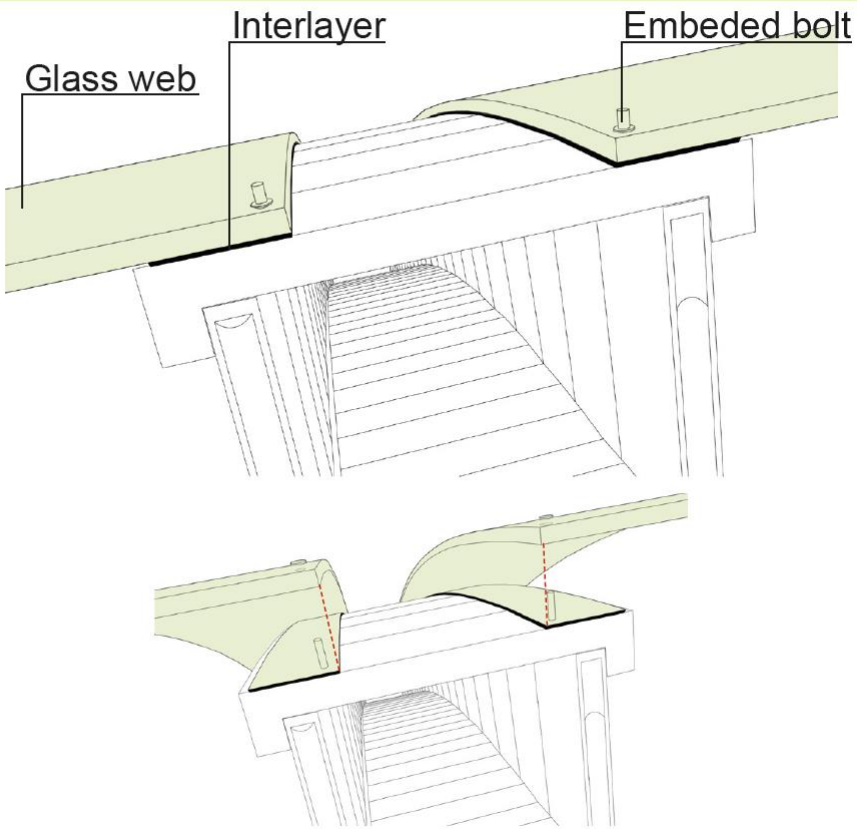
Sliding resistance of an interlocking block in an arch. Retrieved from Casapulla et al (2019).

Height<width

Variant 3 (fixed)



Variant 4 (fixed)



Reference connection of a steel structure.
Retrieved from Architectureartdesign (n.d.).

Reference connection of a bolt.
Retrieved from Trombe (n.d.).

Glass component with interlocking