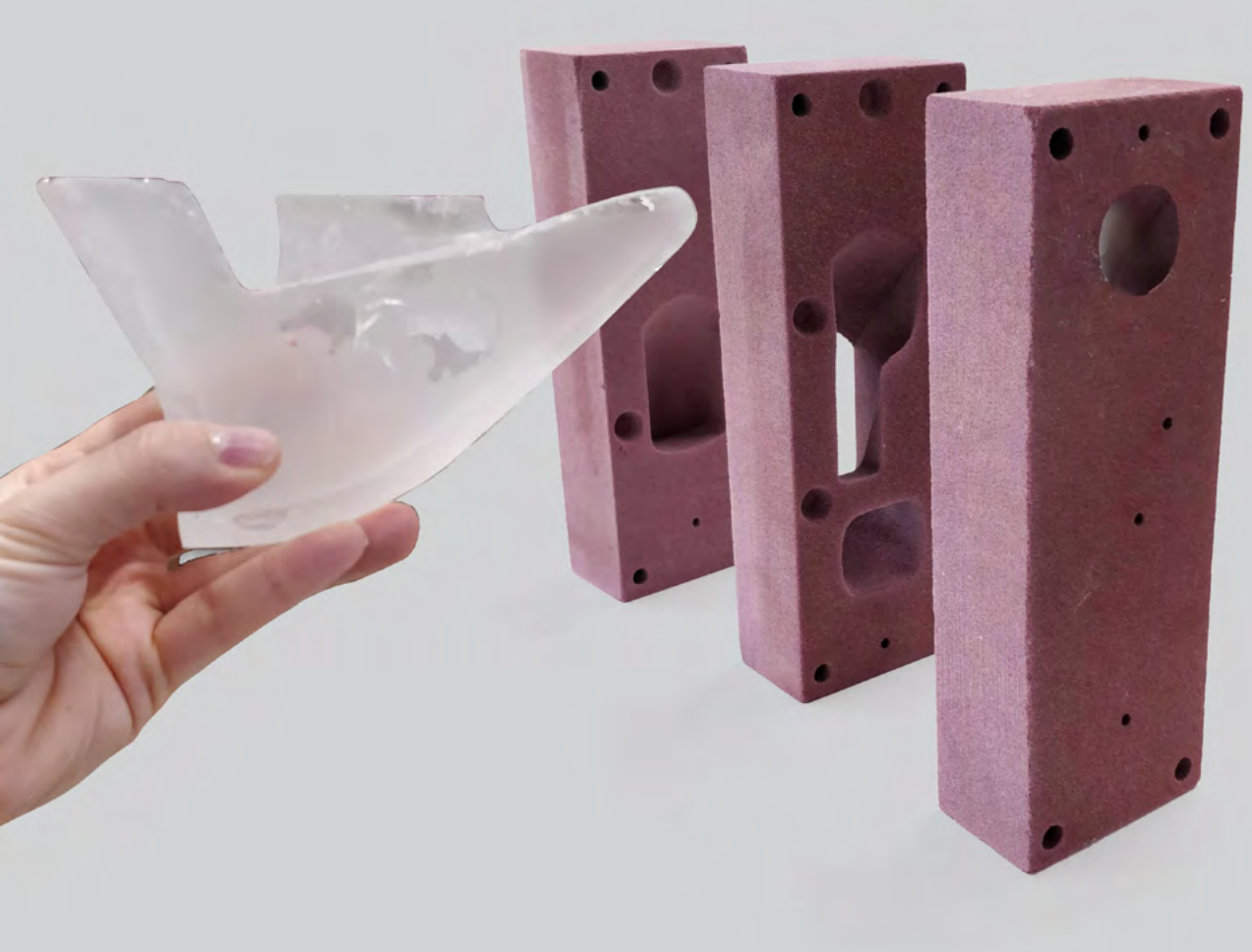


SHAPING TRANSPARENT SAND IN SAND

FABRICATING TOPOLOGICALLY OPTIMIZED CAST GLASS COLUMN USING SAND MOULDS

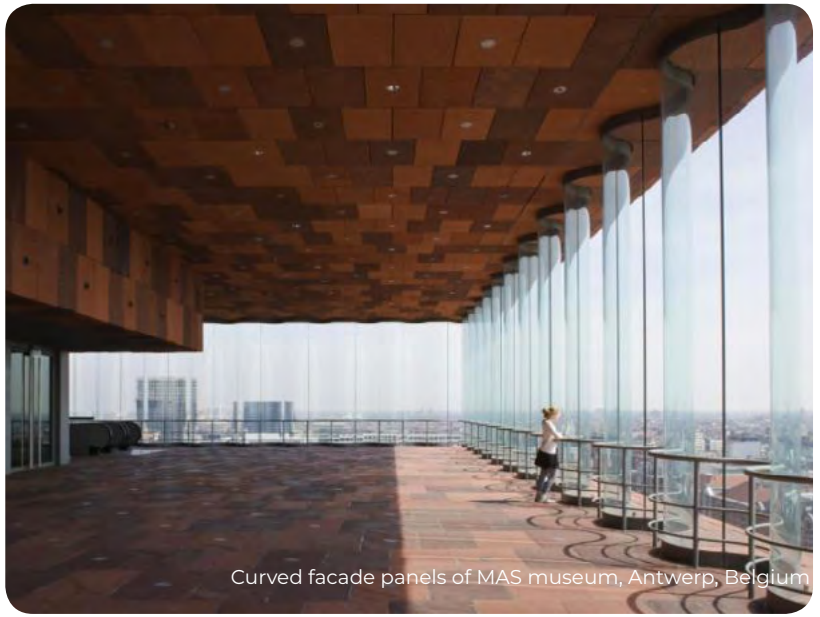
IVNEET SINGH BHATIA | 4724518 | TU DELFT 2018-19

SHAPING TRANSPARENT SAND IN SAND

FABRICATING **TOPOLOGICALLY OPTIMIZED** CAST GLASS COLUMN USING **SAND MOULDS**

IVNEET SINGH BHATIA | 4724518 | TU DELFT 2018-19

Apple store, Shanghai



Curved facade panels of MAS museum, Antwerp, Belgium

Complete glass floor of Hongyagu glass suspension bridge, Hebei, China

Glass roof structure of Van Gogh Museum, Amsterdam

Glass House, Milan

MECHANICAL PROPERTIES

TRANSPARENT

BRITTLE

MECHANICAL PROPERTIES

TRANSPARENT

BRITTLE

HIGH COMPRESSIVE STRENGTH

RESISTANT TO CORROSION

RECYCLABLE

MATERIAL	ULTIMATE STRENGTH (THEORETICAL)	
	Tension (MPa)	**Compression (MPa)**
Aluminum (2014-T6)	469	469
Structural Steel (A36)	400	400
Concrete	5	40
Glass	**>1000**	**>1000**

2 DIMENSIONAL STRUCTURES

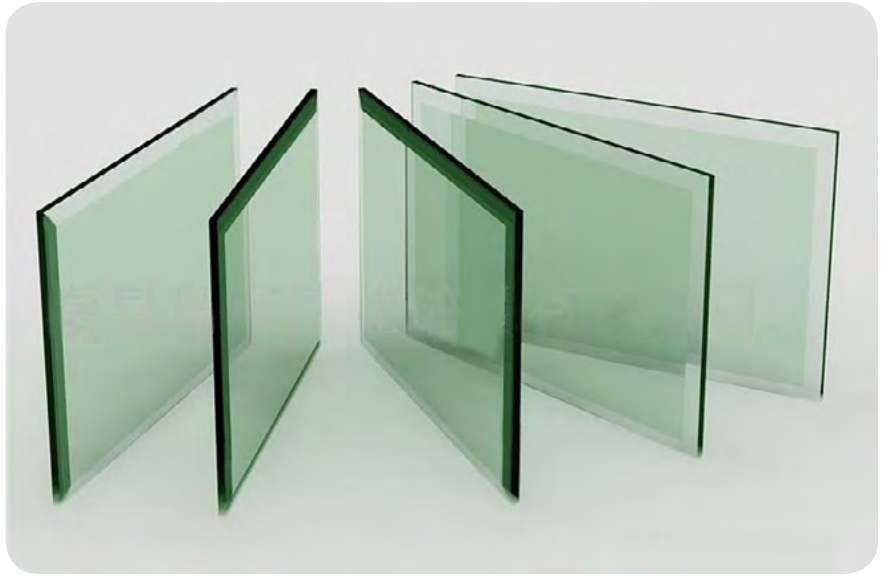

St-Germain-en-Laye in France

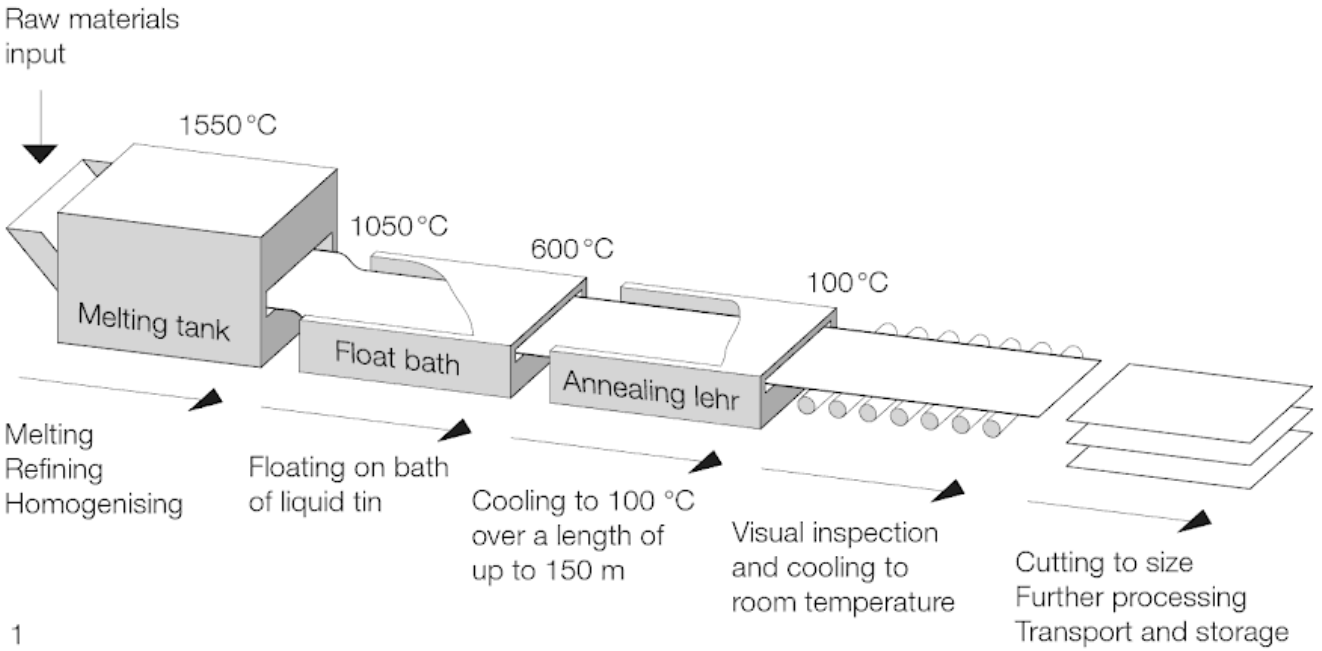

Structural glass solutions by Vision AGI


Apple Showroon, New york


Glass Lift, Netherlands

2 DIMENSIONAL STRUCTURES



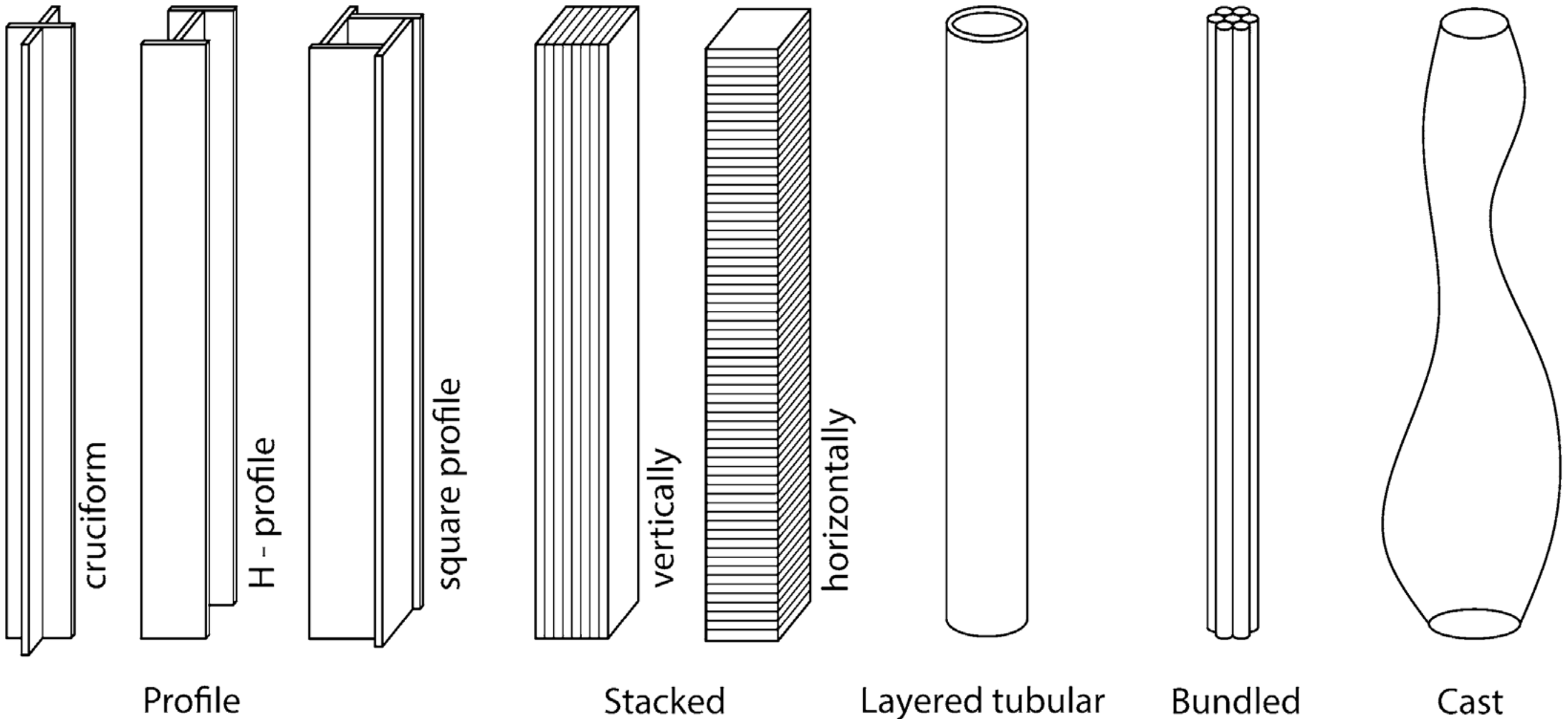


(+) **Less annealing time**

(+) **Standardized Process**

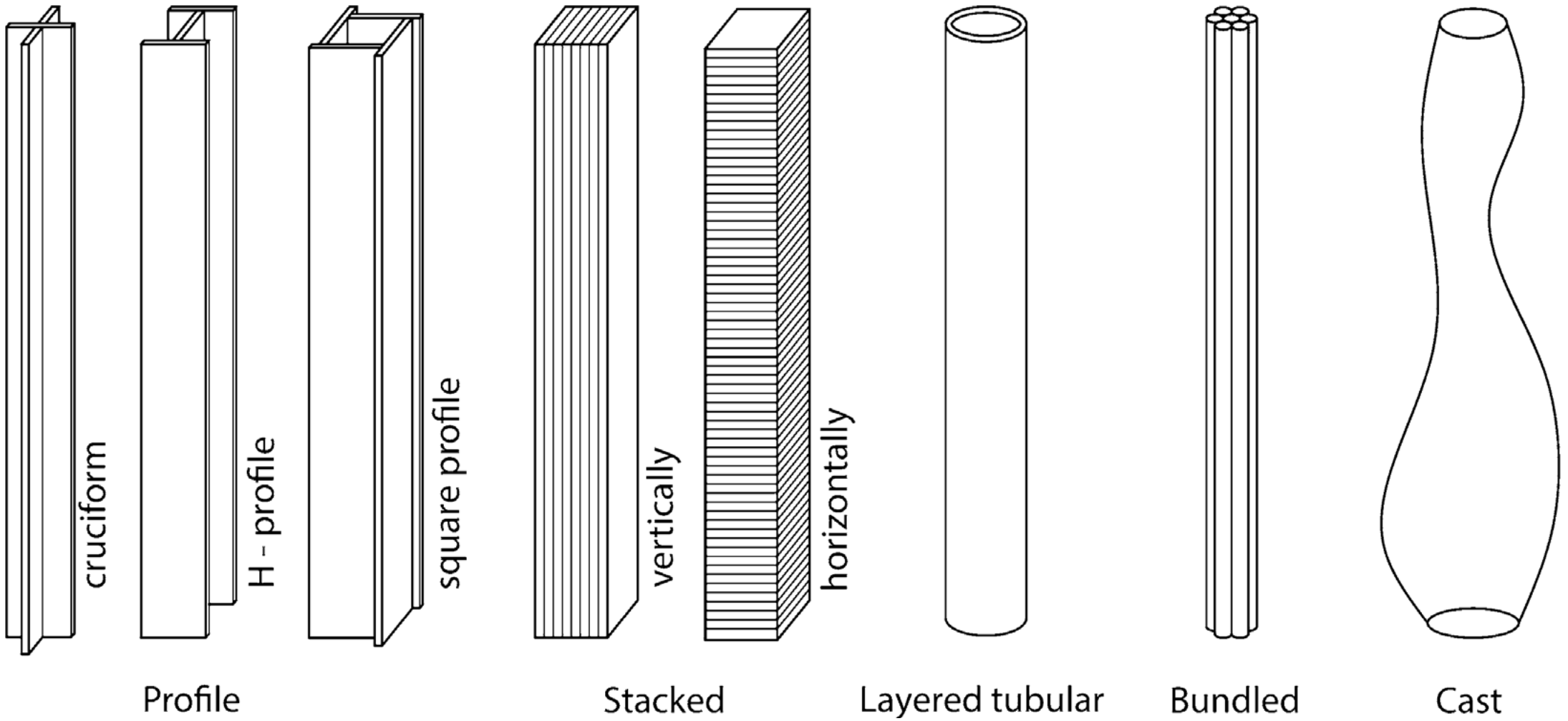
(+) **Ease of Fabrication**

TYPES OF GLASS COLUMNS



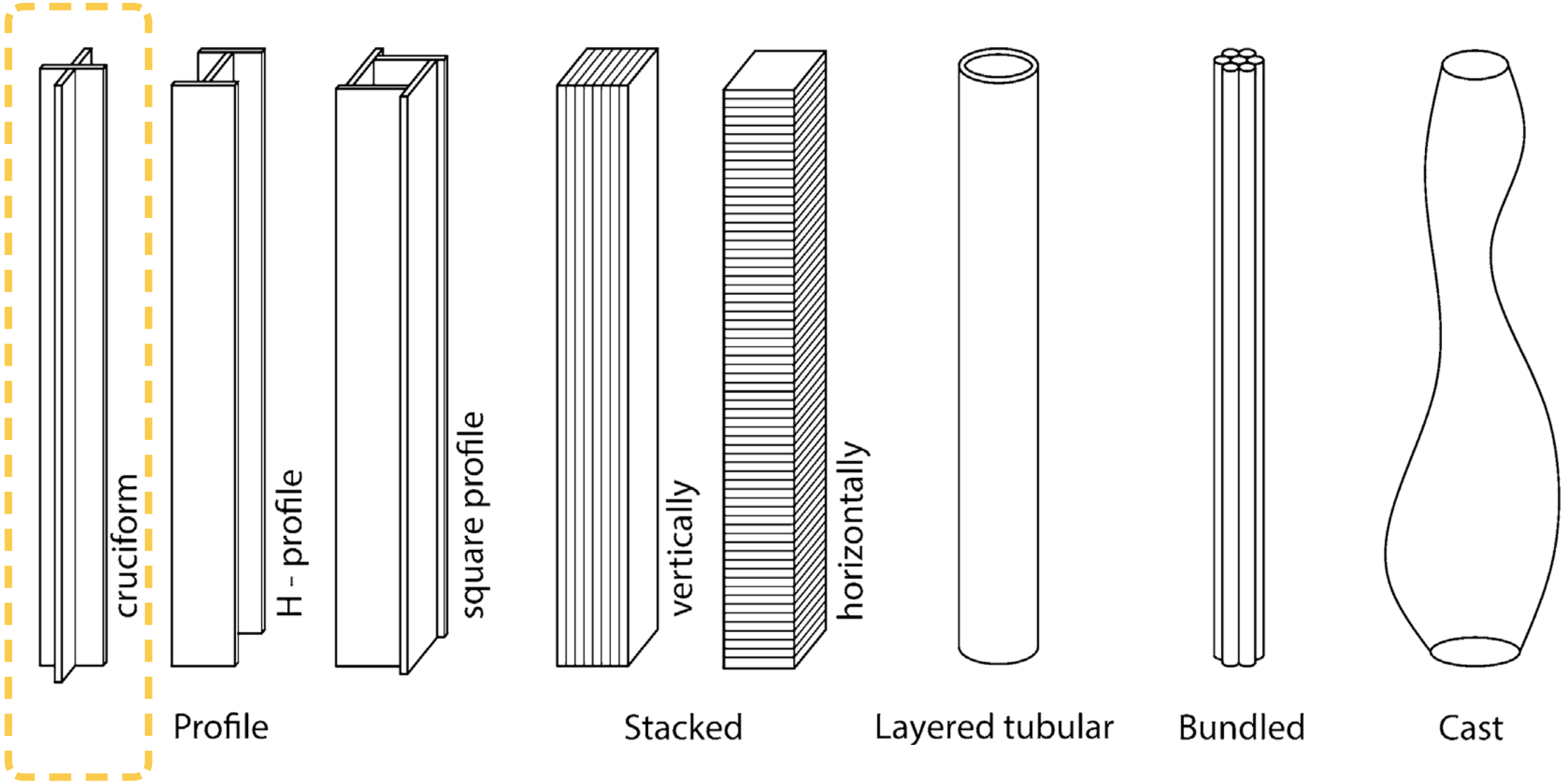
5 different types of columns defined by R. Nijsse & E. ten Brincke

TYPES OF GLASS COLUMNS



FLOAT GLASS | **GLASS EXTRUSION** | **CAST GLASS**

TYPES OF GLASS COLUMNS



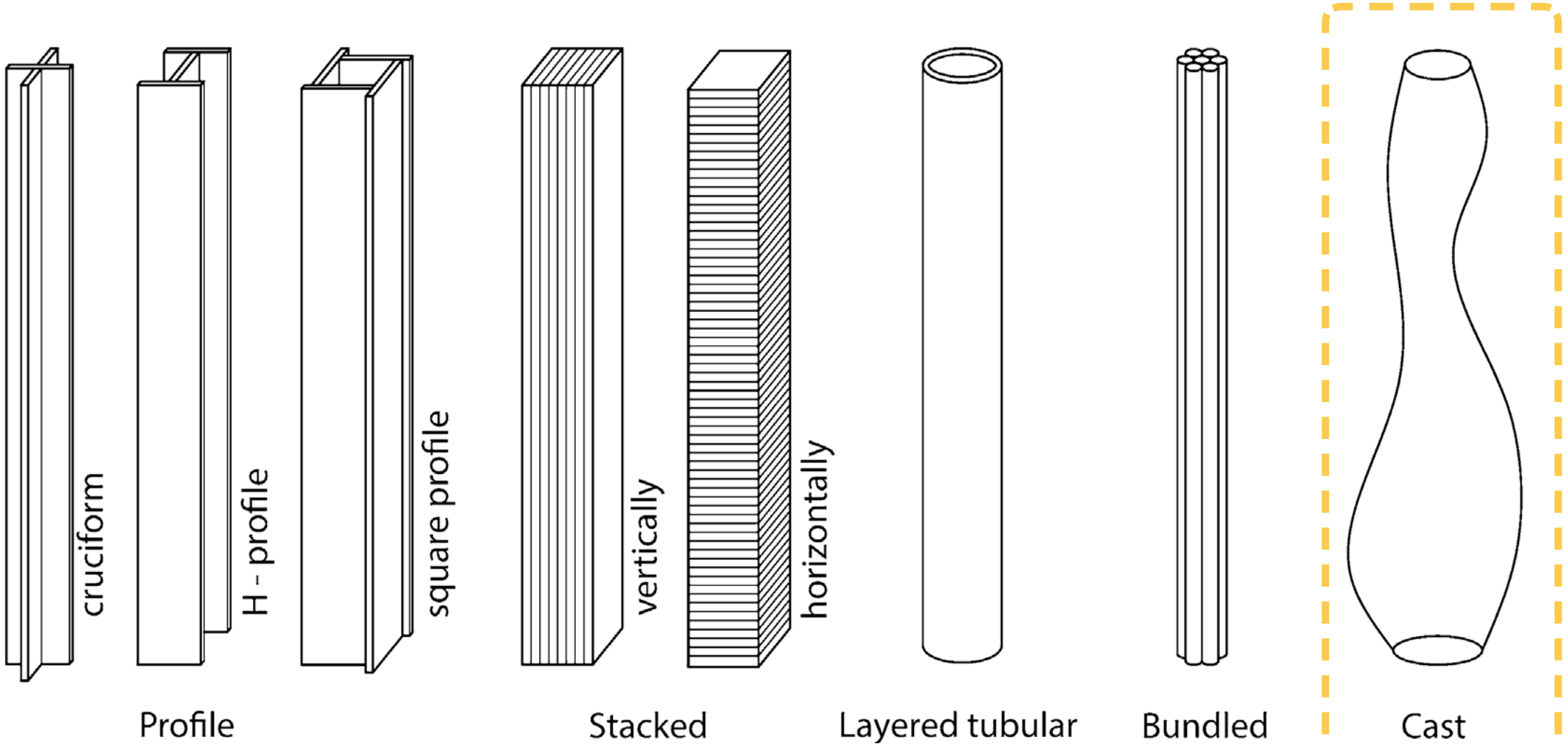
FLOAT GLASS | **GLASS EXTRUSION** | **CAST GLASS**

PROFILED GLASS COLUMNS

Cruciform glass column at Danfoss HQ, Denmark

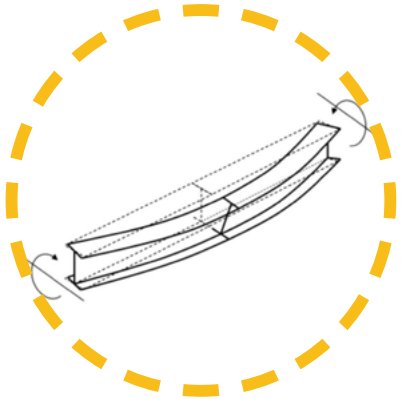
Cruciform glass column at St-Germain-en-Laye in France

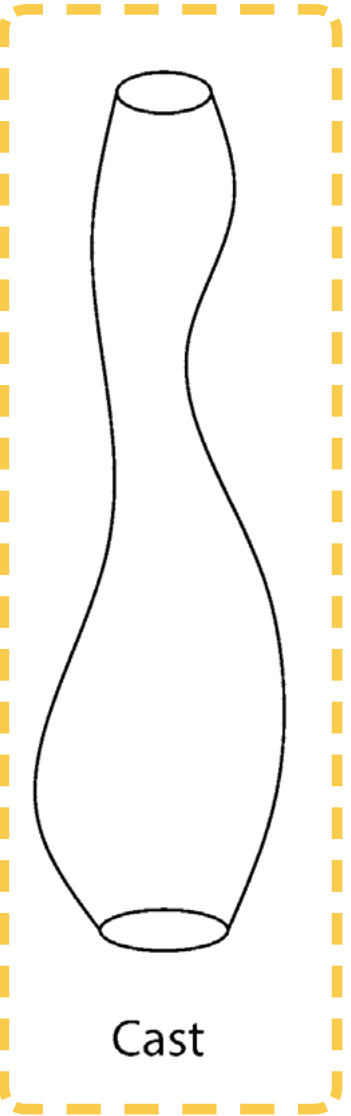
TYPES OF GLASS COLUMNS



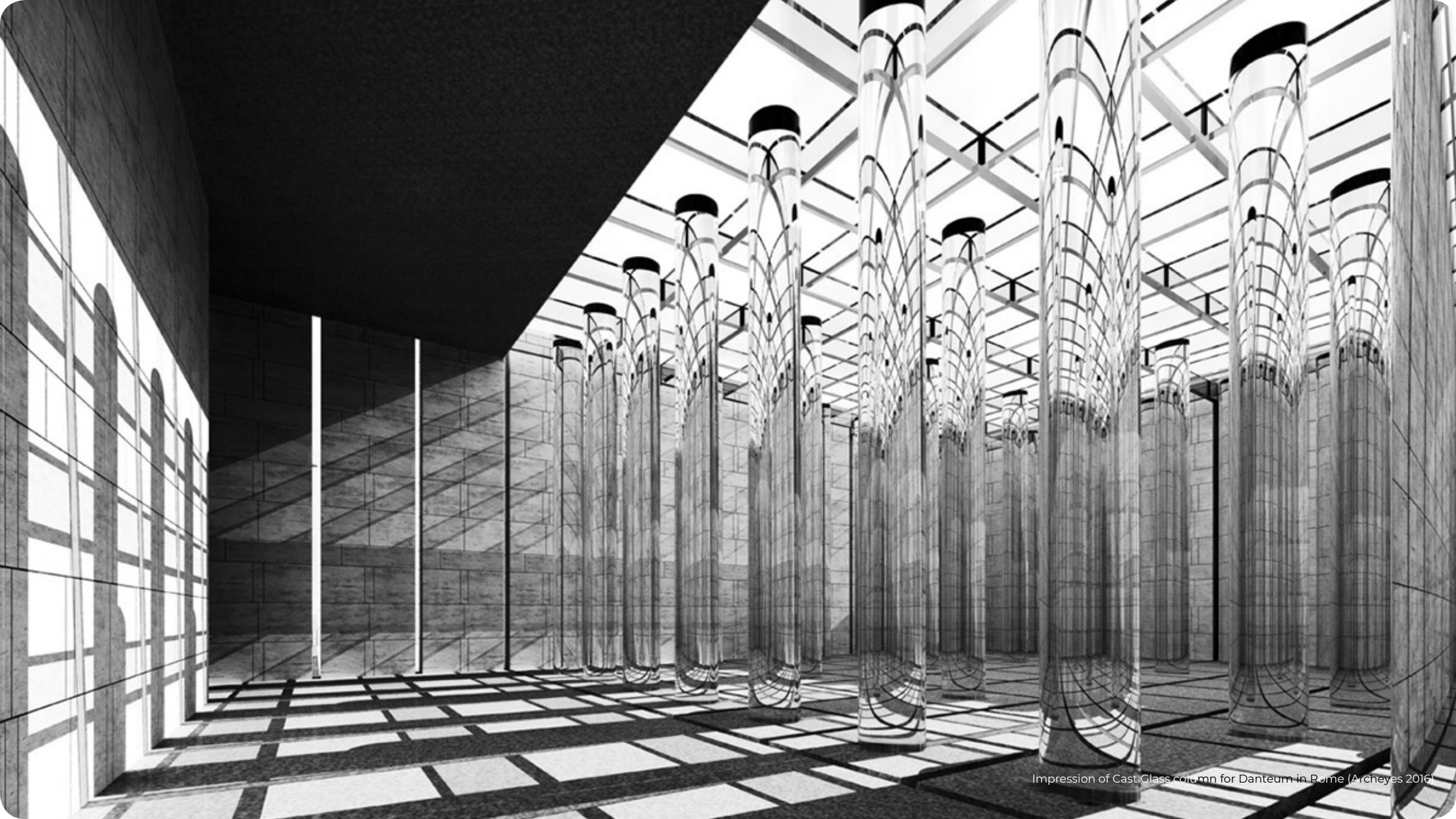
FLOAT GLASS | **GLASS EXTRUSION** | **CAST GLASS**

TYPES OF GLASS COLUMNS





CAST GLASS



Impression of Cast Glass column for Danteum in Rome (Archeyes 2016)

3 DIMENSIONAL STRUCTURES

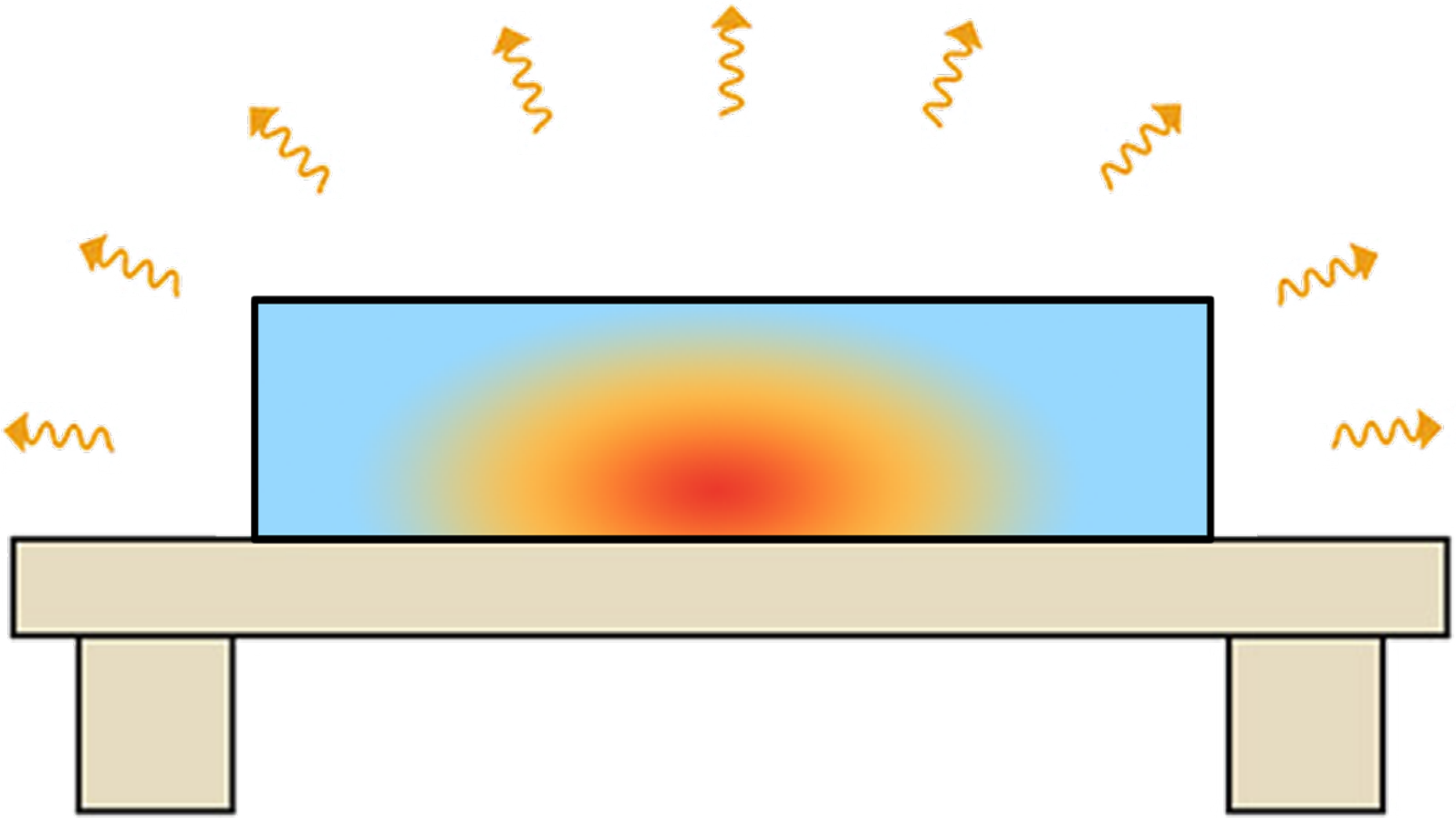

Cast glass brick of Optical House, Japan

Cast glass brick of Optical House, Japan

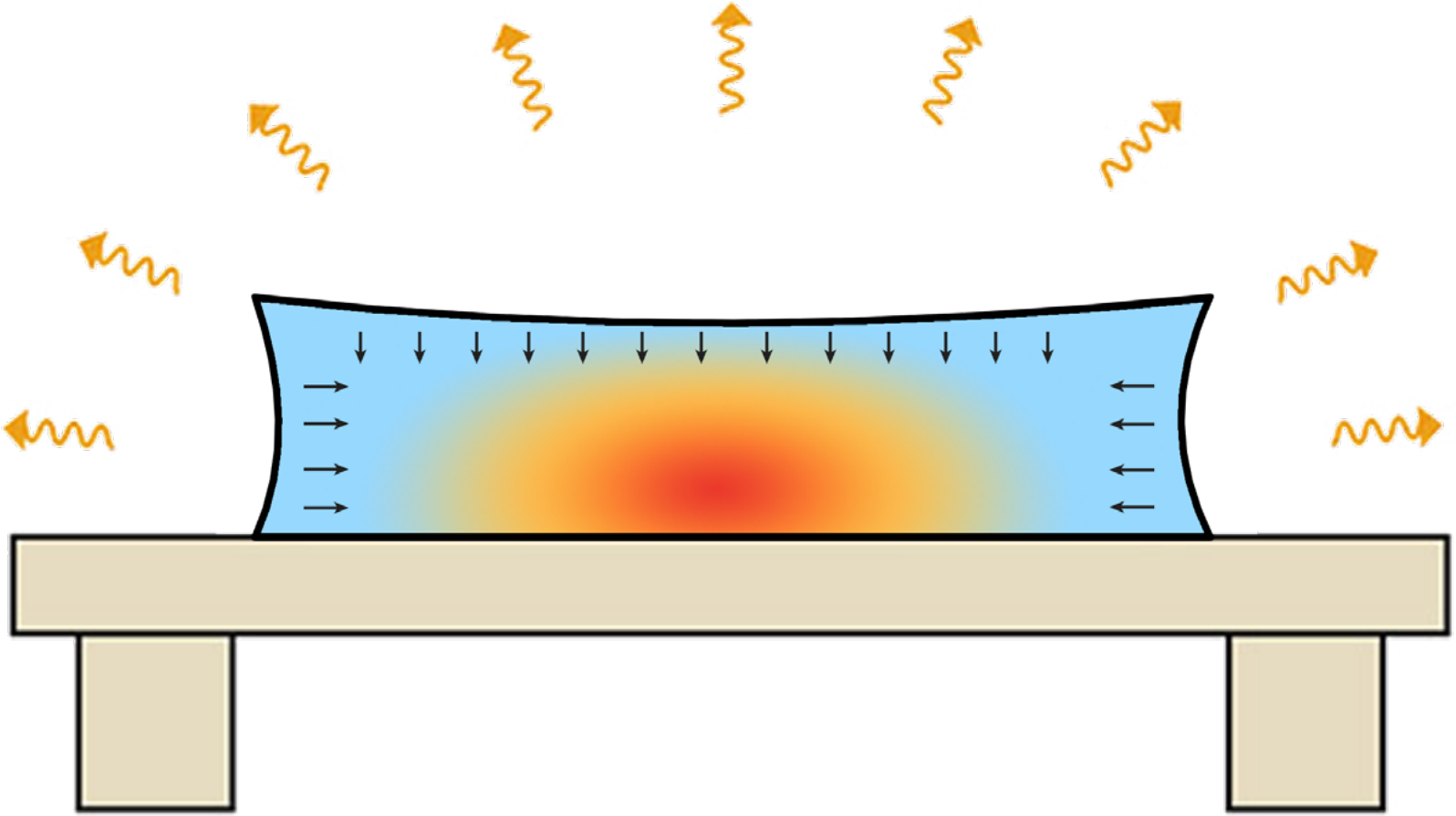

Optical House, Japan

Glass facade of Crystal House, Amsterdam

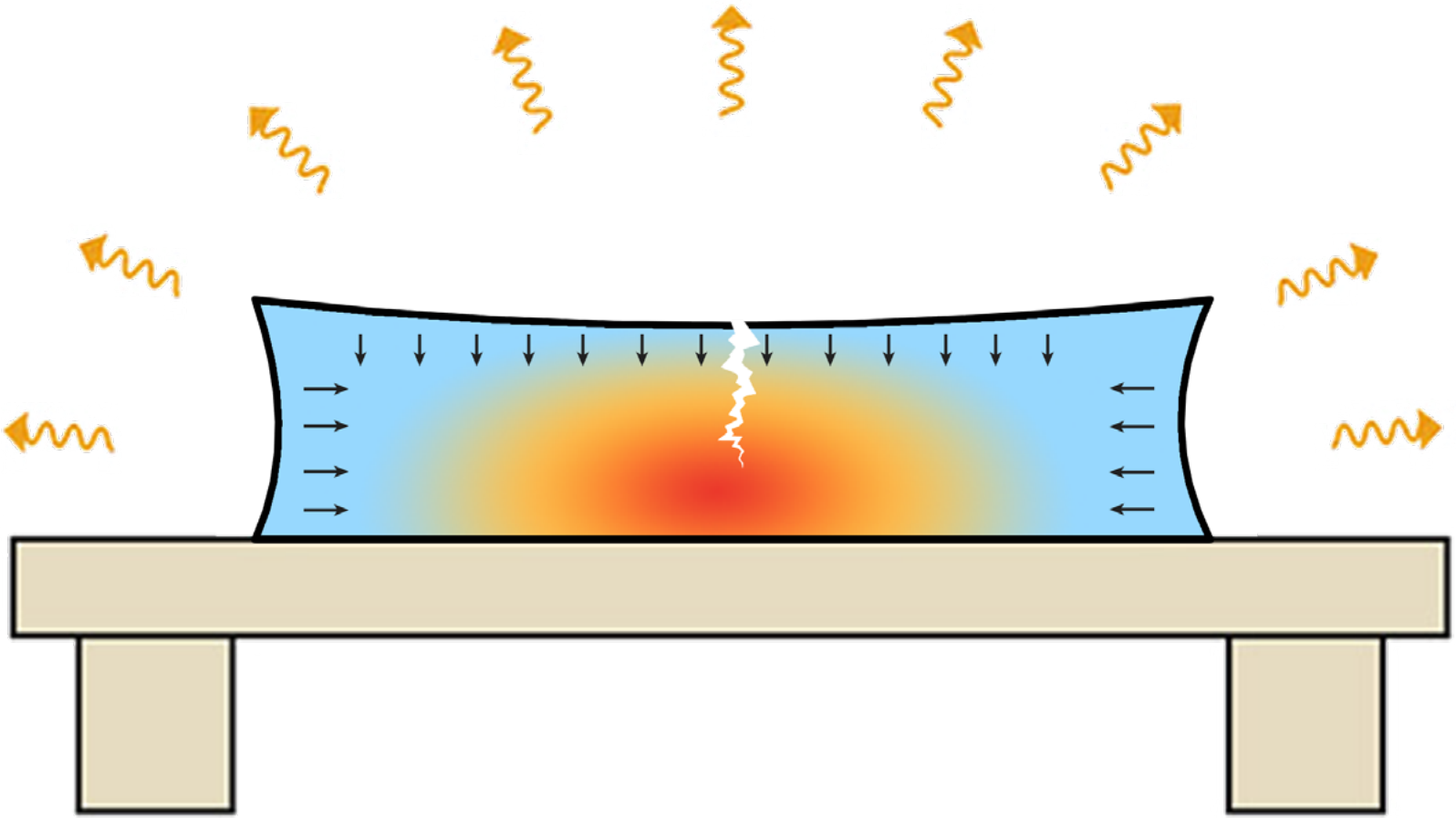
ANNEALING OF GLASS



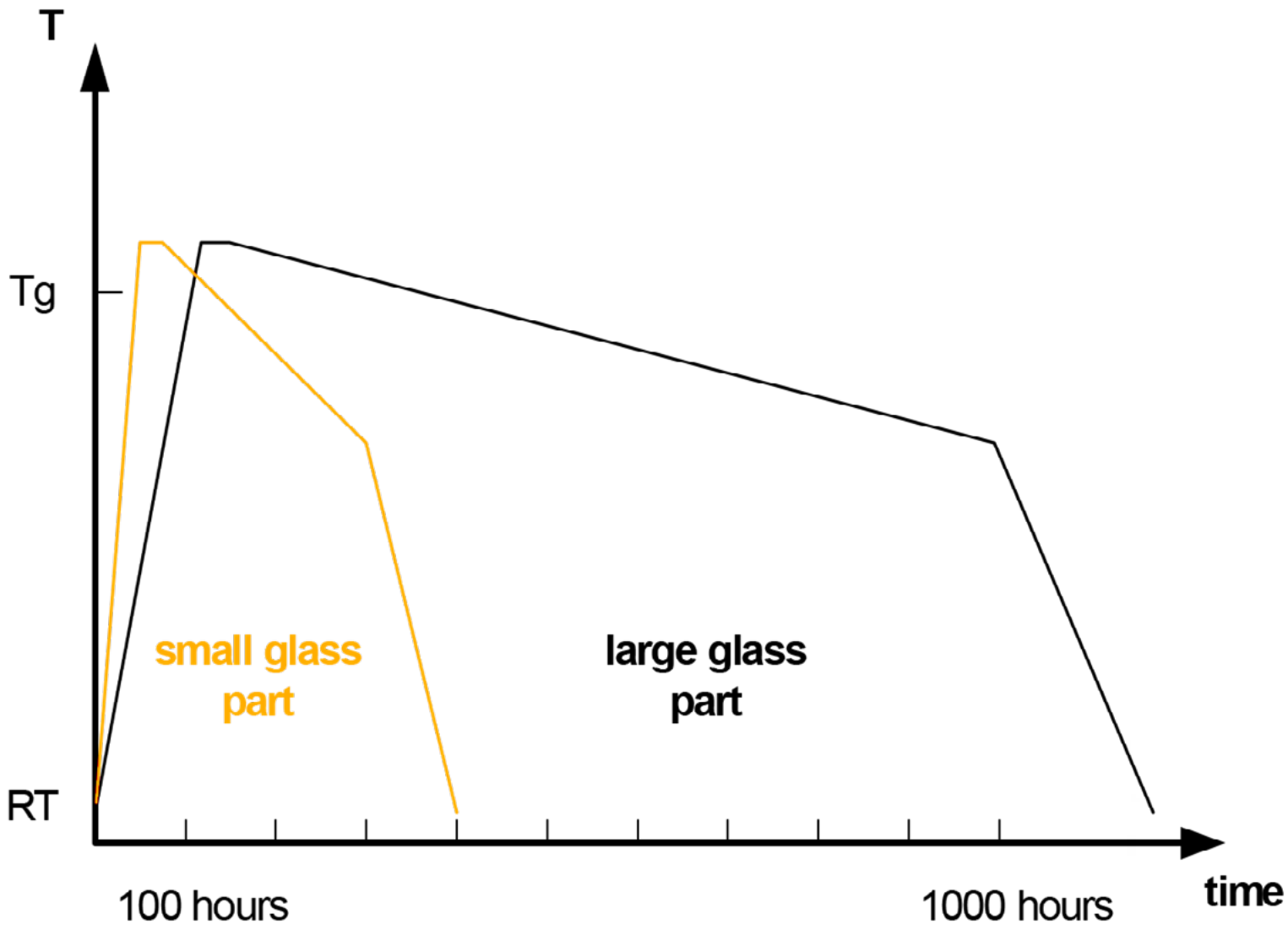
ANNEALING OF GLASS



ANNEALING OF GLASS

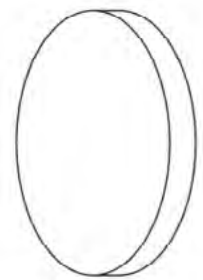


ANNEALING OF GLASS

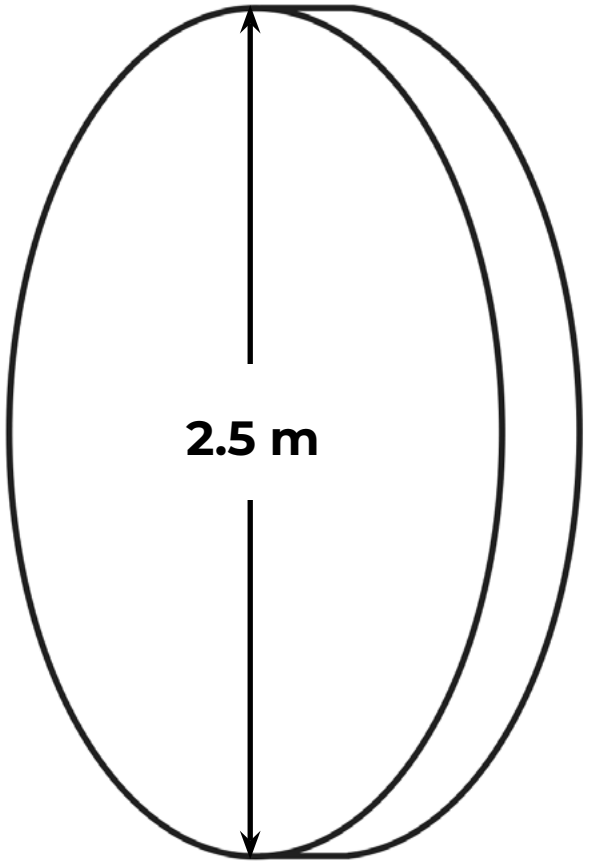


Small v/s Large glass piece in regards to annealing time (SchottAG 2004)

BIGGEST TELESCOPE MIRRORS

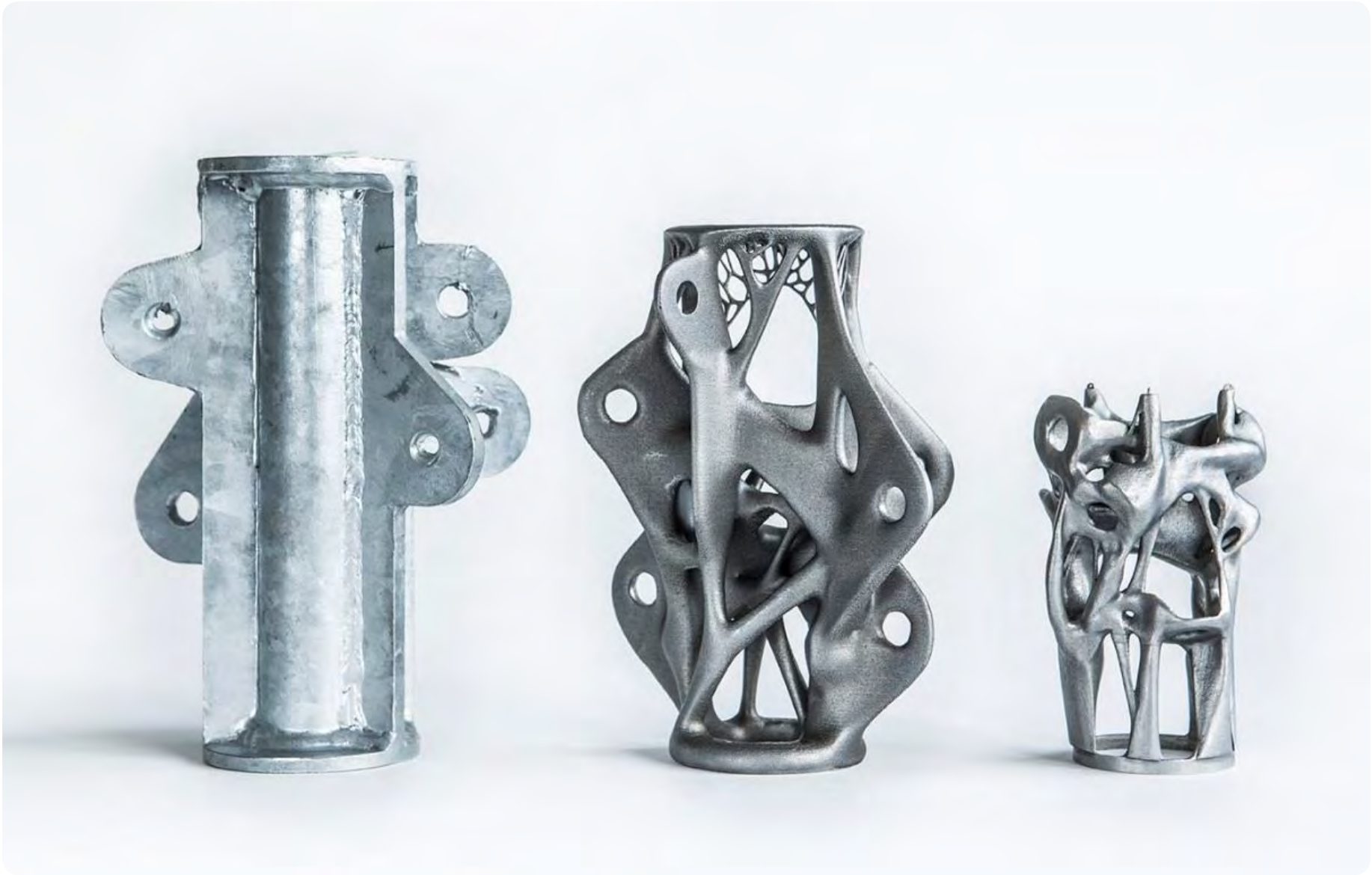


Biggest Solid Blank
2.5 m Diameter
4 tons
12 months



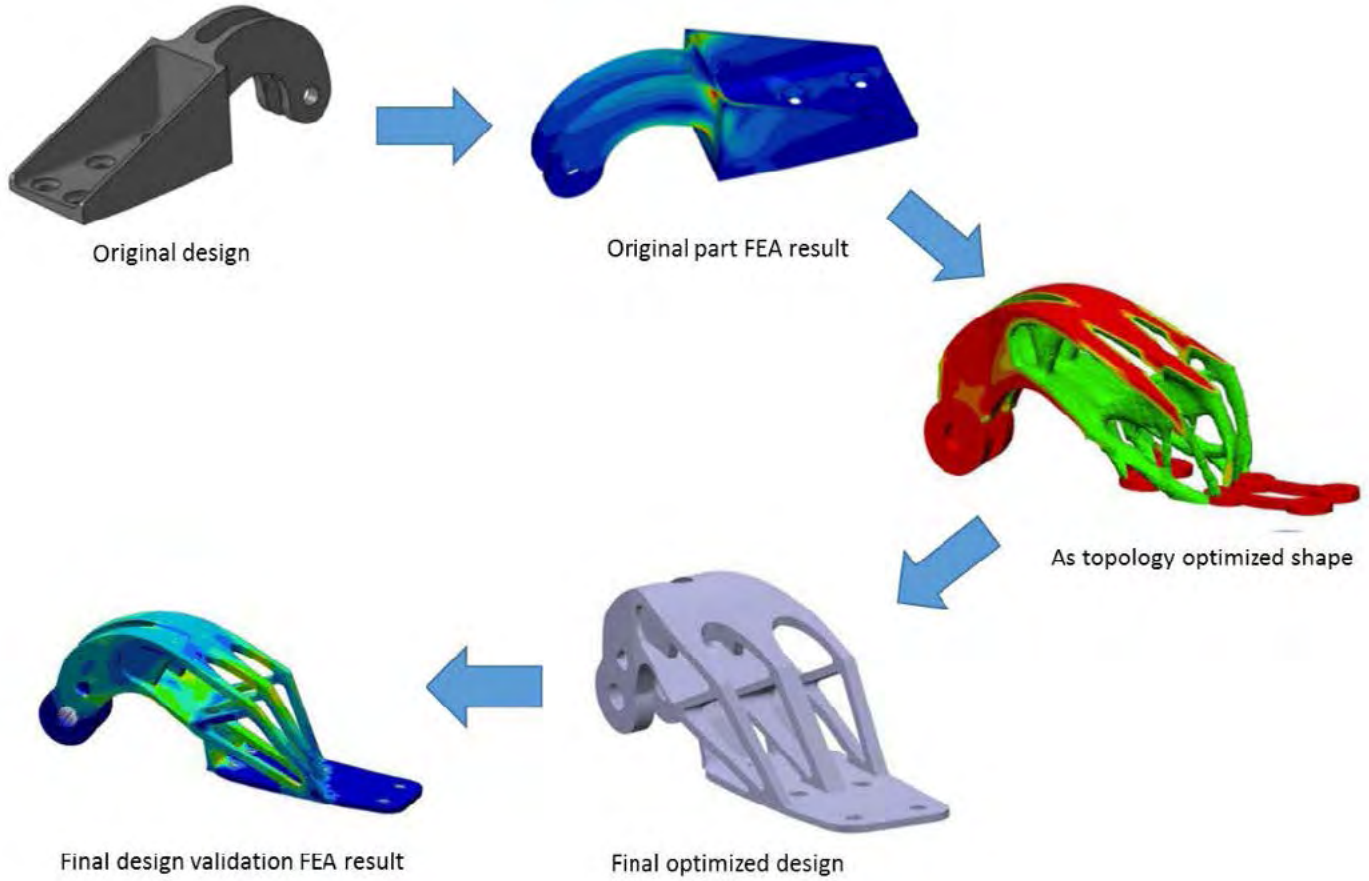
Evolution of the cast mirror blanks in size due to smart geometry and manufacturing process (F. Oikonomopoulou, et al. 2018)

TOPOLOGICAL OPTIMIZATION & EVEN MASS DISTRIBUTION



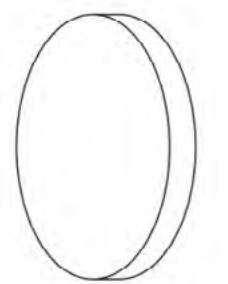
Metal casted node in a 3D printed sand mould designed by Arup (Galjaard 2017)

TOPOLOGICAL OPTIMIZATION PROCESS

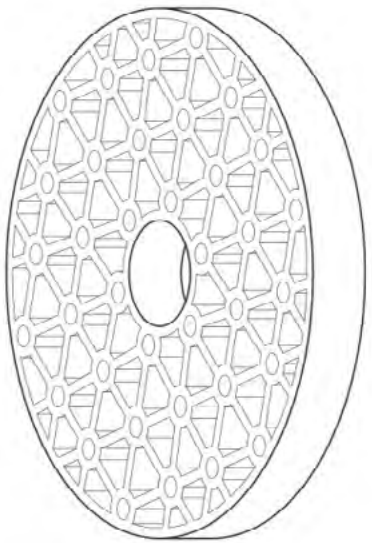


Topological Optimization process by Gebisa & Lemu, 2017

OPTIMIZATION IN TELESCOPE GLASS MIRRORS



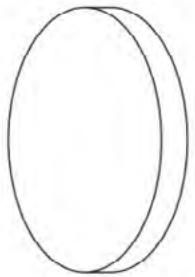
Biggest Solid Blank
2.5 m Diameter
4 tons
12 months



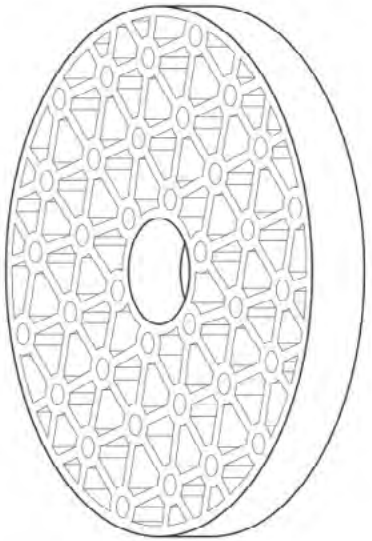
Hale-1 Blank
5 m Diameter
20 tons
10 months

Evolution of the cast mirror blanks in size due to smart geometry and manufacturing process (F. Oikonomopoulou, et al. 2018)

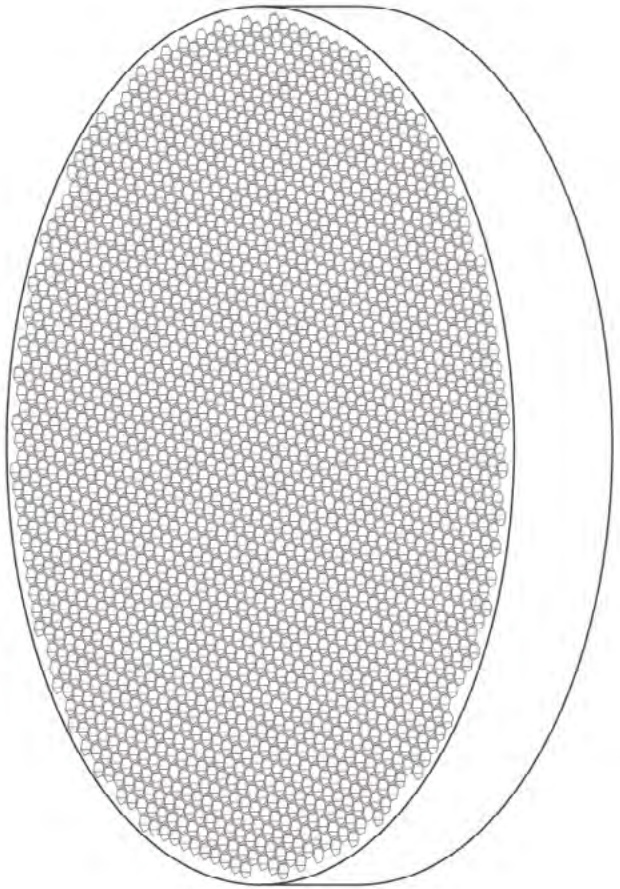
OPTIMIZATION IN TELESCOPE GLASS MIRRORS



Biggest Solid Blank
2.5 m Diameter
4 tons
12 months



Hale-1 Blank
5 m Diameter
20 tons
10 months

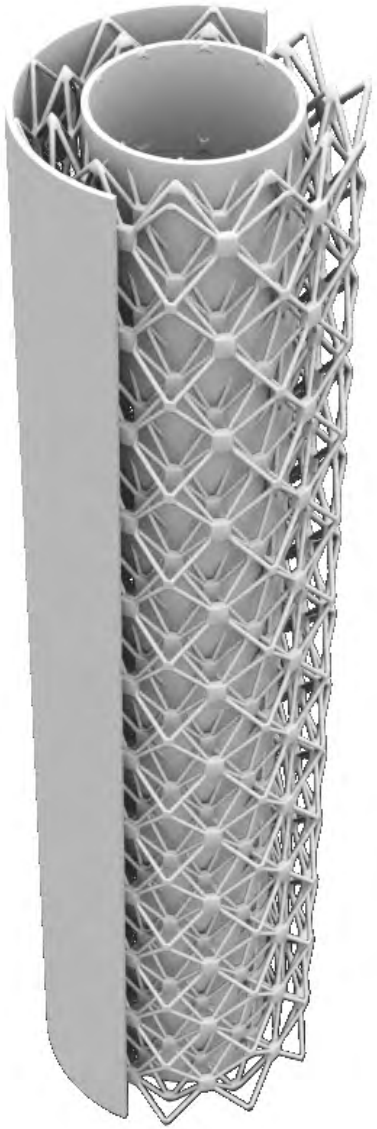


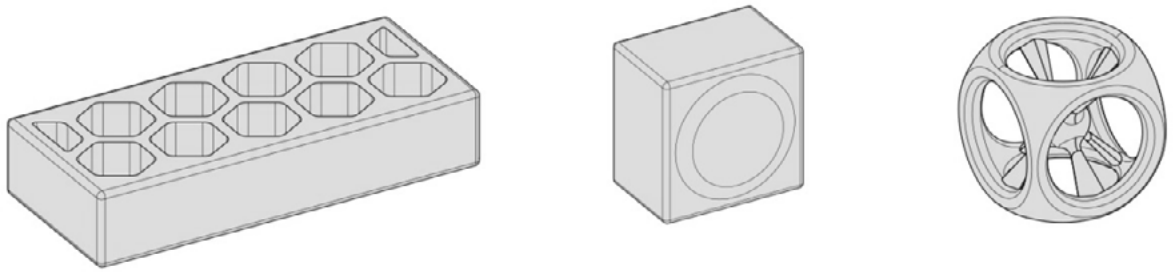
Giant Magellan Blank
8.4 m Diameter
16 tons
3 months

Evolution of the cast mirror blanks in size due to smart geometry and manufacturing process (F. Oikonomopoulou, et al. 2018)

OPTIMIZATION IN TELESCOPE GLASS MIRRORS

OPTIMIZED GLASS COLUMN GEOMETRIES



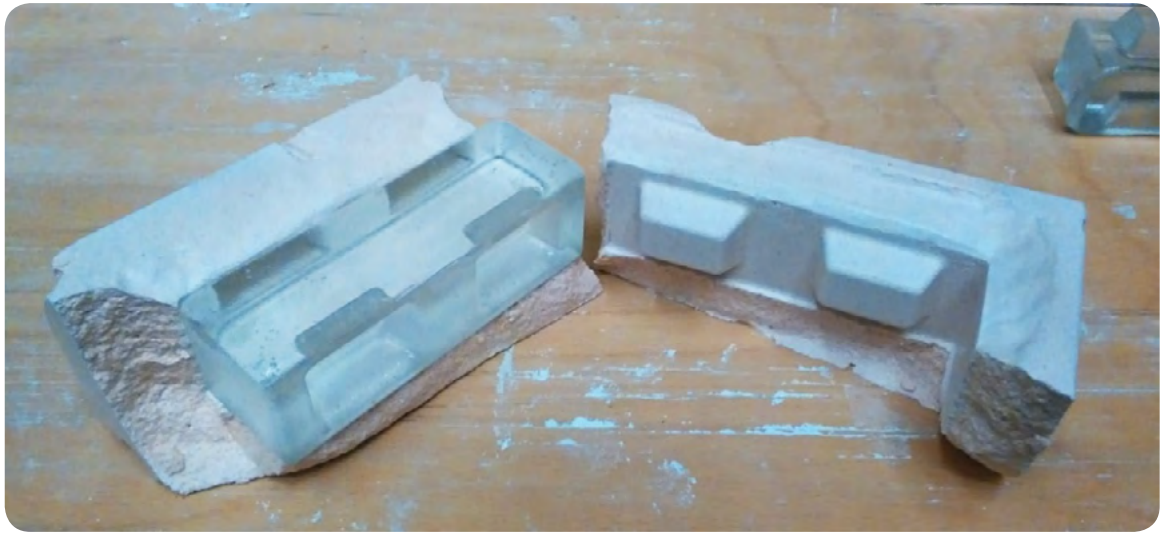


(F. Oikonomopoulou, et al. 2018)

TYPES OF CASTING MOULDS

1. DISPOSABLE

Made of cheaper materials -Silica Plaster and Alumina-silica fiber.



2. PERMANENT

Made of more durable expensive material- steel or Stainless steel and Graphite

(F. Oikonomopoulou, et al. 2018)

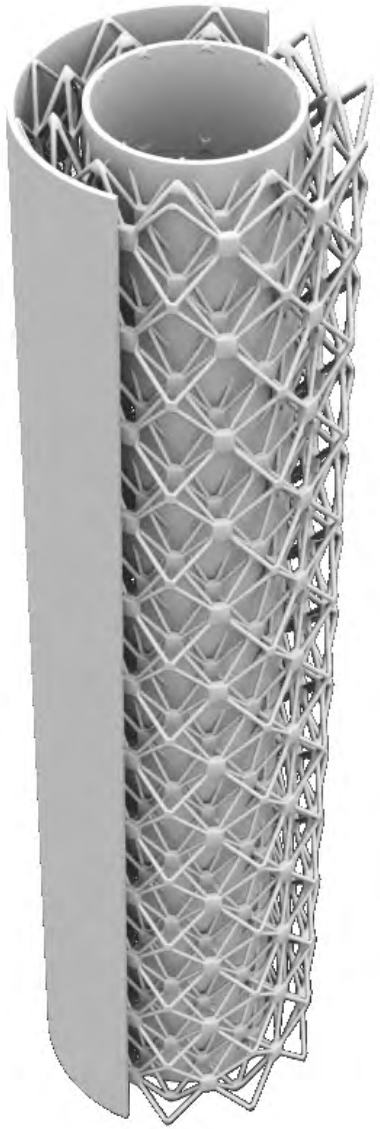
TYPES OF CASTING MOULDS

LABORIOUS & TIME CONSUMING PROCESS

LOST WAX TECHNIQUE OR INVESTMENT CASTING

(T. Bristogianni, et al. 2017)

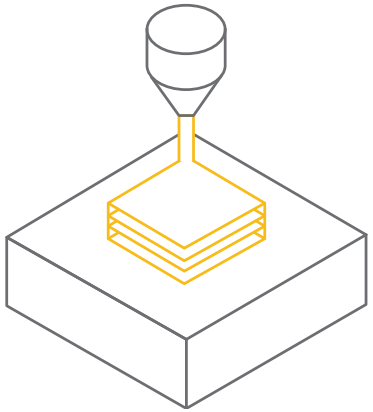
REQUIREMENT OF A NEW FABRICATION TECHNIQUE



MOULD ?

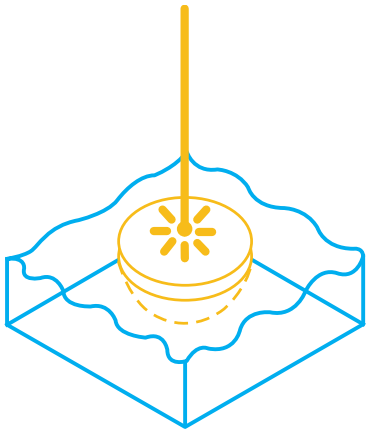
ADDITIVE MANUFACTURING

1. MATERIAL EXTRUSION



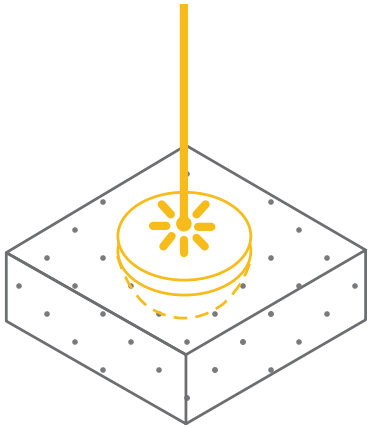
FFF

2. VAT POLYMERIZATION



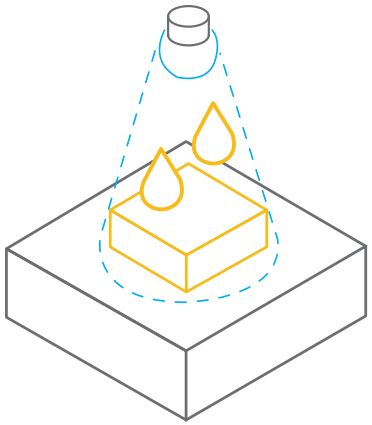
SLA
DLP

3. POWDER BED FUSION (POLYMERS)



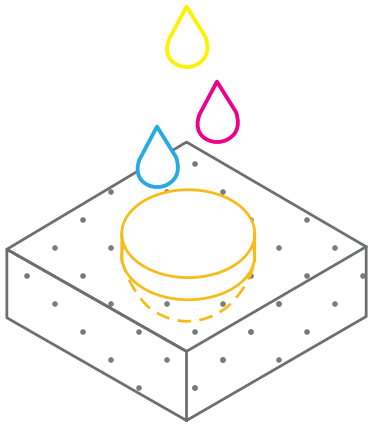
SLS

4. MATERIAL JETTING



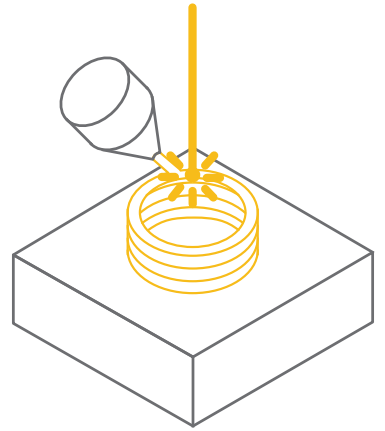
MATERIAL
JETTING
DOD

5. BINDER JETTING



BINDER JETTING

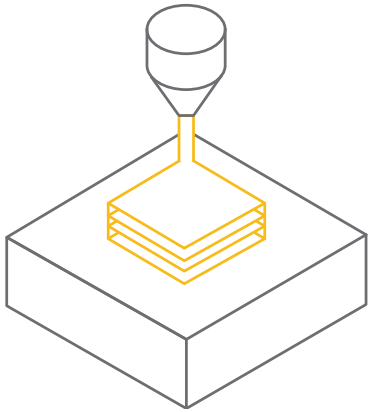
6. POWDER BED FUSION (METALS)



DMLS
SLM
EBM

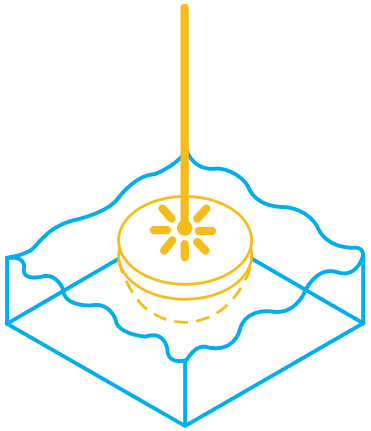
ADDITIVE MANUFACTURING

1. MATERIAL EXTRUSION



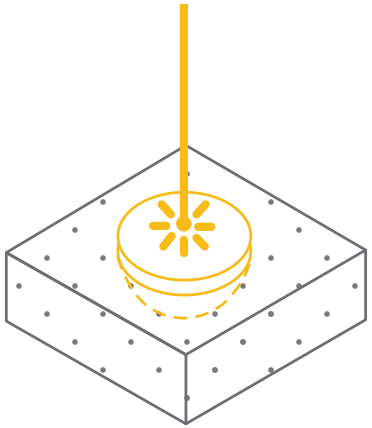
FFF

2. VAT POLYMERIZATION



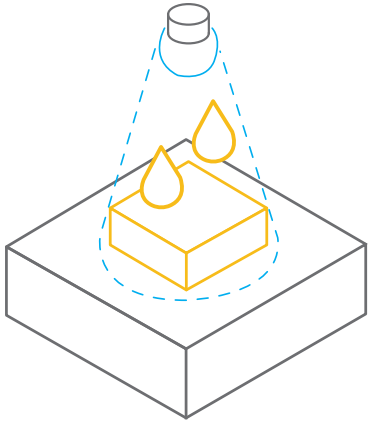
SLA
DLP

3. POWDER BED FUSION (POLYMERS)



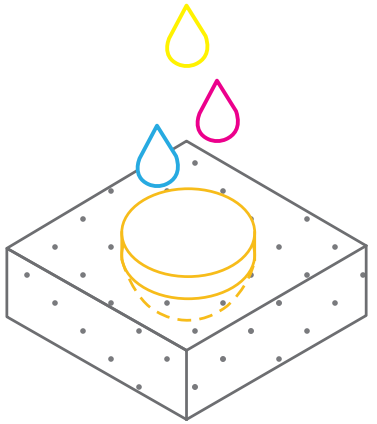
SLS

4. MATERIAL JETTING



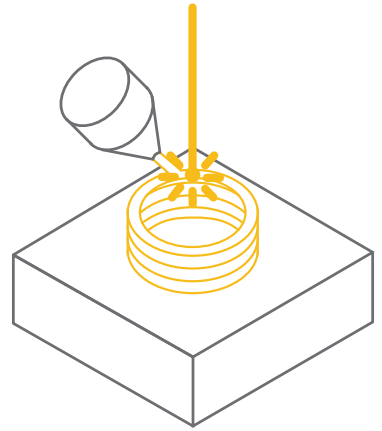
MATERIAL
JETTING
DOD

5. BINDER JETTING



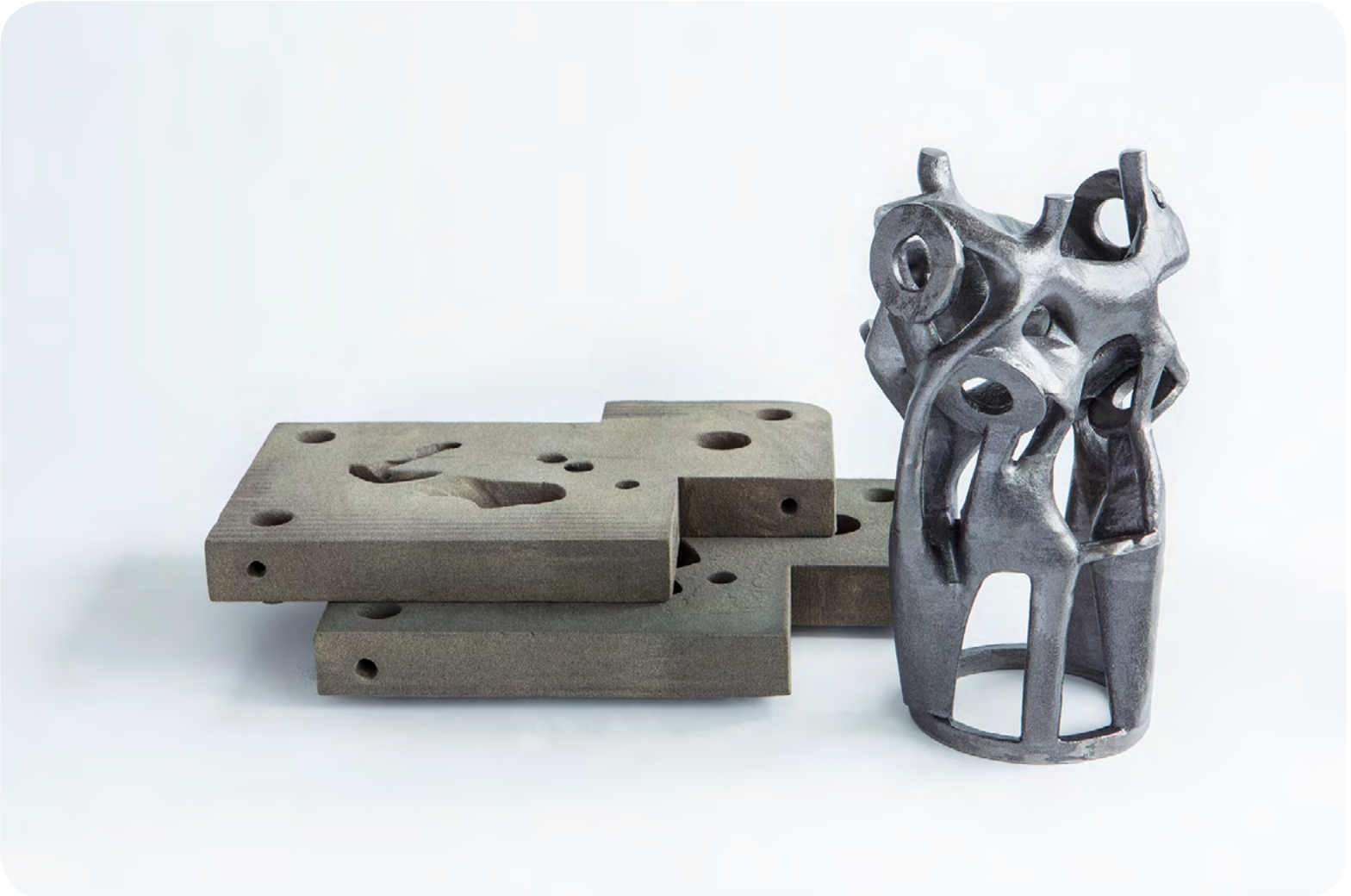
BINDER JETTING

6. POWDER BED FUSION (METALS)



DMLS
SLM
EBM

3D PRINTED SAND MOULD



Metal casted node in a 3D printed sand mould designed by Arup (Galjaard 2017)

3D PRINTED SAND MOULD

RESEARCH QUESTION

RESEARCH QUESTION

“How to fabricate a Topologically Optimized structural Glass Column using 3D printed moulds?”

RESEARCH QUESTION

“How to fabricate a Topologically Optimized structural Glass Column using 3D printed **SAND MOULDS**?”

RESEARCH QUESTION

“How to fabricate a Geometrically Optimized structural Glass Column using 3D printed SAND MOULDS?”

SUB- RESEARCH QUESTIONS:

1. How does Topological Optimization contribute to the feasibility of cast glass column?
2. What are the design criteria involved in designing a cast glass element?
3. What are the advantages and limitation of using 3D printed sand mould technology?
4. What are the constraints involved in 3D printing mould- size, thickness, edges/ corners etc?
5. Which binders and coatings are most promising?

COLUMN DESIGN

KOLUMBA MUSEUM- CASE STUDY

COLOGNE, GERMANY

BY **PETER ZUMTHOR**

KOLUMBA MUSEUM- CASE STUDY

Romanesque Church, 11th century

Romanesque expansion, 12th century

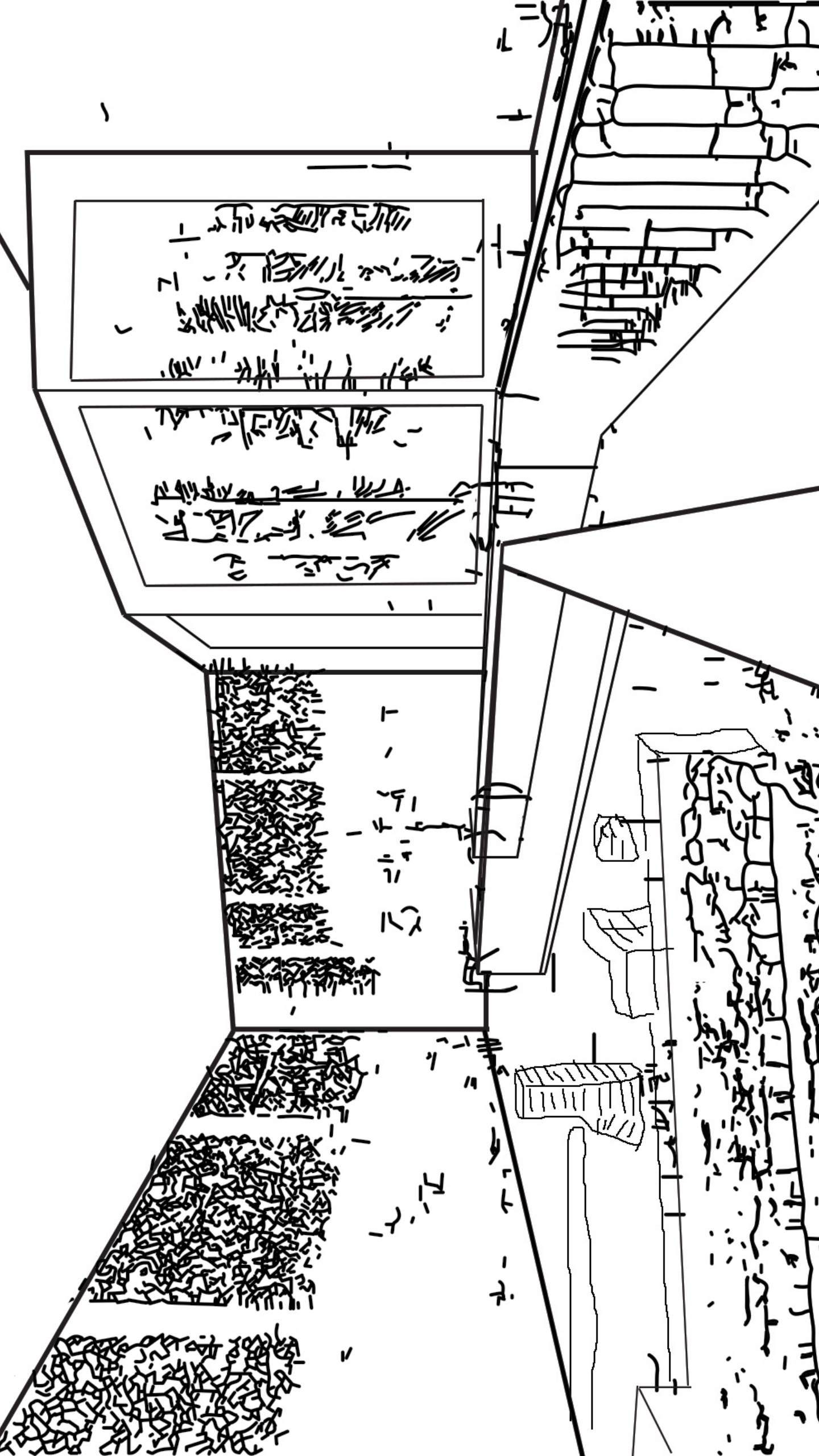
Gothic church, 16th century

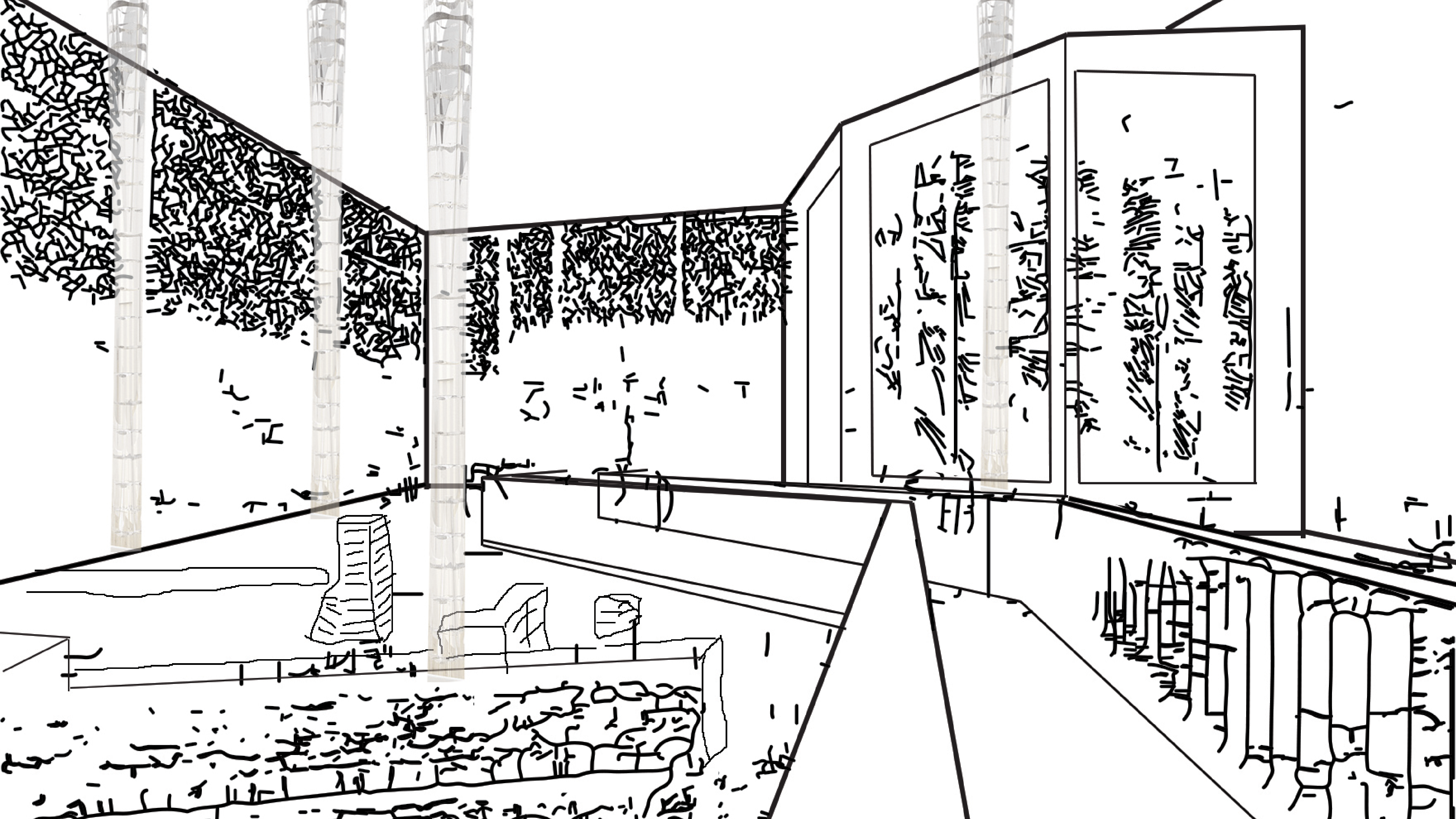
World War 2 Destruction, 1943

Kolumba-Chapel, 1949

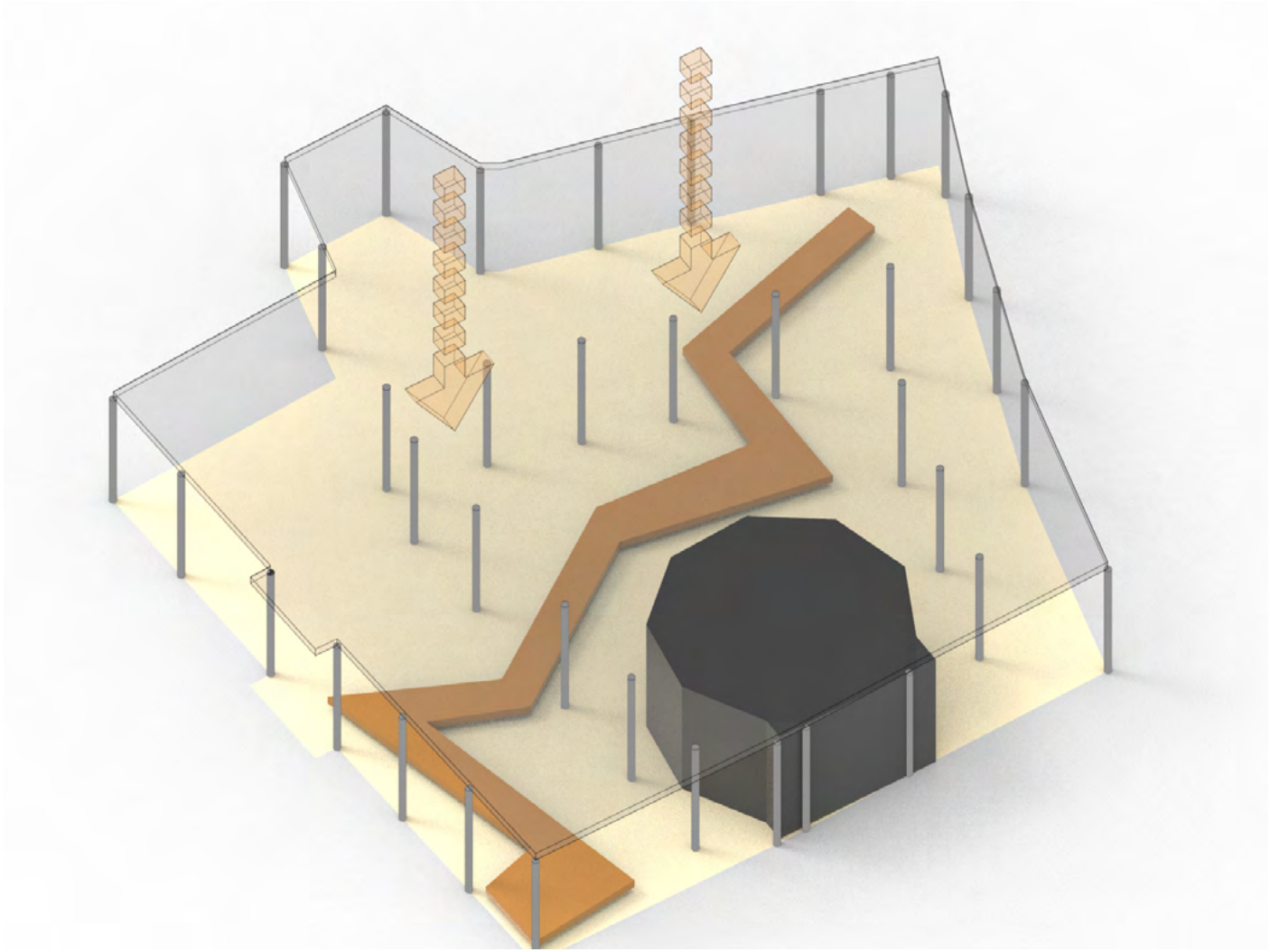
Kolumba museum, 2007

HISTORICAL EVOLUTION OF CHURCH OVER YEARS





LOAD CALCULATION



0.32 KN/M² WIND LOAD

0.65 KN/M² SNOW LOAD

5 KN/M² (MUSEUM)

1 KN/M² (ROOF) LIVE LOAD

4.74 KN/M² (MUSEUM)

3.58 KN/M² (ROOF) DEAD LOAD

DESIGN CRITERIA

DESIGN CRITERIA

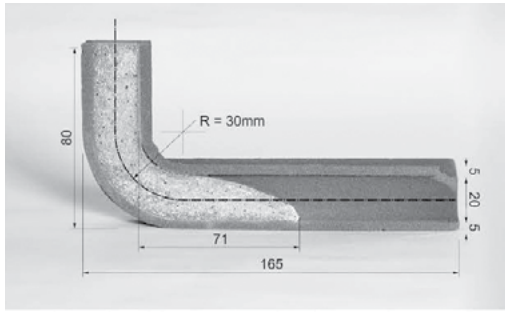
MATERIAL FABRICATION CHALLENGES

Homogenous Mass Distribution

Limited Annealing Time

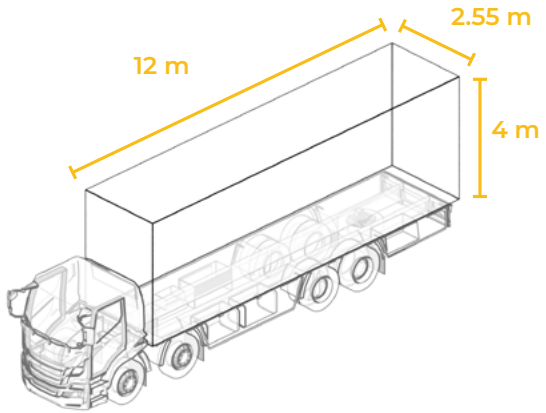
CHALLENGES OF SAND MOULDS

Wall Thickness



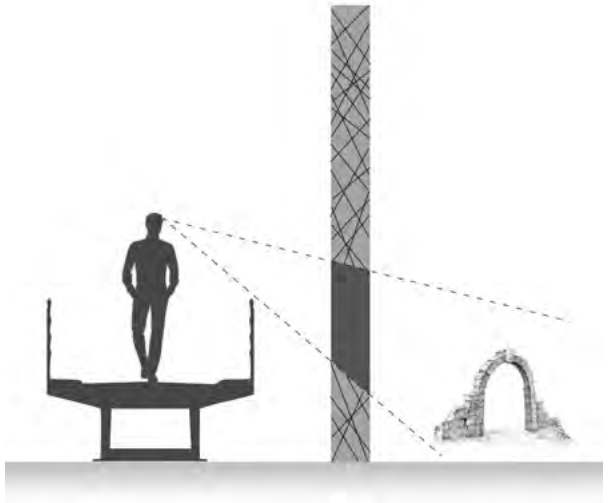
No sharp corners

TRANSPORTATION & LOGISTICS



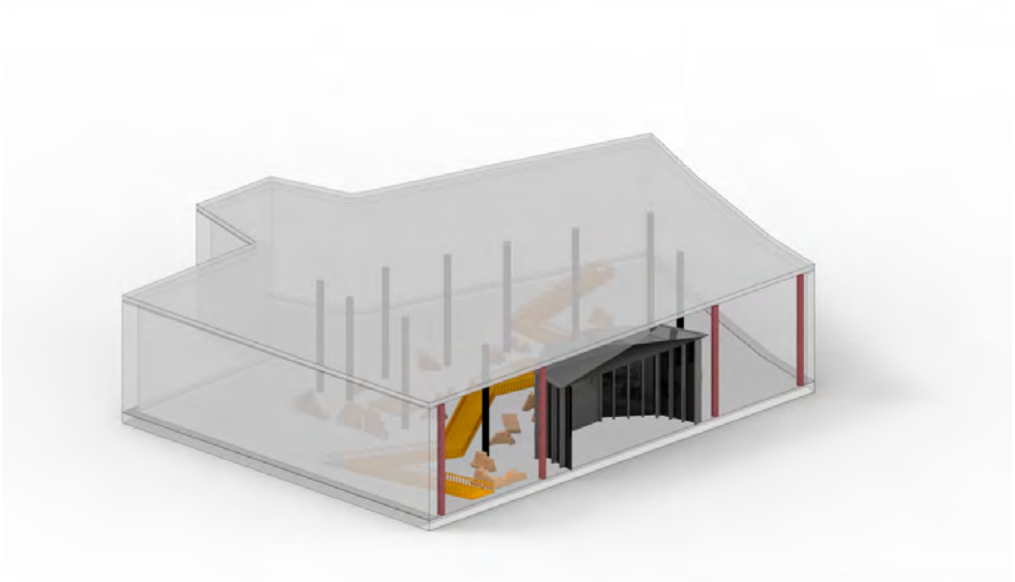
Maximum Permissible size on german roads

VISUAL PERFORMANCE

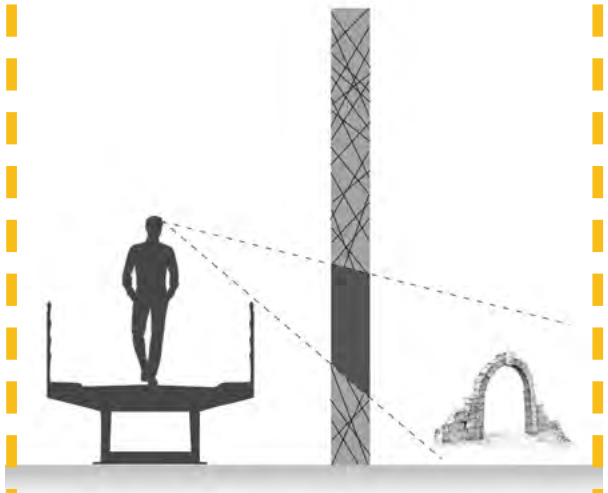


Solid cross section for better transparency in the eye level area

VISUAL PERFORMANCE

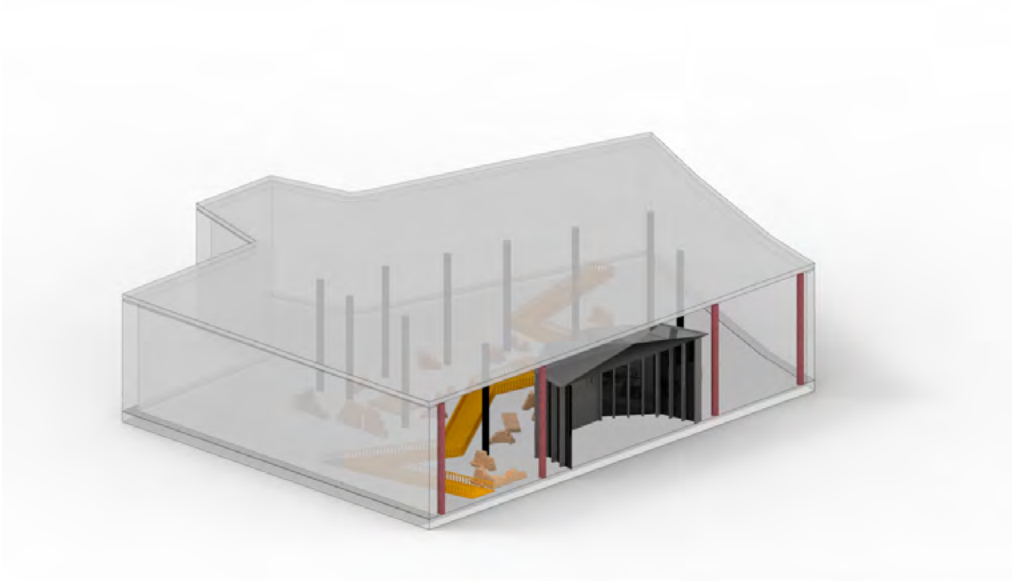


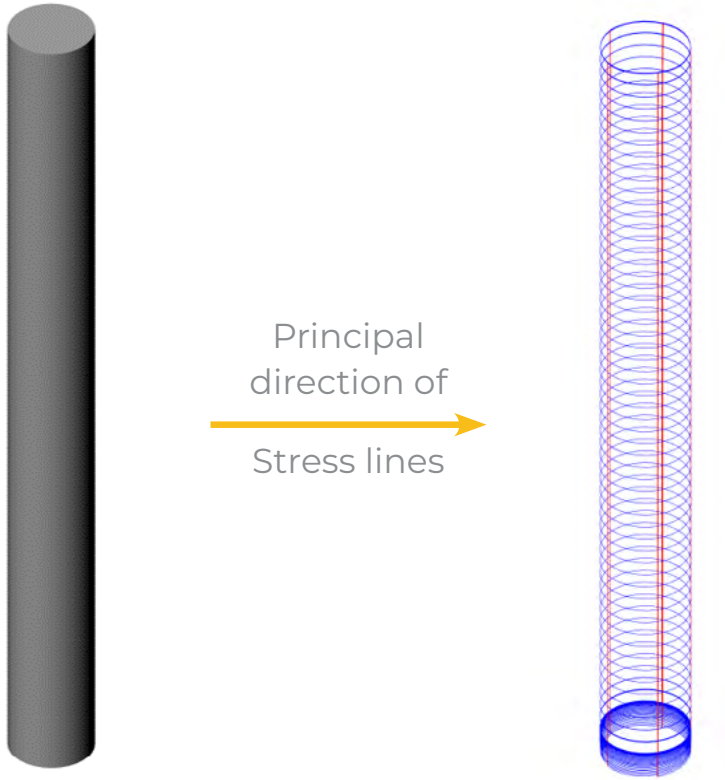
VISUAL PERFORMANCE



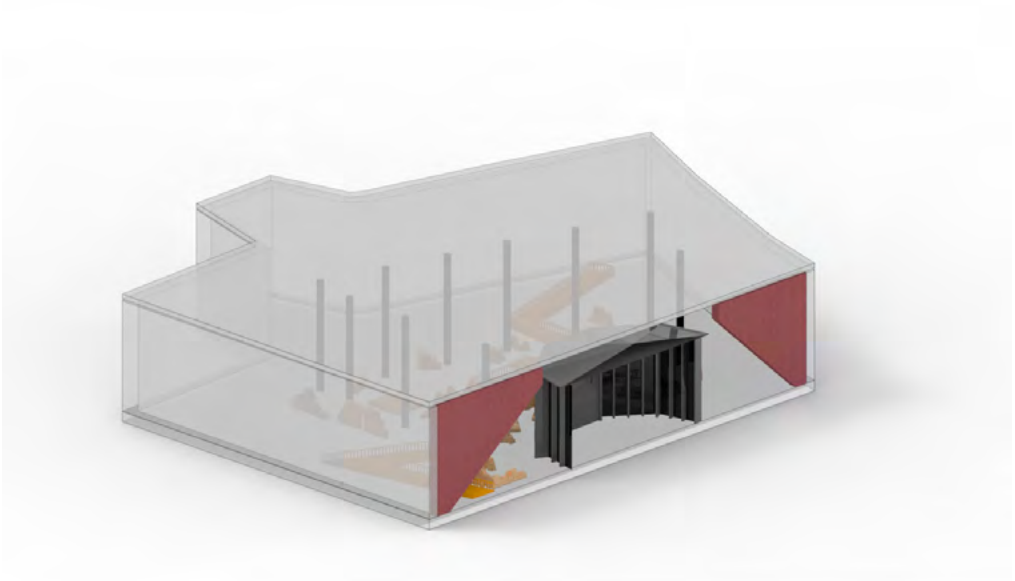
Solid cross section for better transparency in the eye level area

STRIAGHT COLUMN

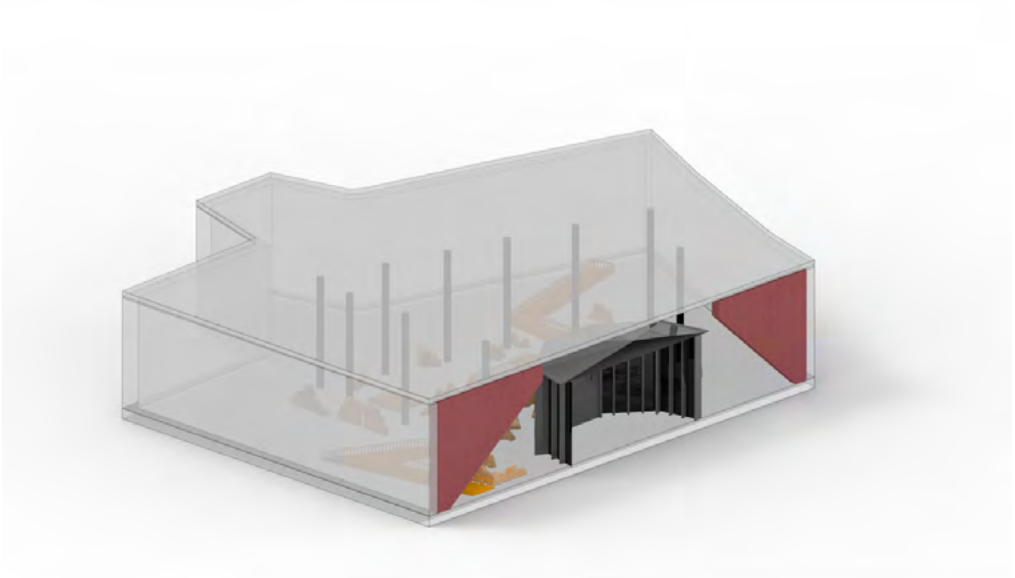


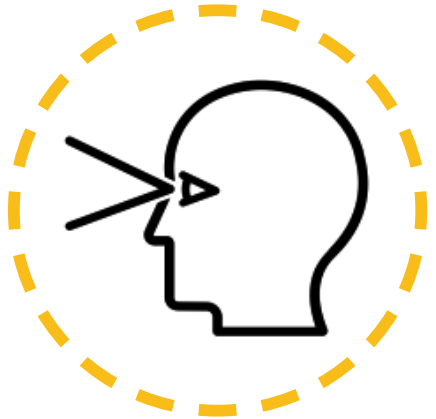


TRIANGULAR COLUMN

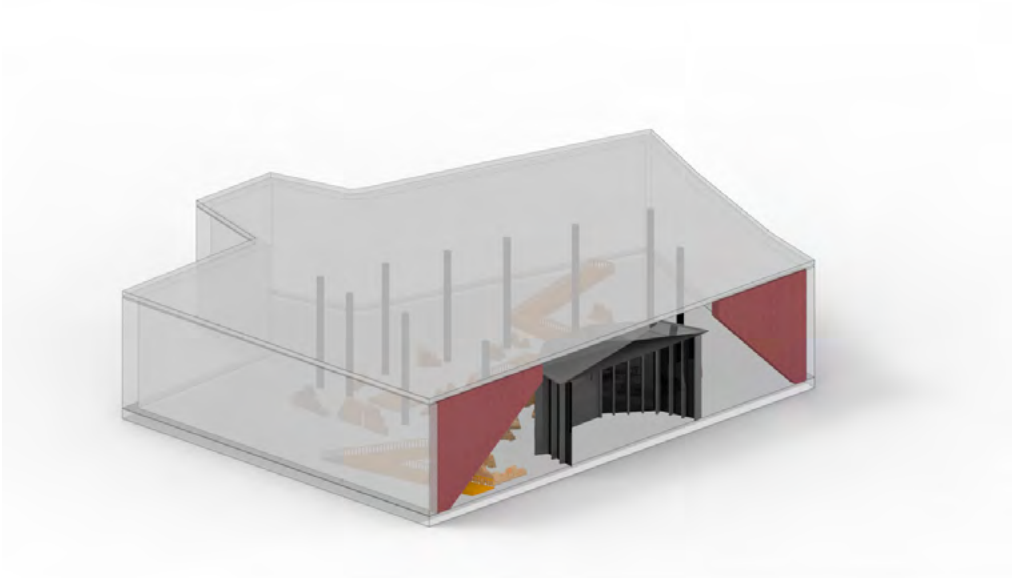


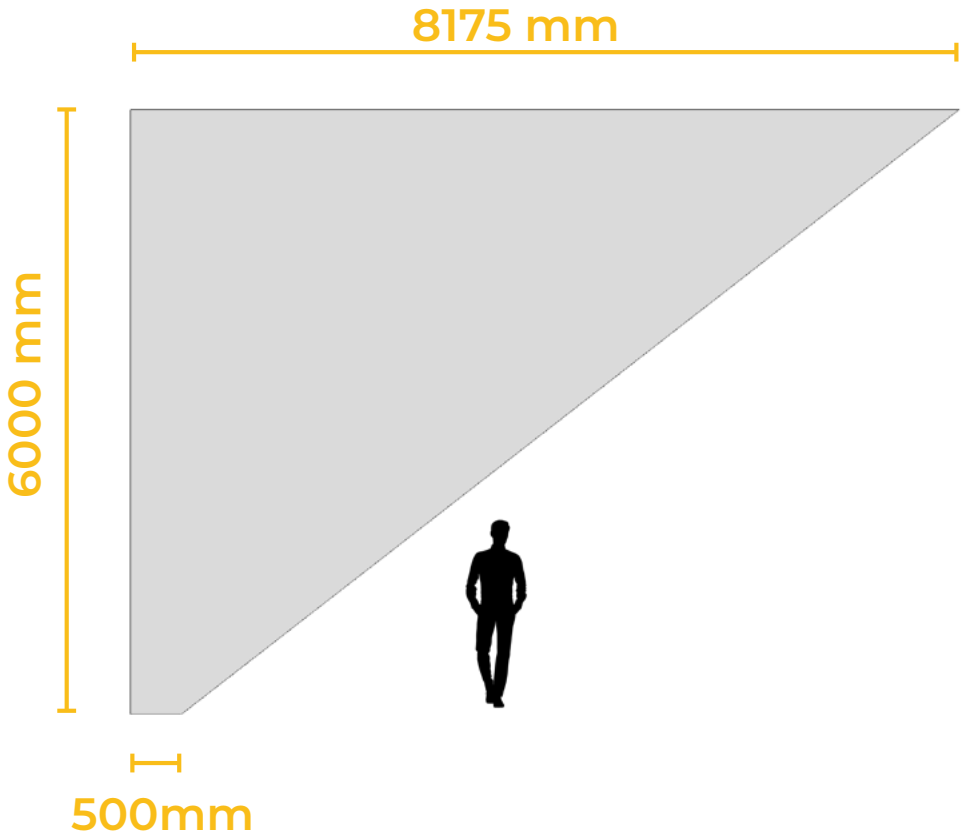
TRIANGULAR COLUMN



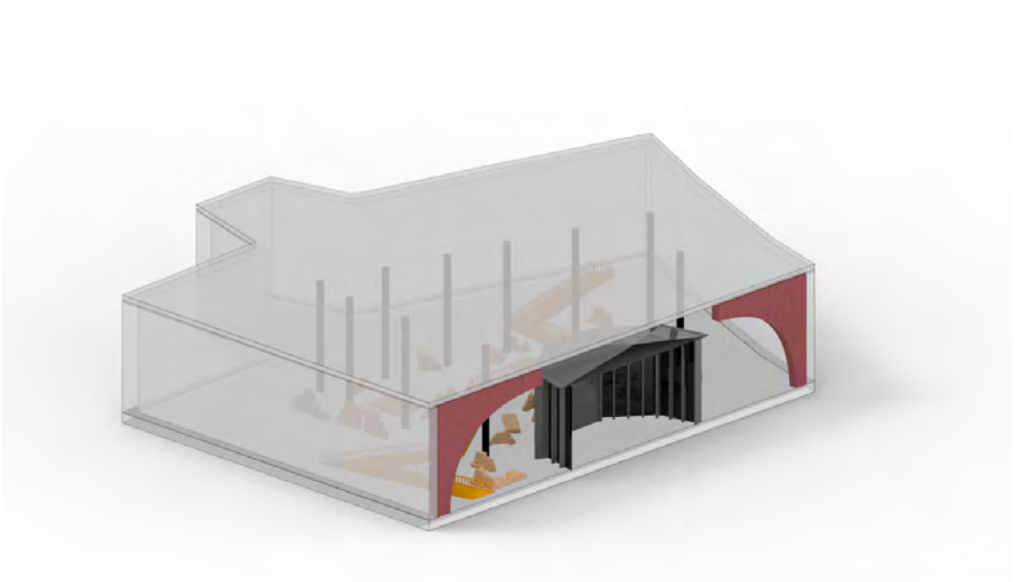


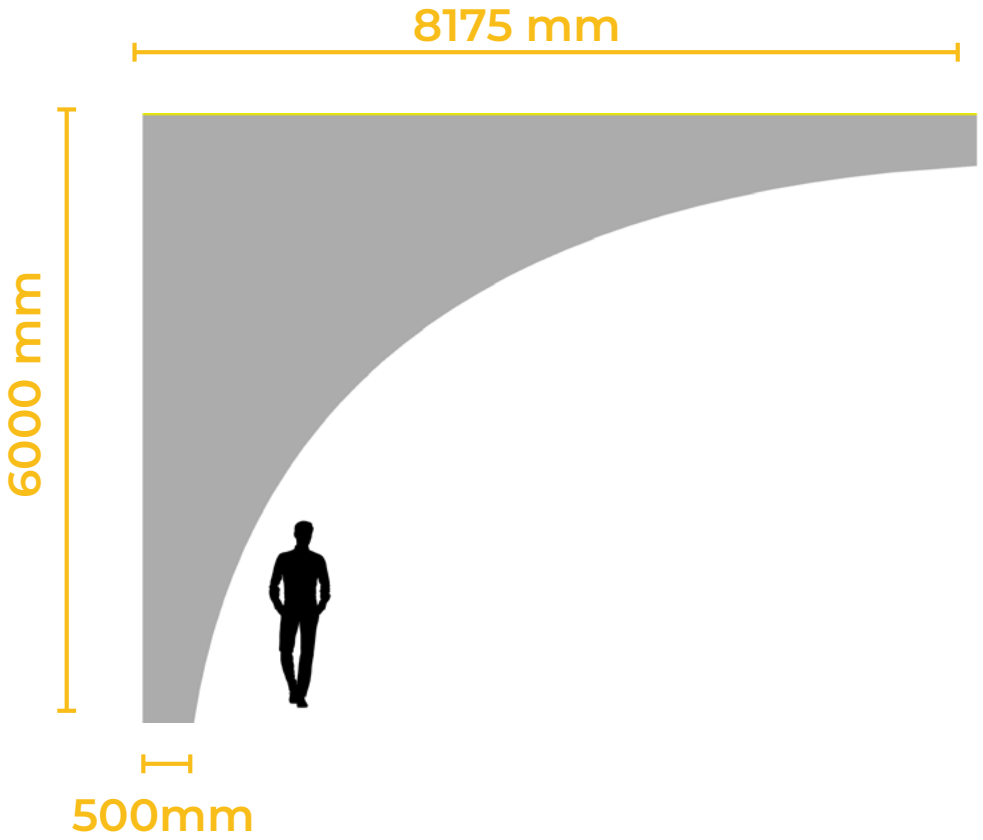
UN-ERGONOMIC DESIGN





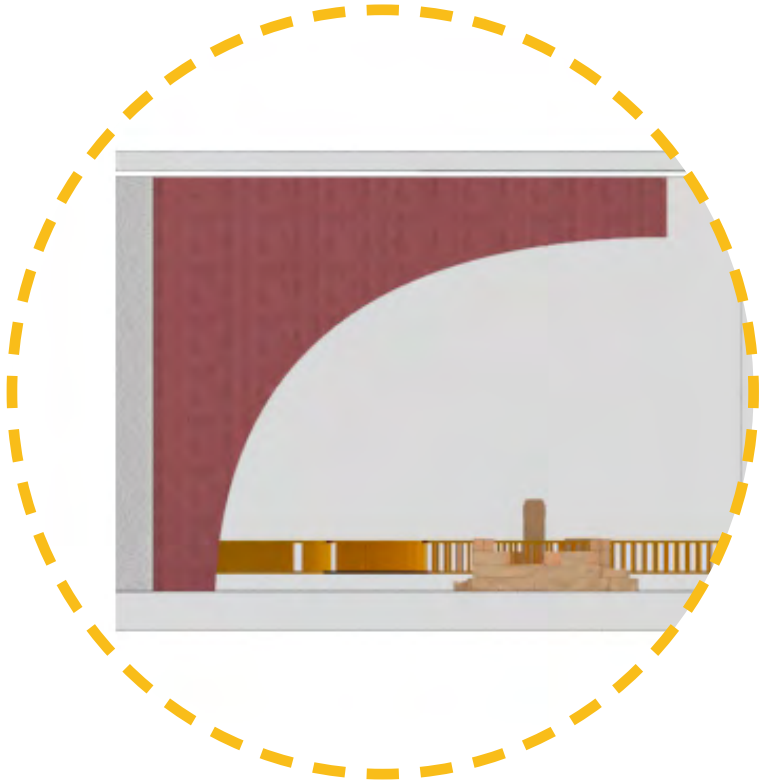
ARCH SHAPED COLUMN

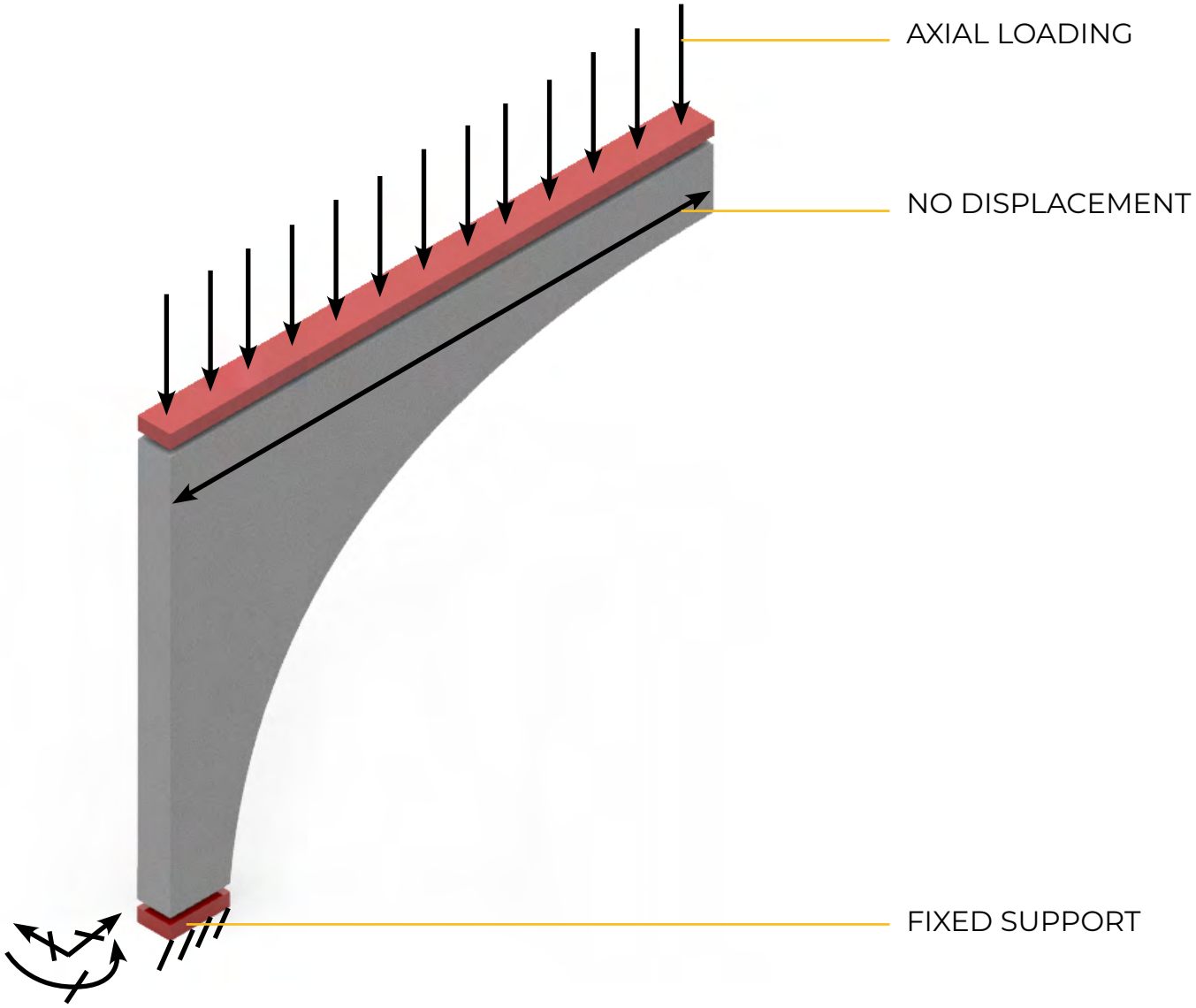




ARCH SHAPED COLUMN

OPTIMIZATION CONSTRAINTS





OPTIMIZATION SOFTWARE

MILLIPEDE

ANSYS

AMEBA (BESO)

Altair

OPTISTRUCT

THICKNESS ASSESSMENT

250 mm

500 mm

750 mm

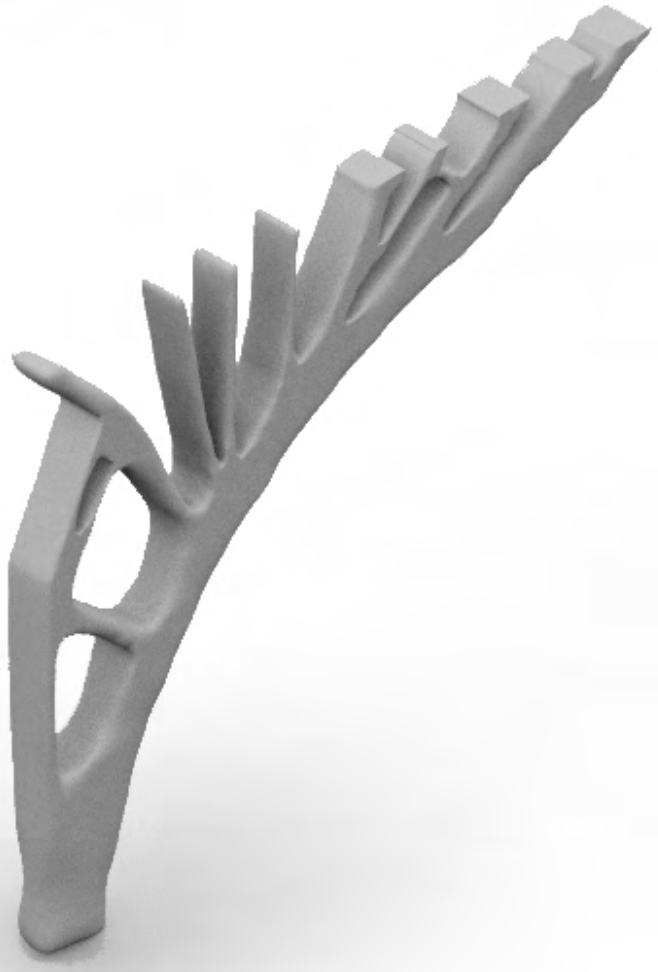
THICKNESS ASSESSMENT

250 mm

500 mm

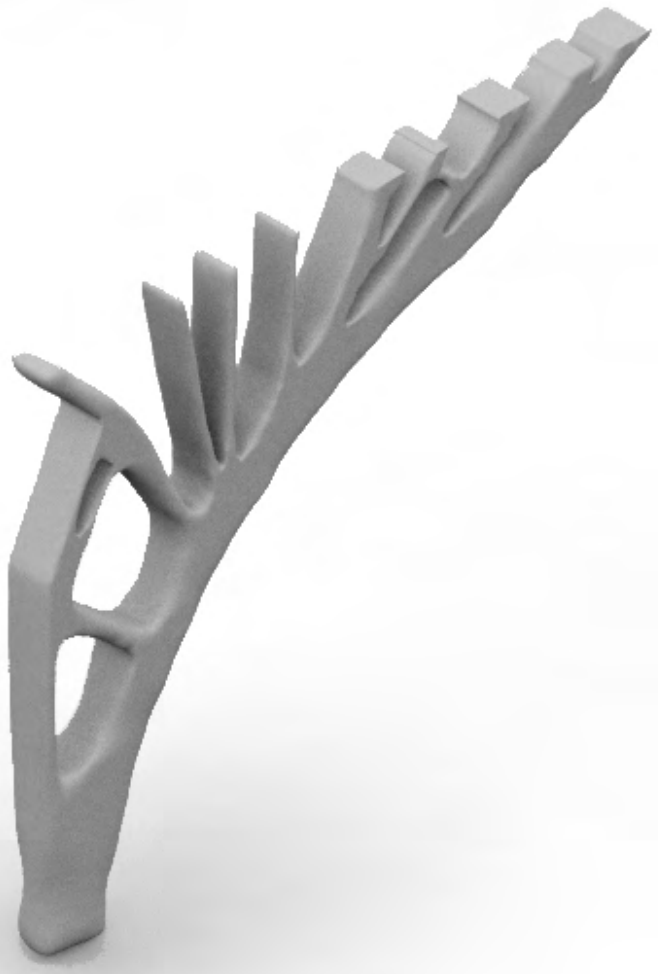
750 mm

OPTIMIZED GEOMETRY

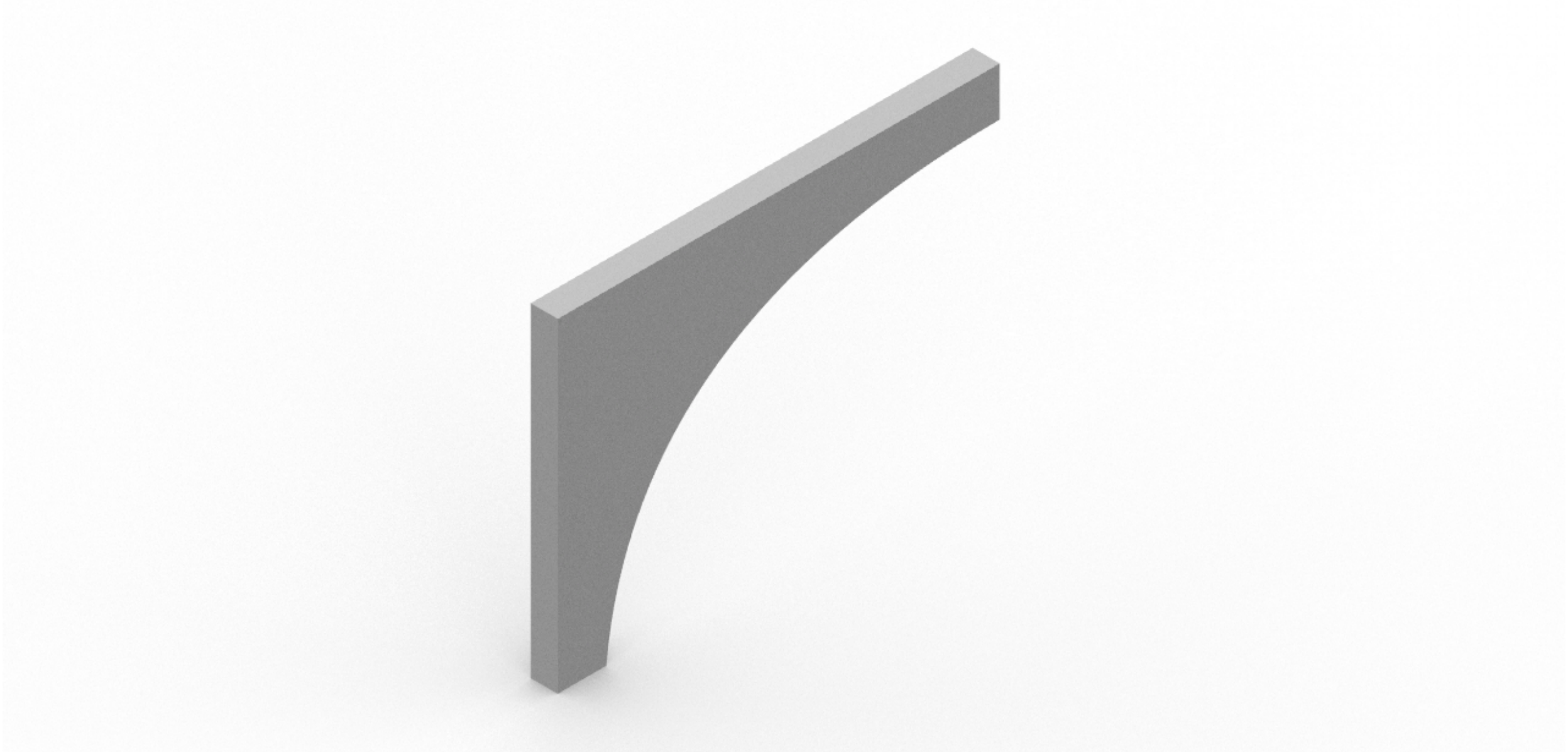


60% mass reduction
Weight before optimization: 20369 kg
Weight after optimization: 8221.6 kg

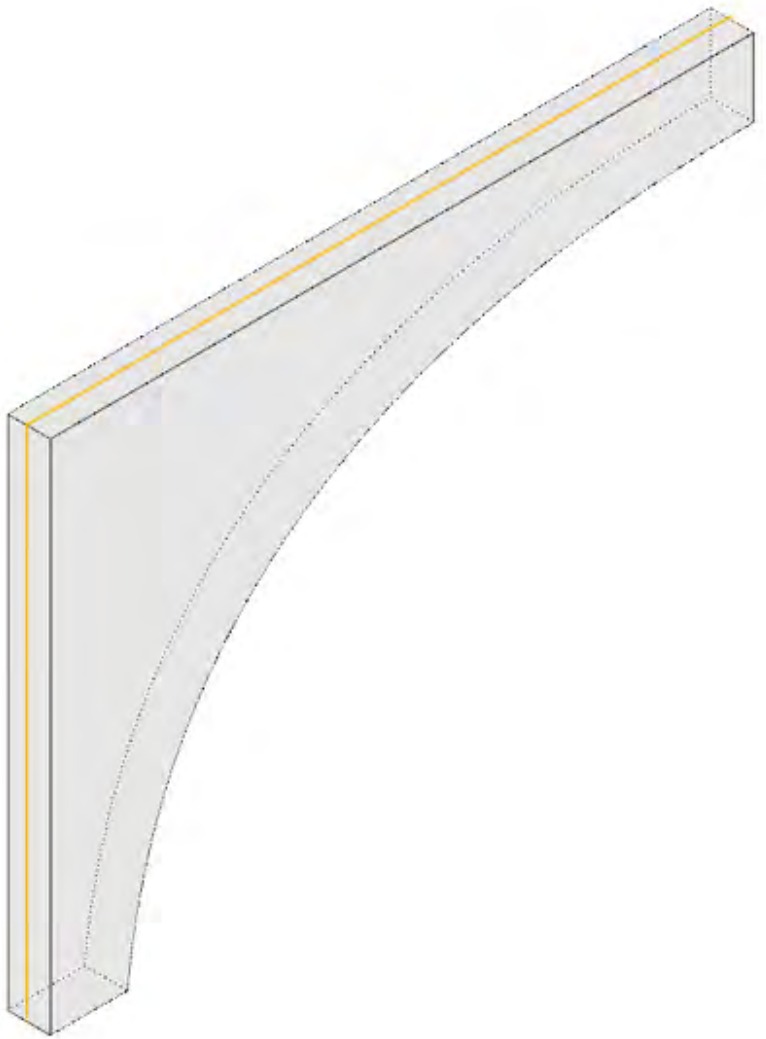
OPTIMIZED GEOMETRY



SPLIT GEOMETRY



SPLIT GEOMETRY



SPLIT GEOMETRY

SOLID GEOMETRY V/S SPLIT GEOMETRY

SOLID GEOMETRY V/S SPLIT GEOMETRY

GEOMETRY	SPLIT GEOMETRY	500mm
Maximum Principal Stress (Tensile stress) (MPa)	15.38	28.8
Minimum Principal Stress (Compressive stress) (MPa)	-29.39	-35.5
Total Deformation (mm)	3.25	4.3
Maximum Shear stress	19.47	19.62

SMOOTHENED GEOMETRY

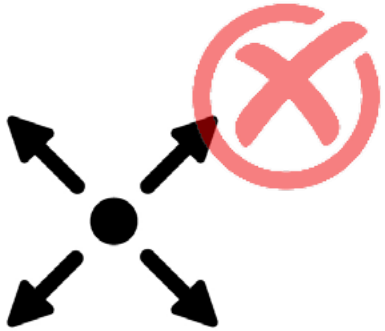
75% mass reduction
Weight before optimization: 17146 kg
Weight after optimization: 4404.4 kg

SMOOTHENED GEOMETRY

Weight of one piece: 2202.2 kg

DESIGN CRITERIA

MATERIAL FABRICATION CHALLENGES

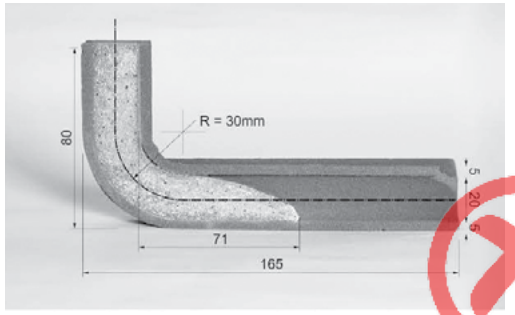


Homogenous Mass Distribution

Limited Annealing Time

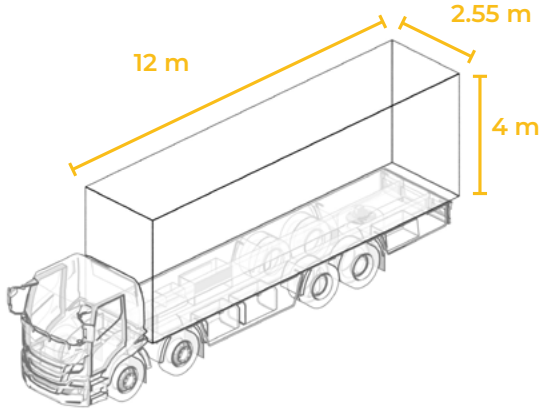
CHALLENGES OF SAND MOULDS

Wall Thickness



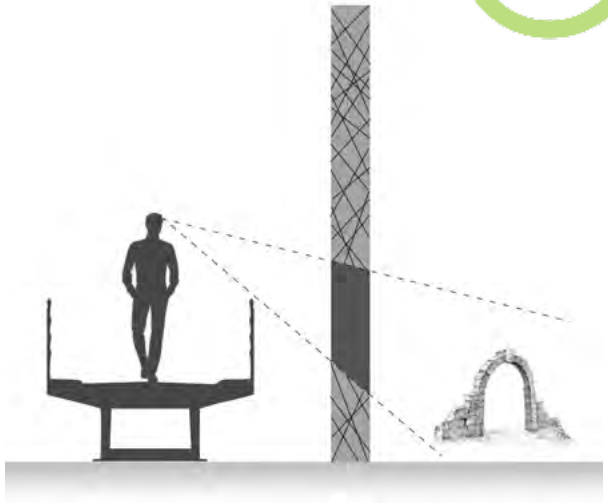
No sharp corners

TRANSPORTATION & LOGISTICS



Maximum Permissible size on german roads

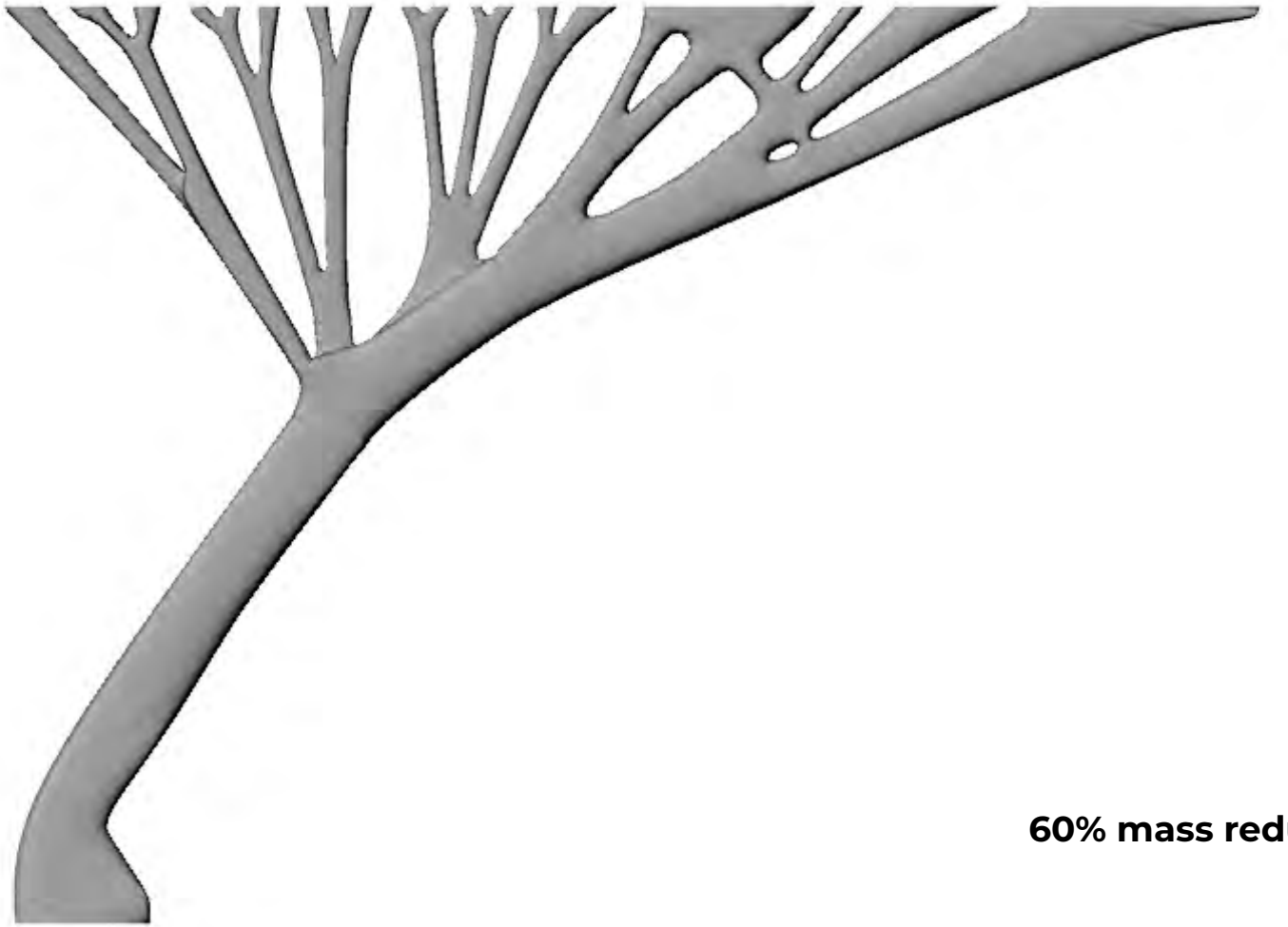
VISUAL PERFORMANCE



Solid cross section for better transparency in the eye level area

POST PROCESSING OF GEOMETRY

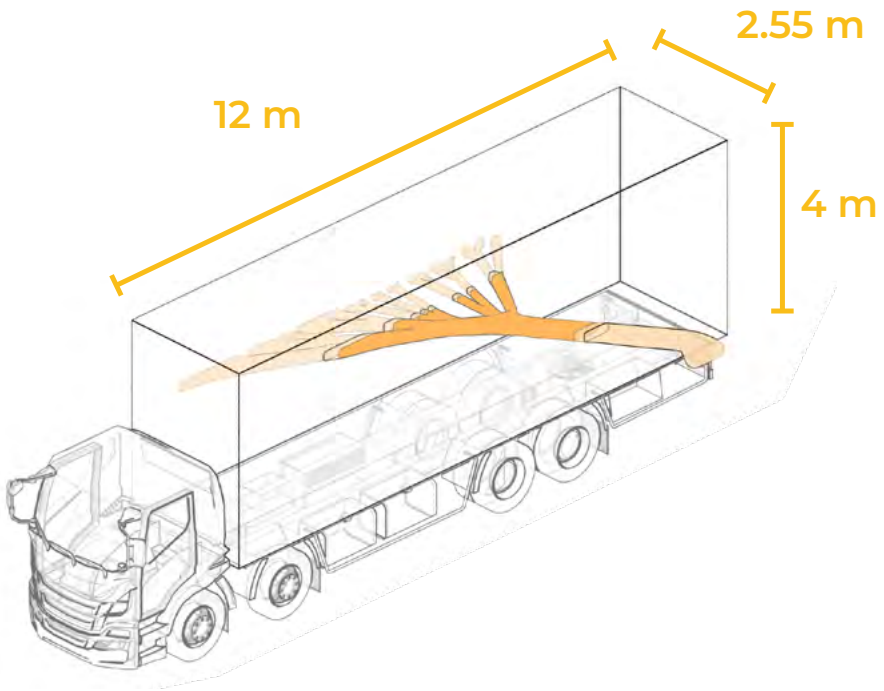
POST PROCESSED GEOMETRY

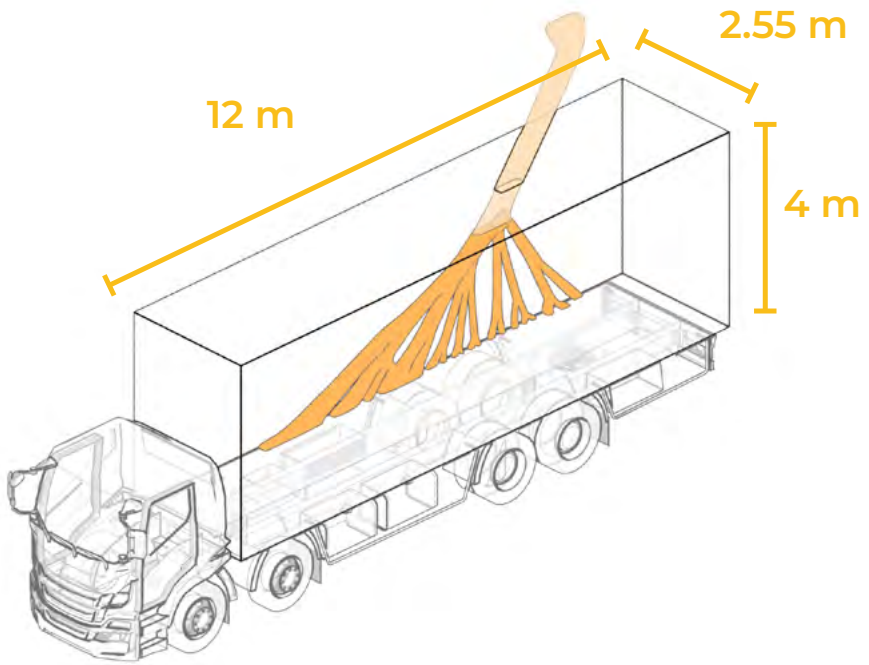


60% mass reduction

POST PROCESSED GEOMETRY

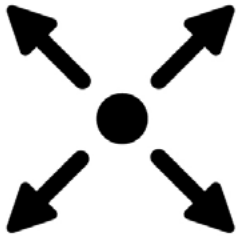
TRANSPORTATION CONSTRAINT





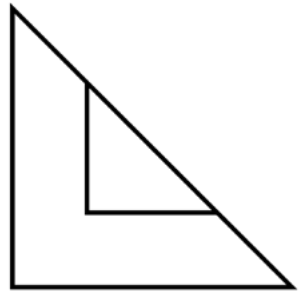
SPLITTING OF GEOMETRY

Pure Compression



Homogeneous Mass

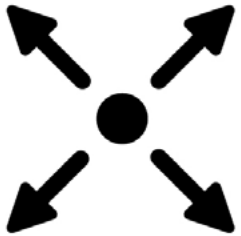
Shear Force



No sharp corners

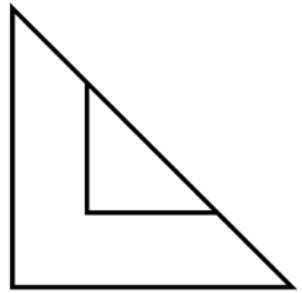
SPLITTING OF GEOMETRY

Pure Compression

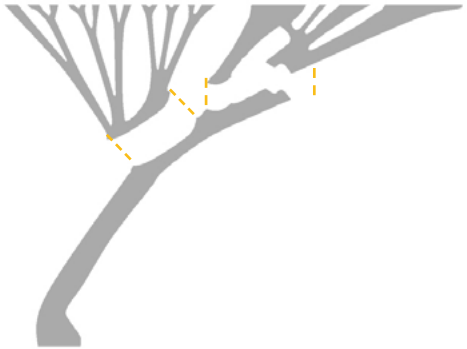


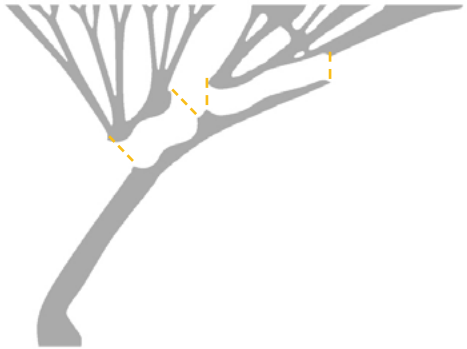
Homogeneous Mass

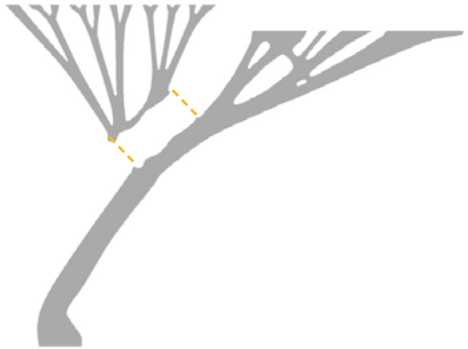
Shear Force



No sharp corners

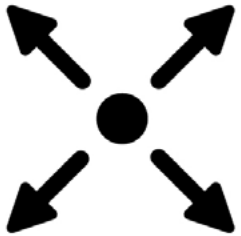






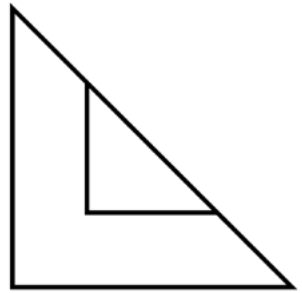
SPLITTING OF GEOMETRY

Pure Compression

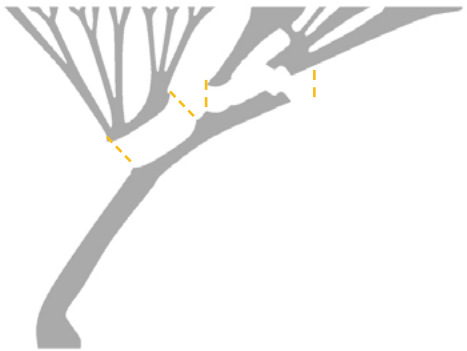


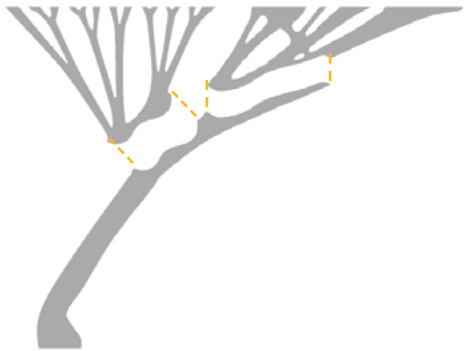
Homogeneous Mass

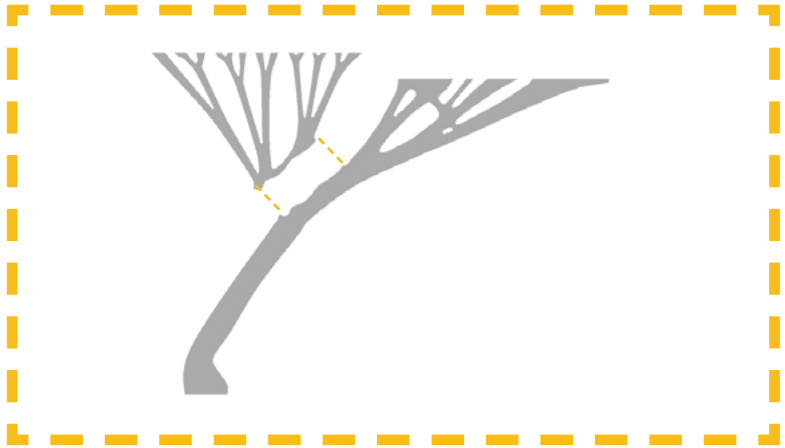
Shear Force



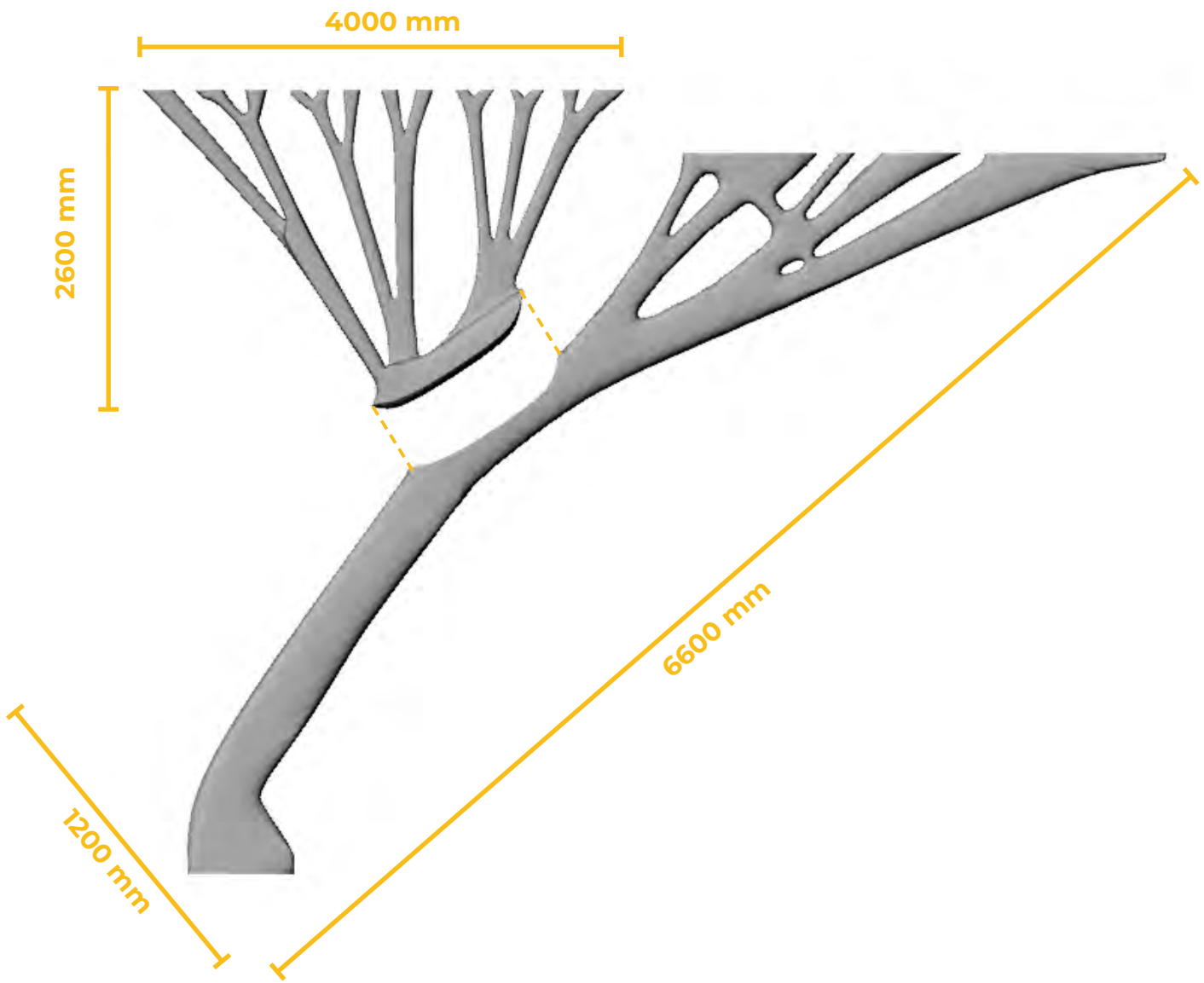
No sharp corners



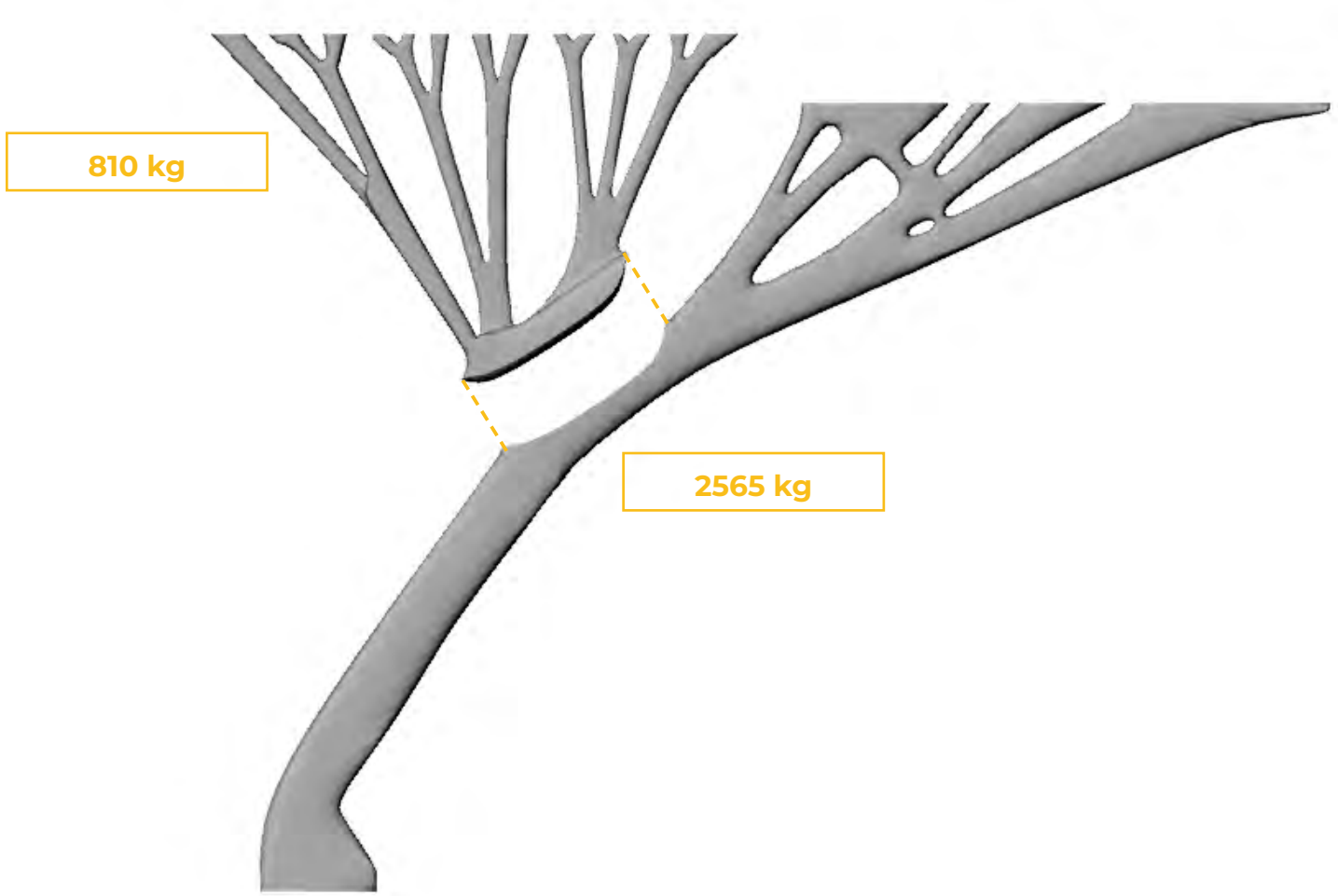




SPLITTING OF GEOMETRY



SPLITTING OF GEOMETRY



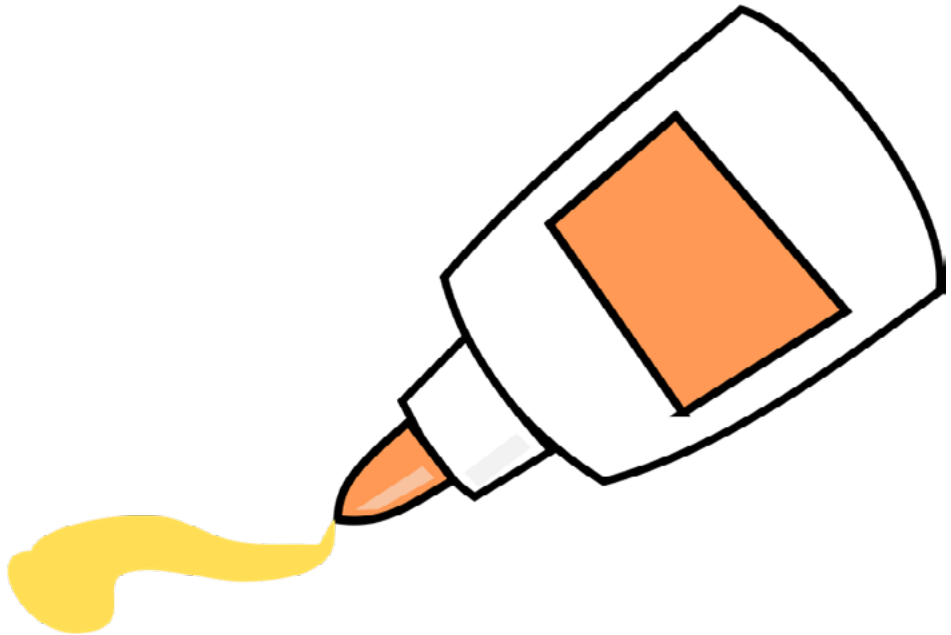
FABRICATION & EXPERIMENTATION

3D PRINTING OF SAND (PROCESS)

https://www.youtube.com/watch?v=LFGnjkoeDng

3D PRINTING OF SAND (PROCESS)

Sand



Binding adhesive

TYPES OF BINDER SYSTEM

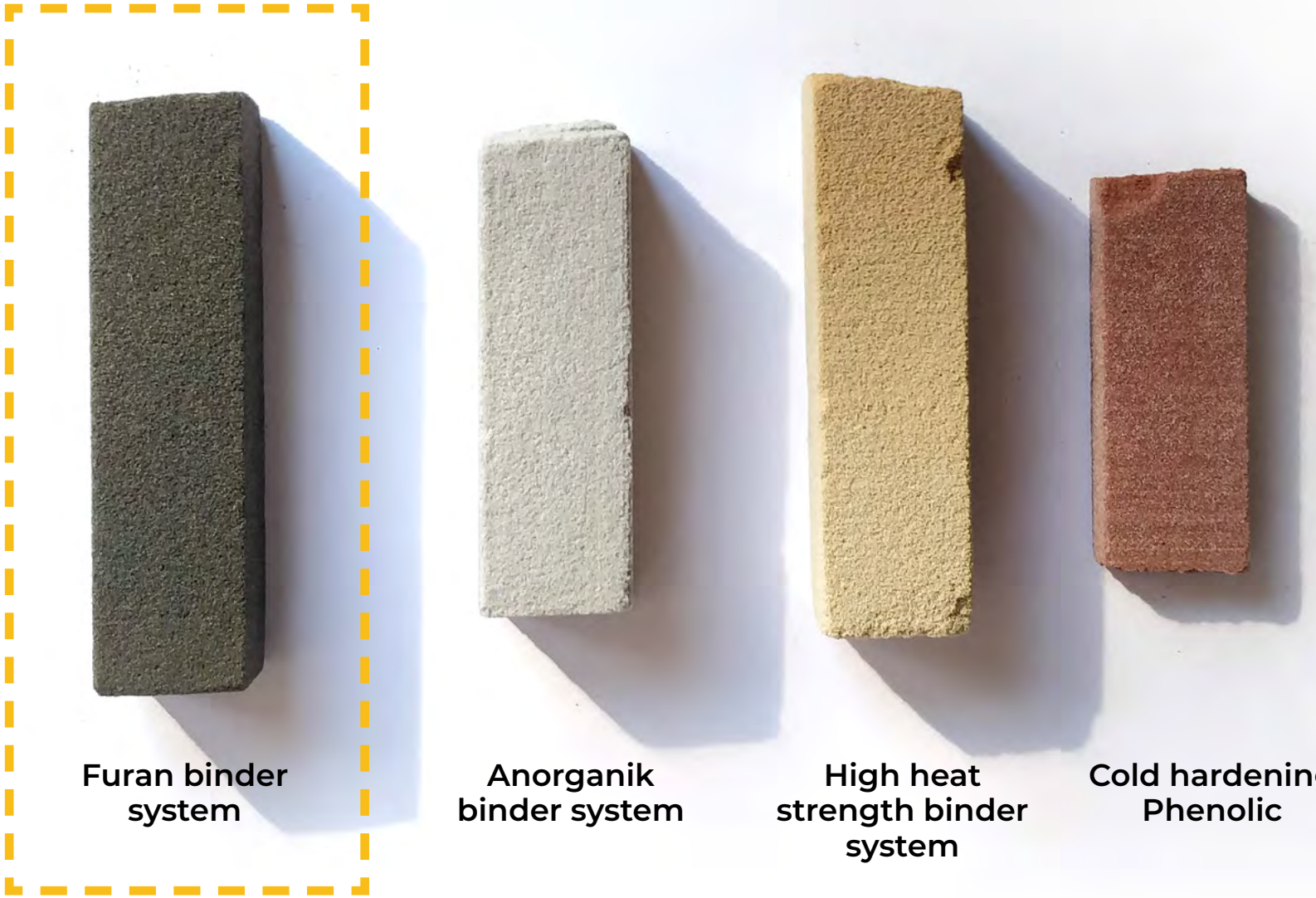
Furan binder system

Anorganik binder system

High heat strength binder system

Cold hardening Phenolic

TYPES OF BINDER SYSTEM



Furan binder system

Anorganik binder system

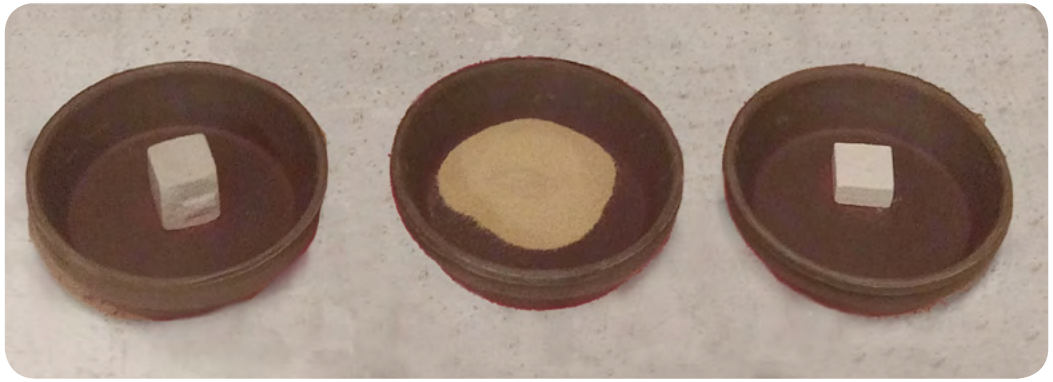
High heat strength binder system

Cold hardening Phenolic

EXPERIMENTATION










TYPES OF BINDER SYSTEM

Furan binder system

Anorganik binder system

High heat strength binder system

Cold hardening Phenolic

SURFACE FINISH

rough finish due to rough surface of sand mould

Cold hardening Phenolic

Anorganik binder system

SURFACE FINISH

Boron Nitride

Crystal cast (gypsum)

Mold Mix 6

EXPERIMENTATION

SURFACE FINISH

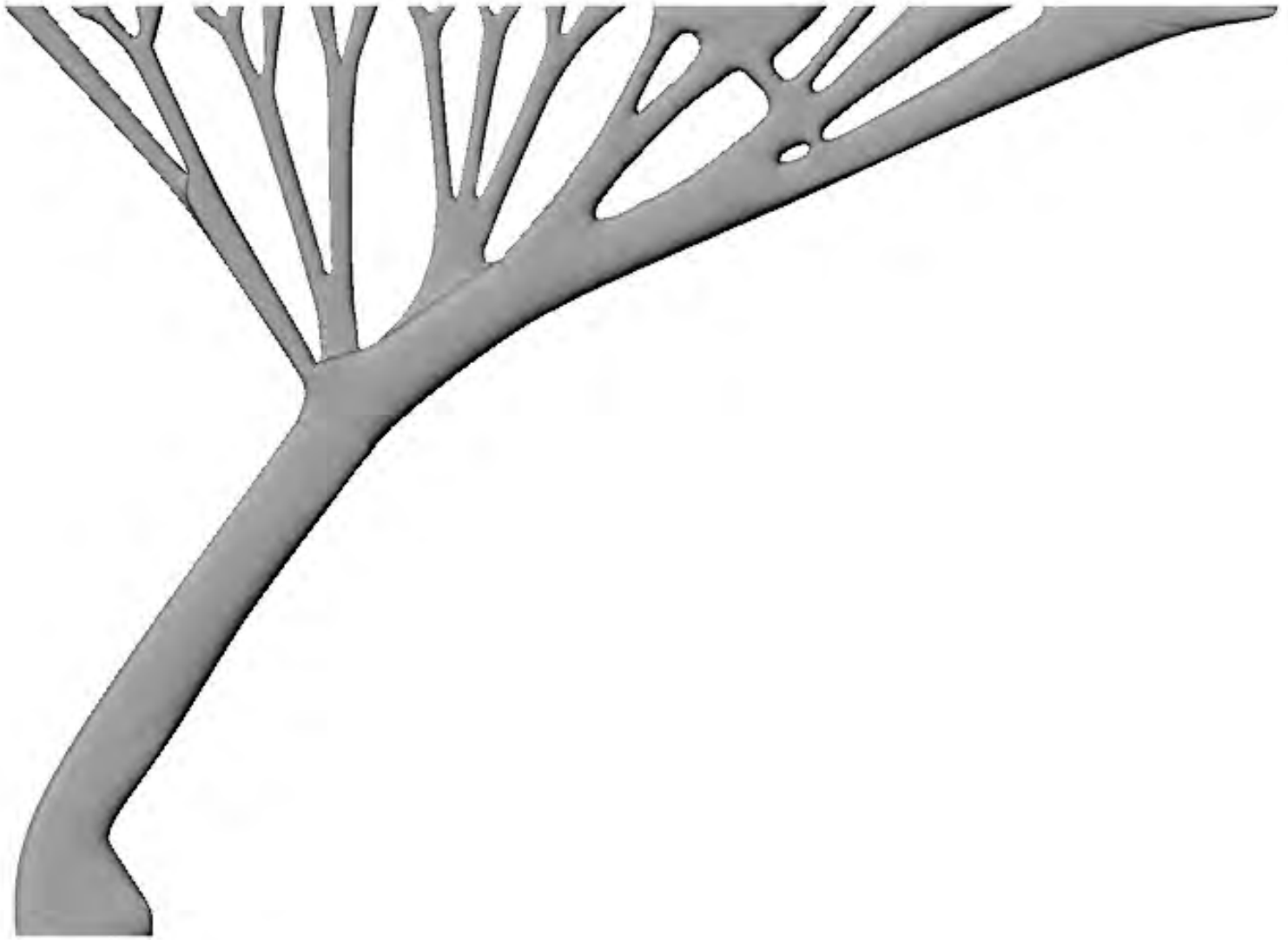
Boron Nitride

Crystal cast (gypsum)

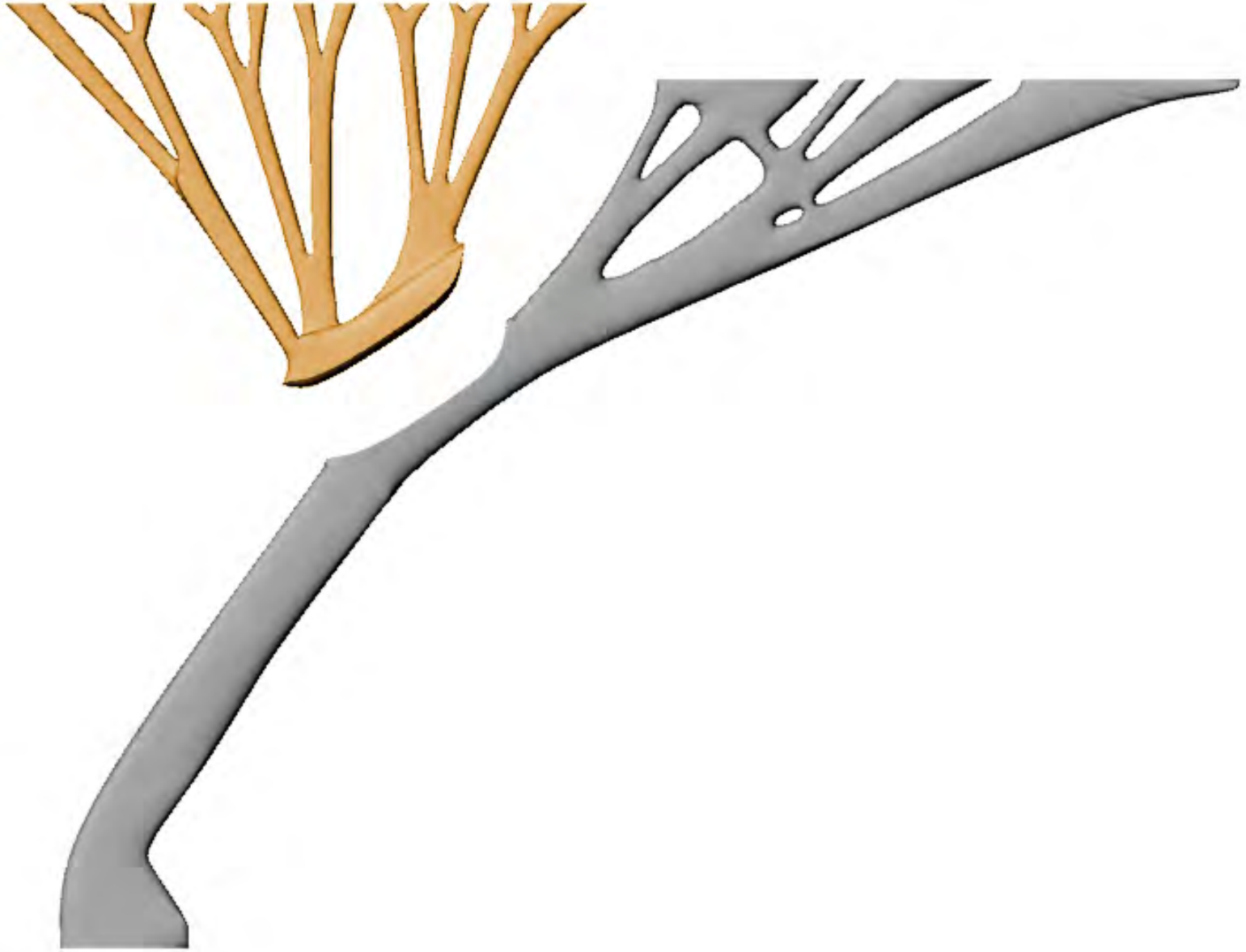
Mold Mix 6

PROTOTYPING

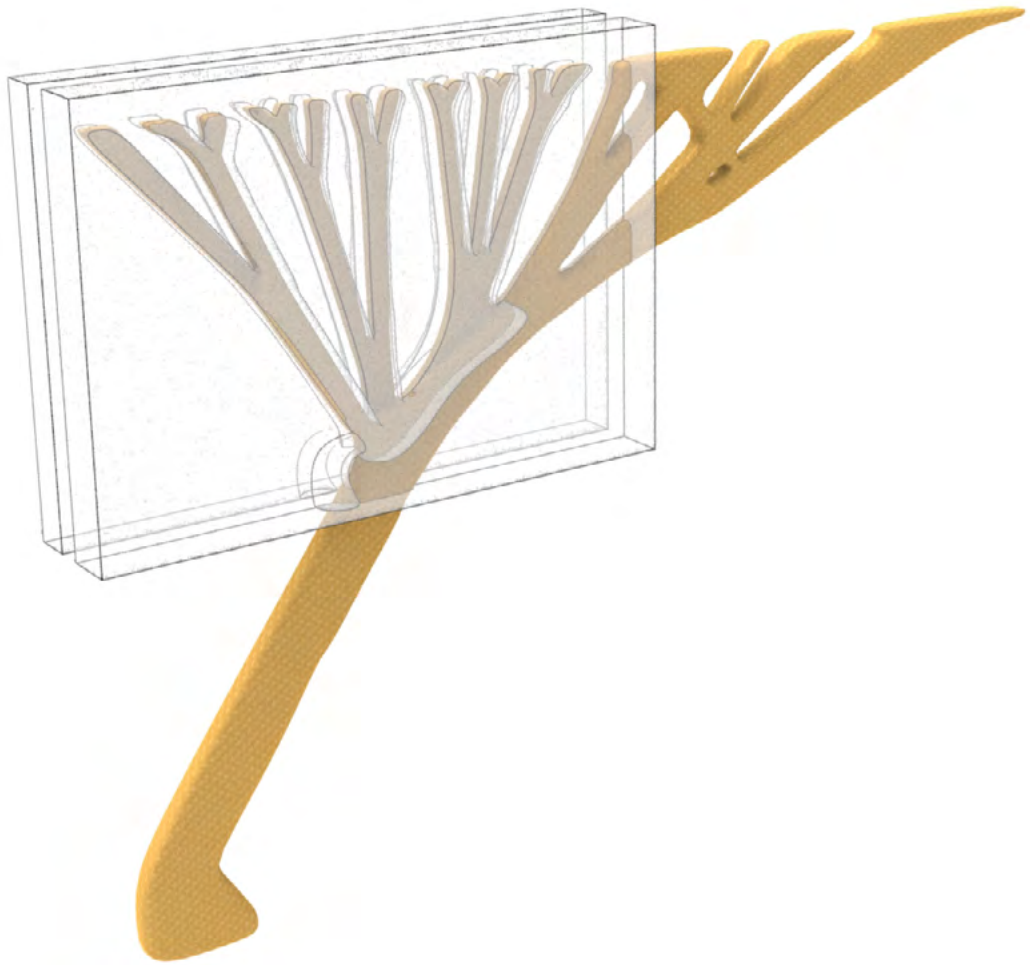
FABRICATION REGIONS



FABRICATION REGIONS

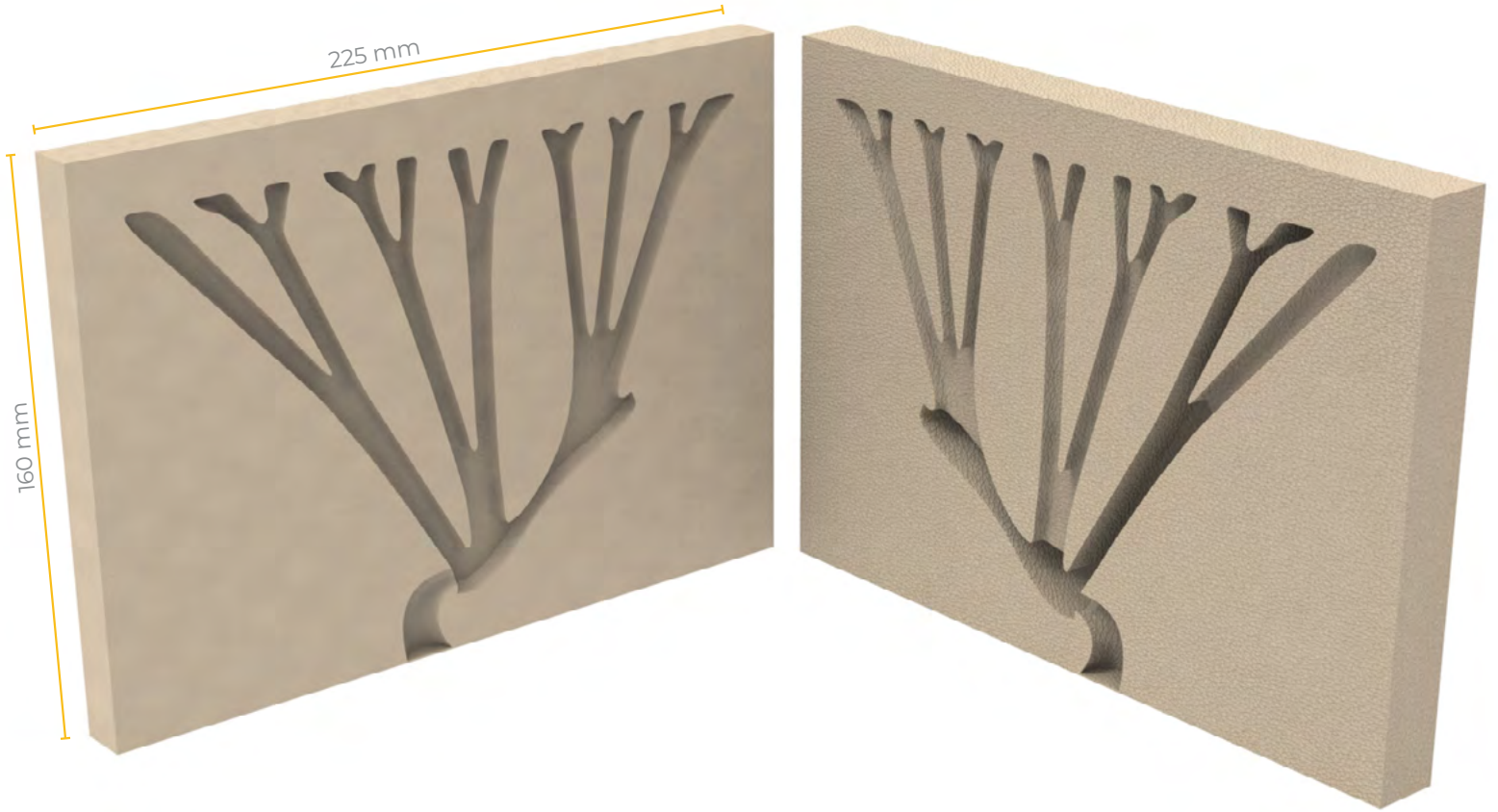


GEOMETRY 1 - SCALE 1:20



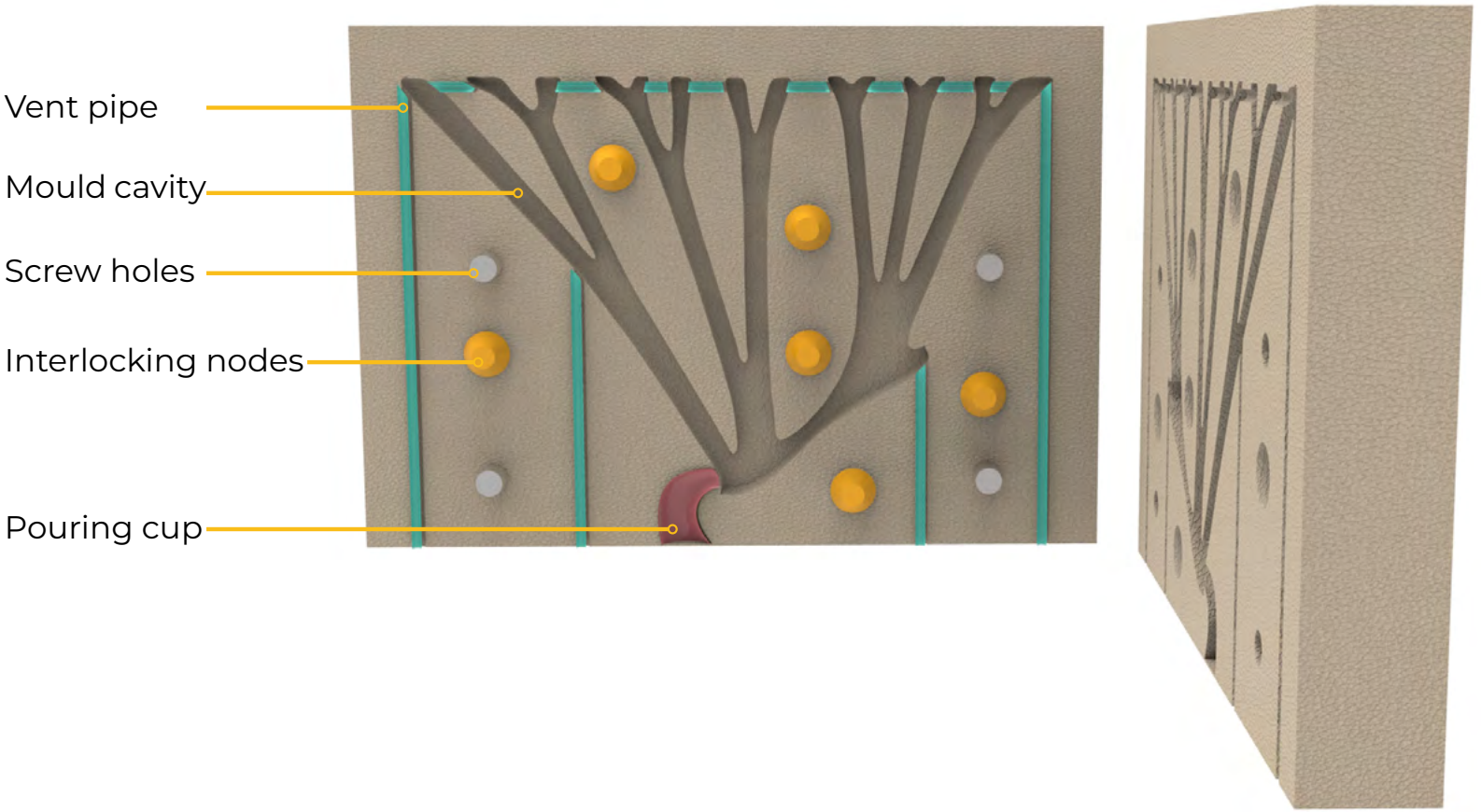
Scale 1:20

GEOMETRY 1 - SCALE 1:20

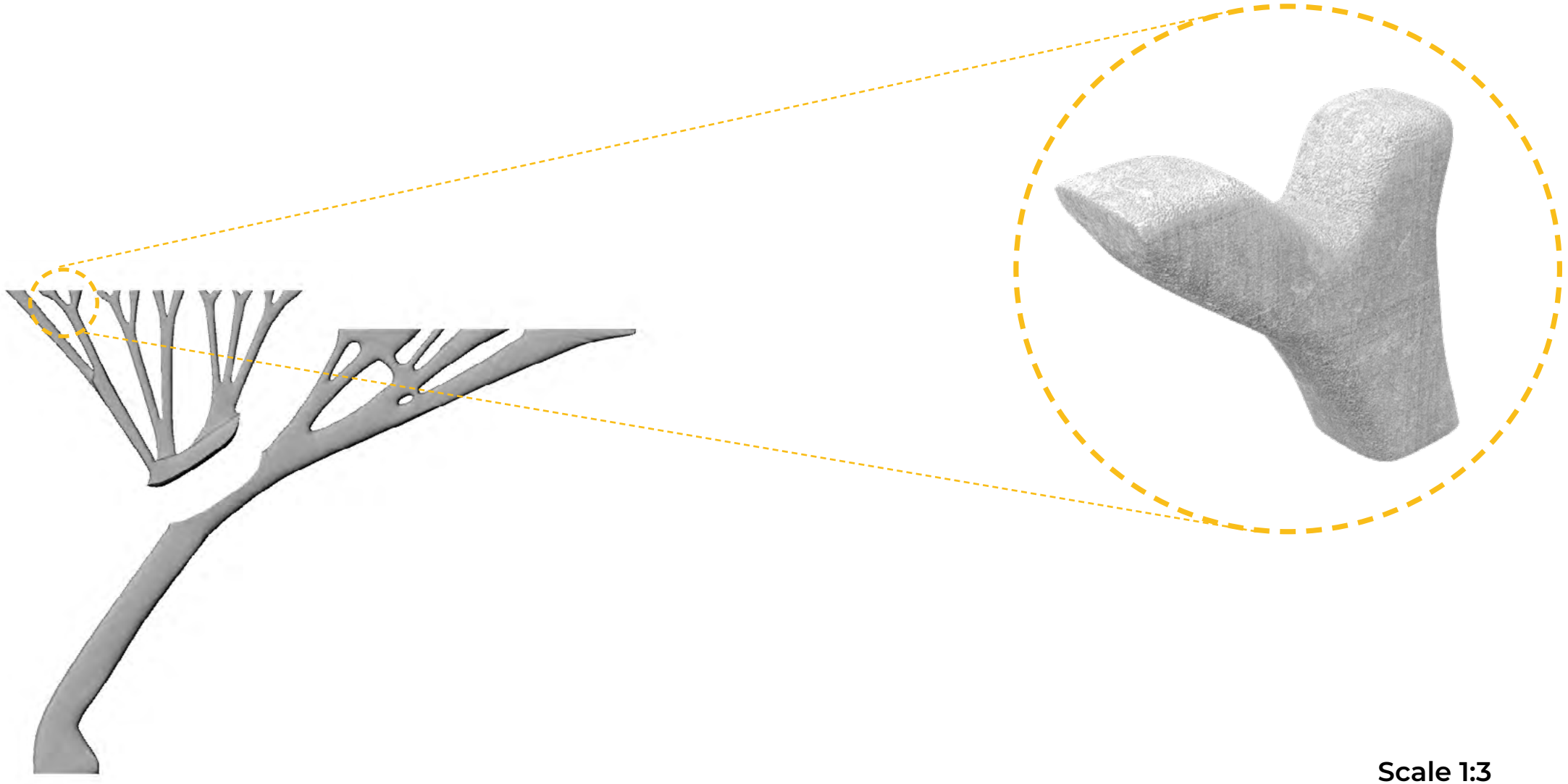


Scale 1:20

GEOMETRY 1 - SCALE 1:20

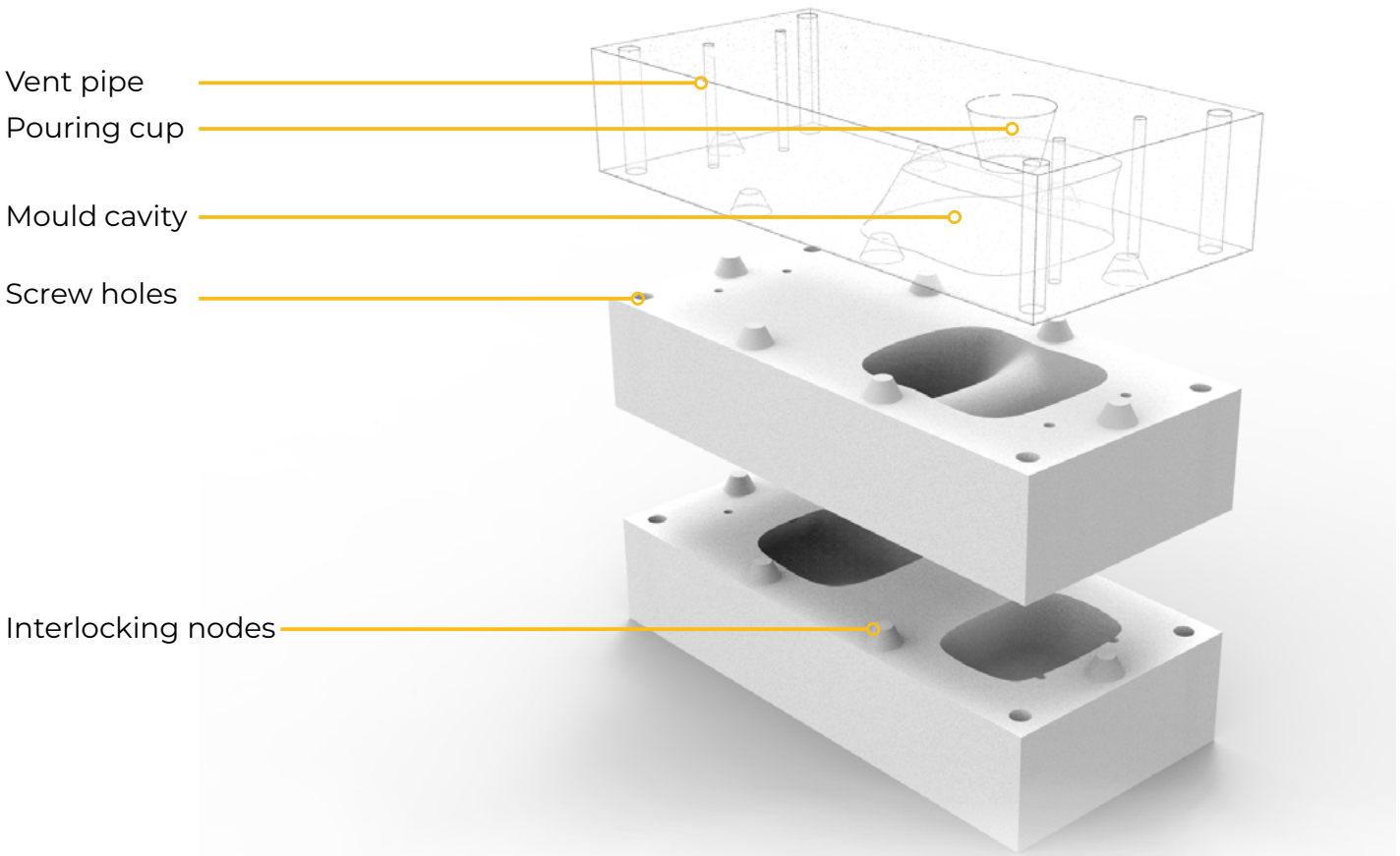


GEOMETRY 2 - SCALE 1:3

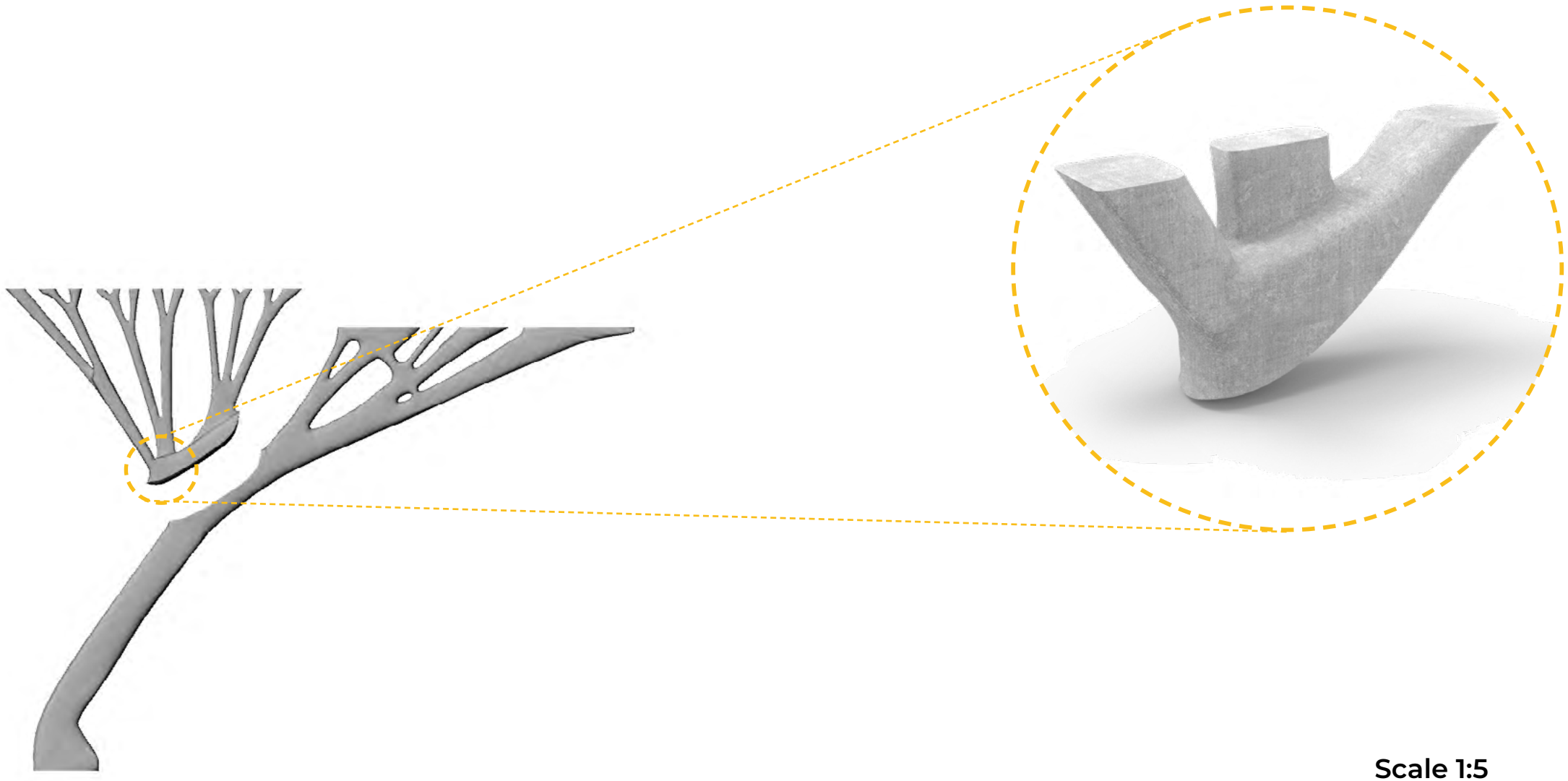


Scale 1:3

GEOMETRY 2 - SCALE 1:3

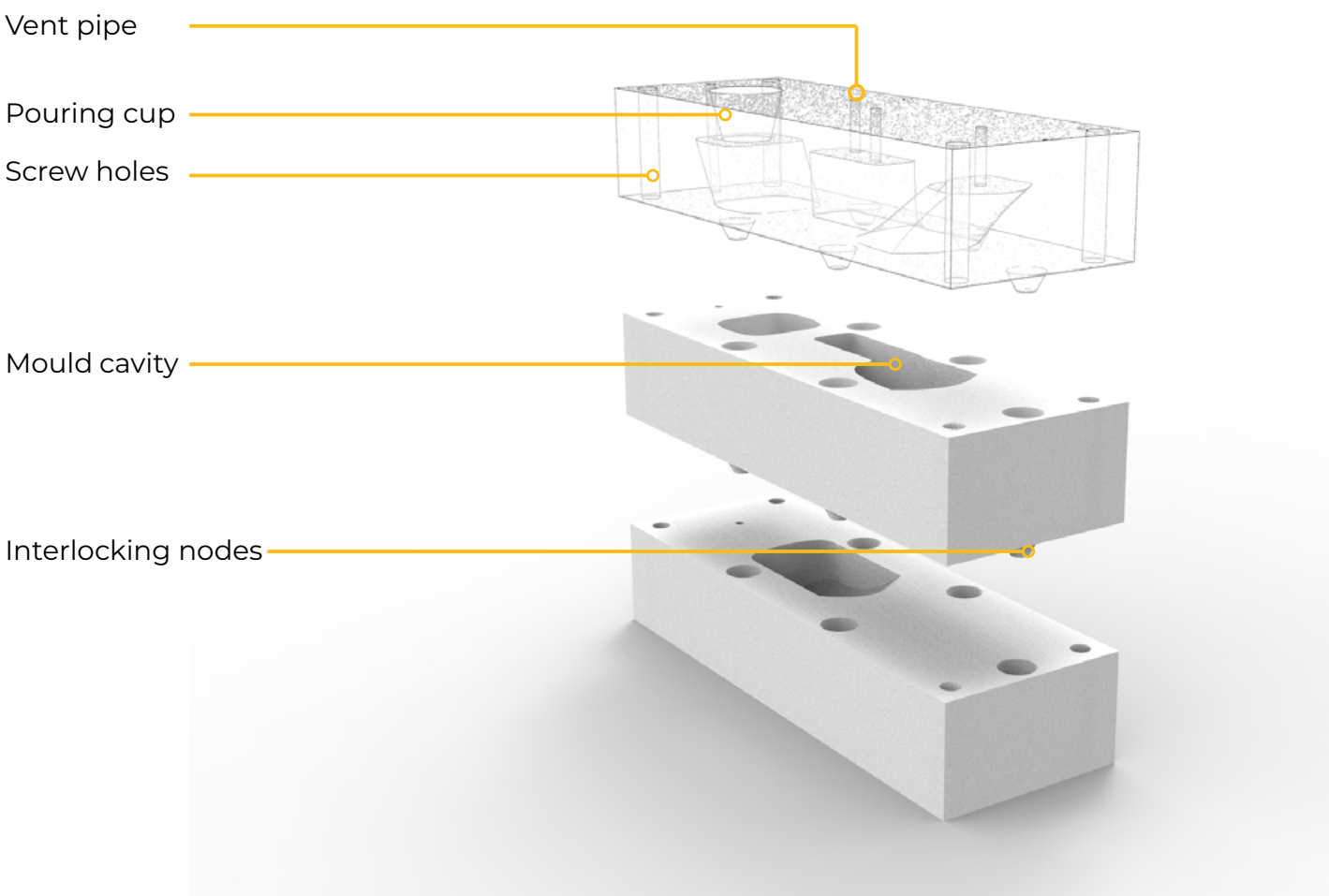


GEOMETRY 3 - SCALE 1:5



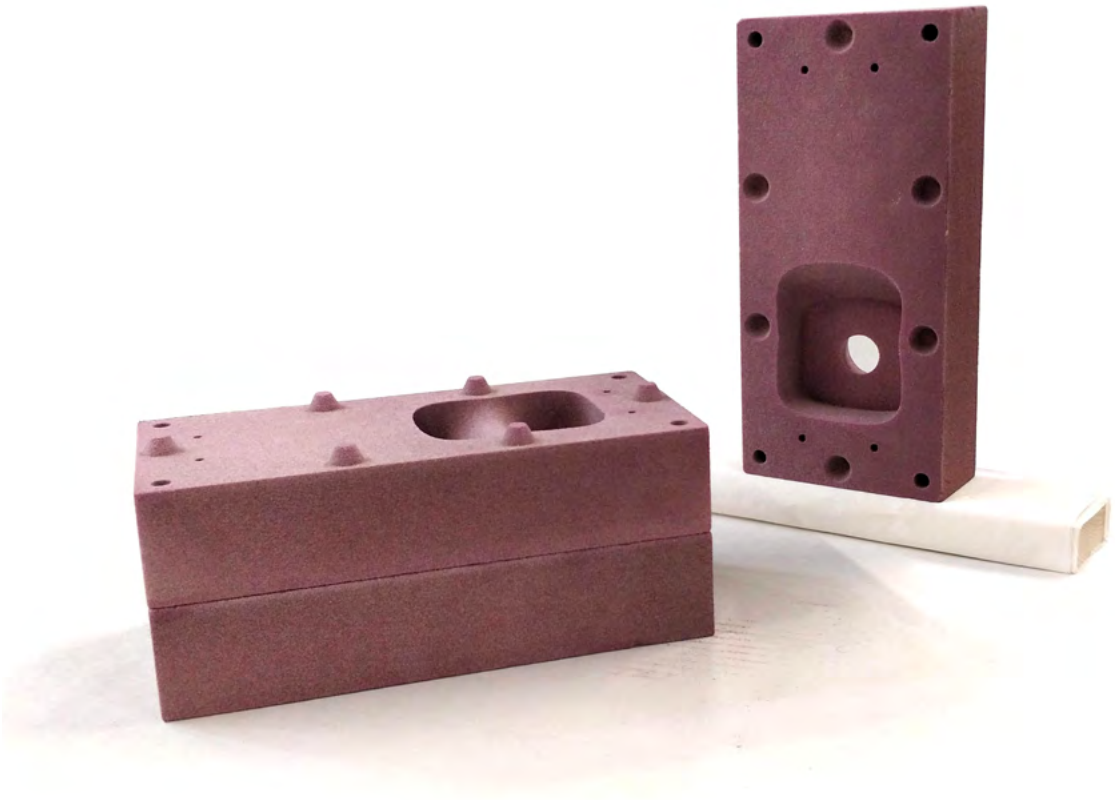
Scale 1:5

GEOMETRY 3 - SCALE 1:5



3D PRINTED MOULDS

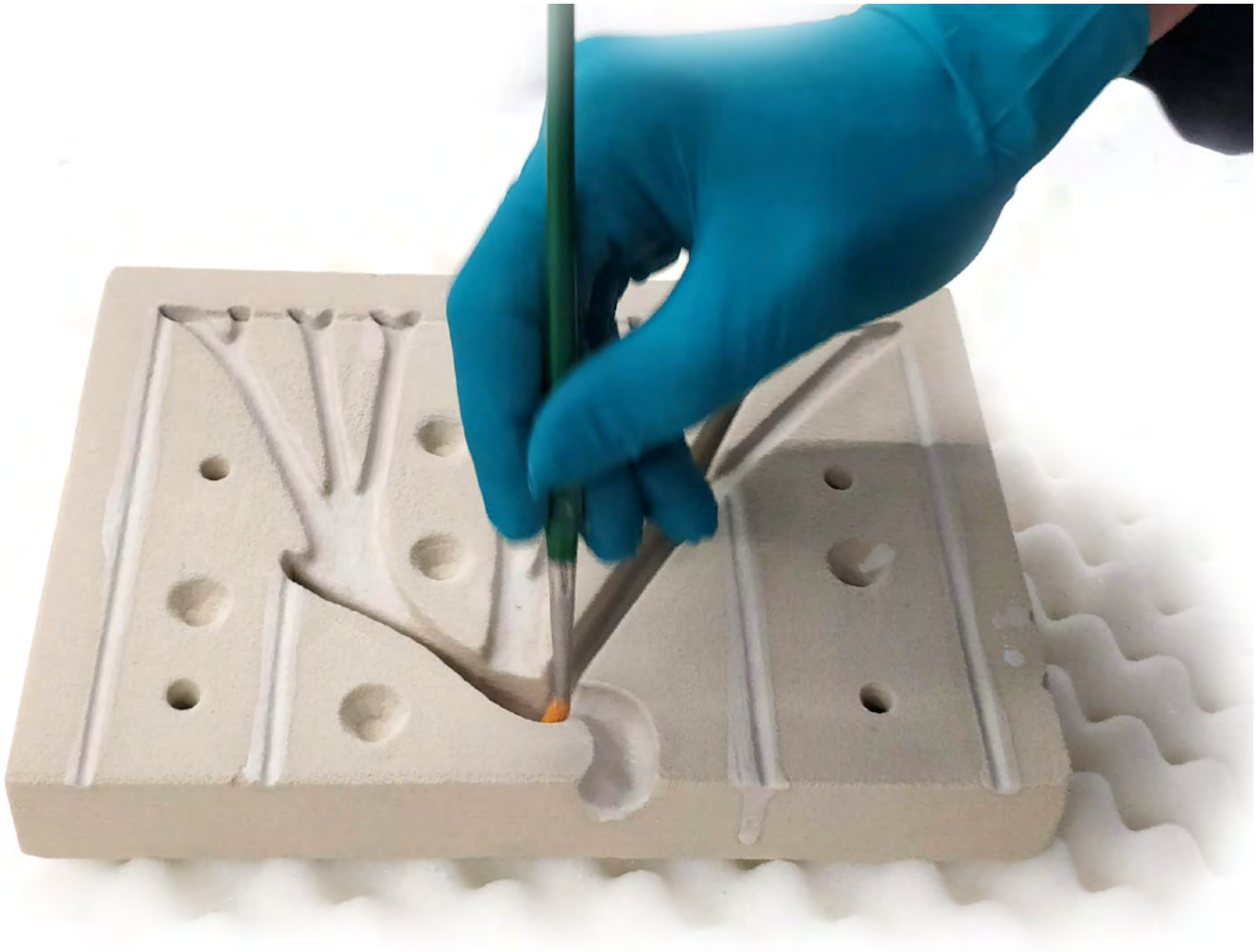
Anorganik binder system



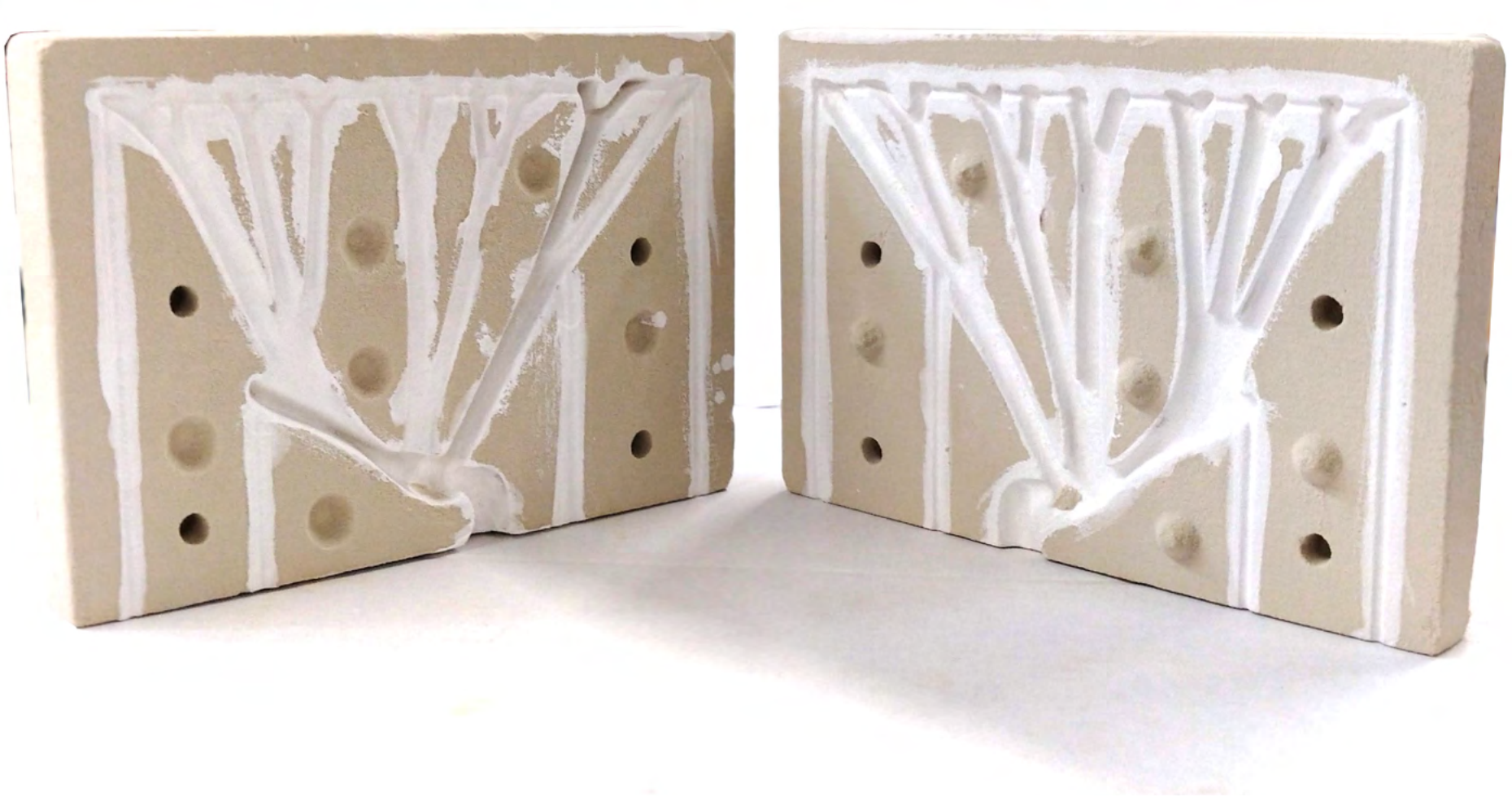
Cold hardening Phenolic

MOULD PREPARATION- GEOMETRY 1

MOULD PREPARATION

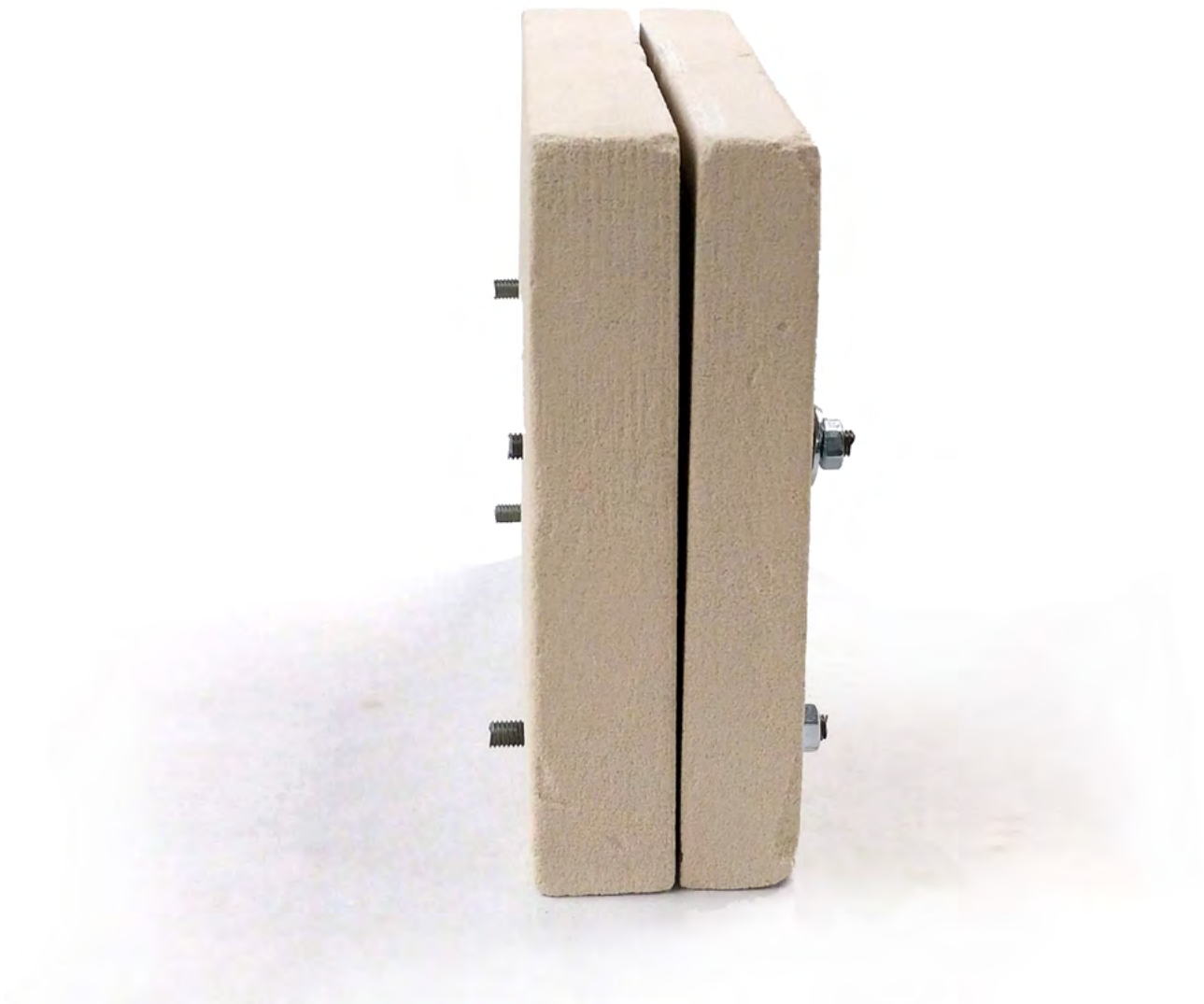


MOULD PREPARATION



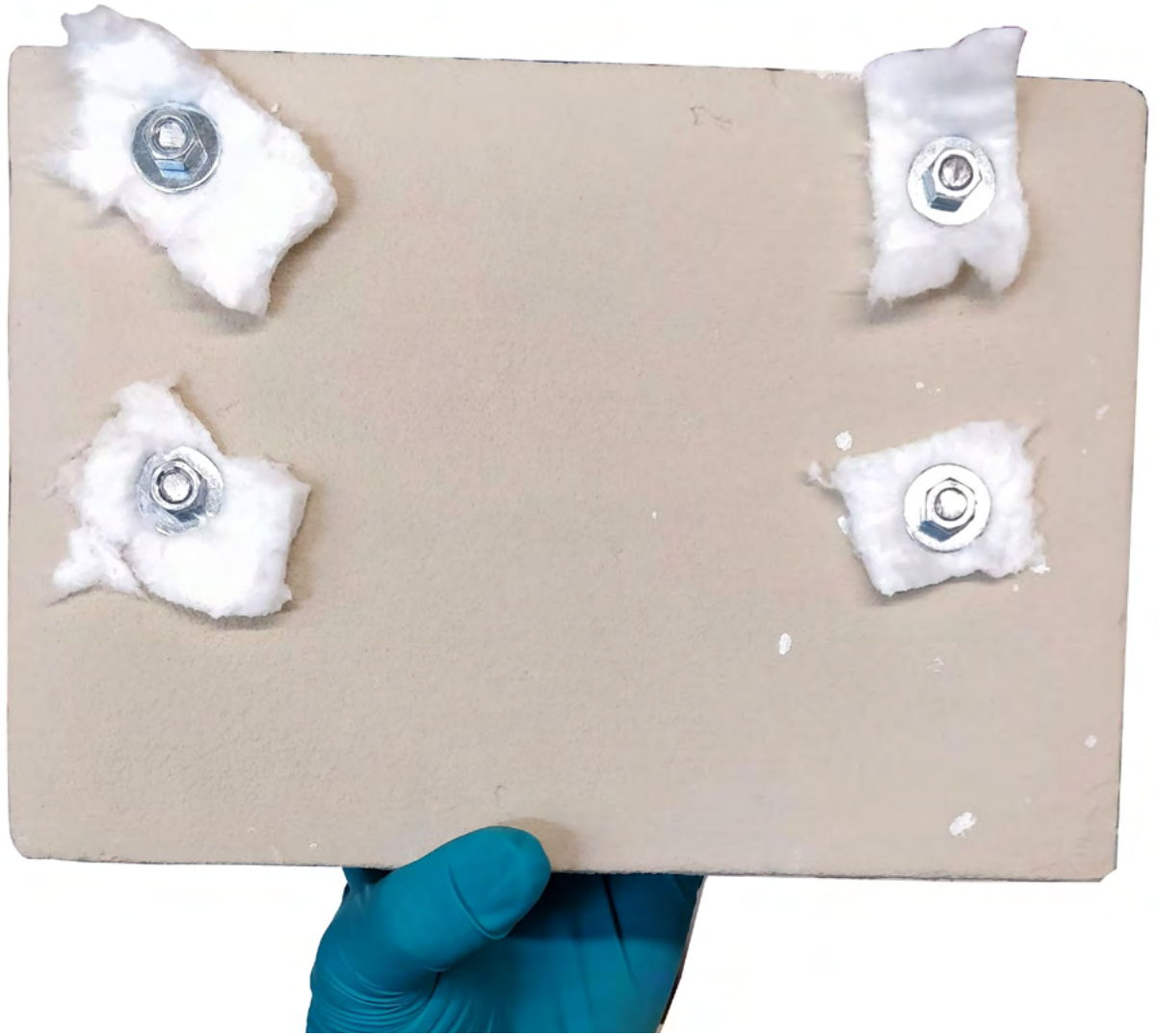
MOULD PREPARATION

MOULD PREPARATION



MOULD PREPARATION

MOULD PREPARATION



MOULD PREPARATION

MOULD PREPARATION

MOULD PREPARATION

MOULD PREPARATION

MOULD PREPARATION

MOULD PREPARATION

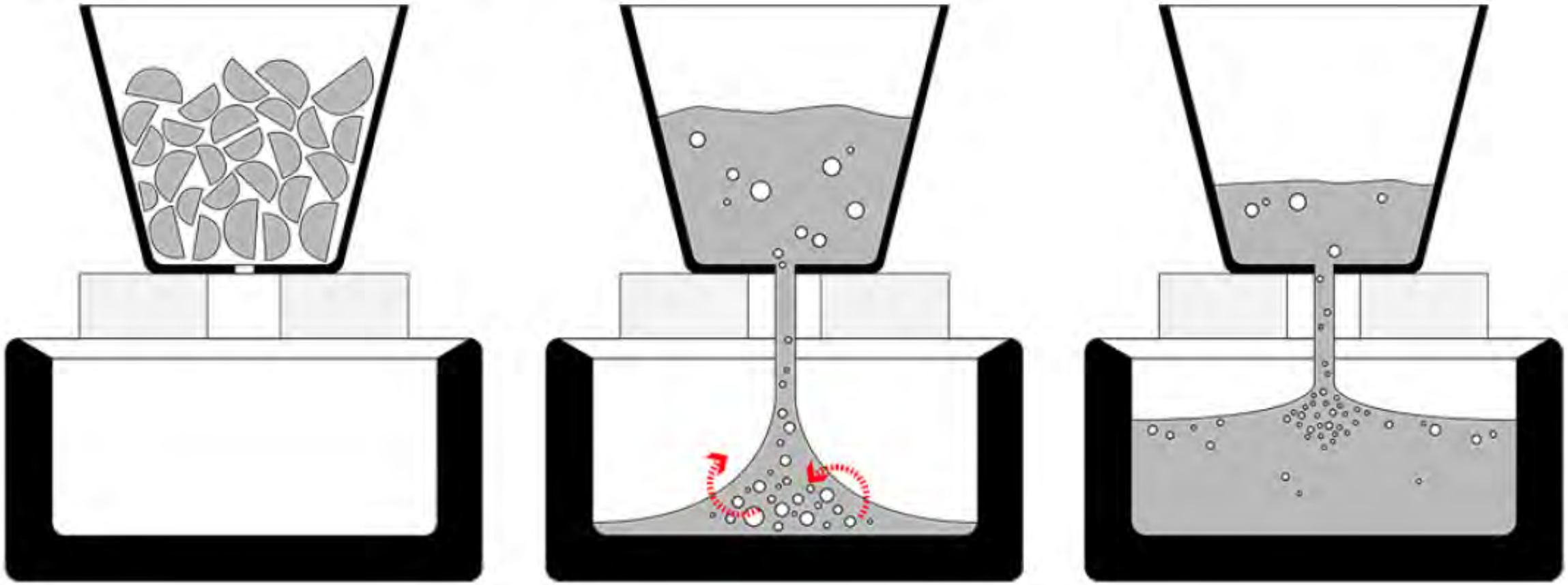
MOULD PREPARATION

MOULD PREPARATION

MOULD PREPARATION

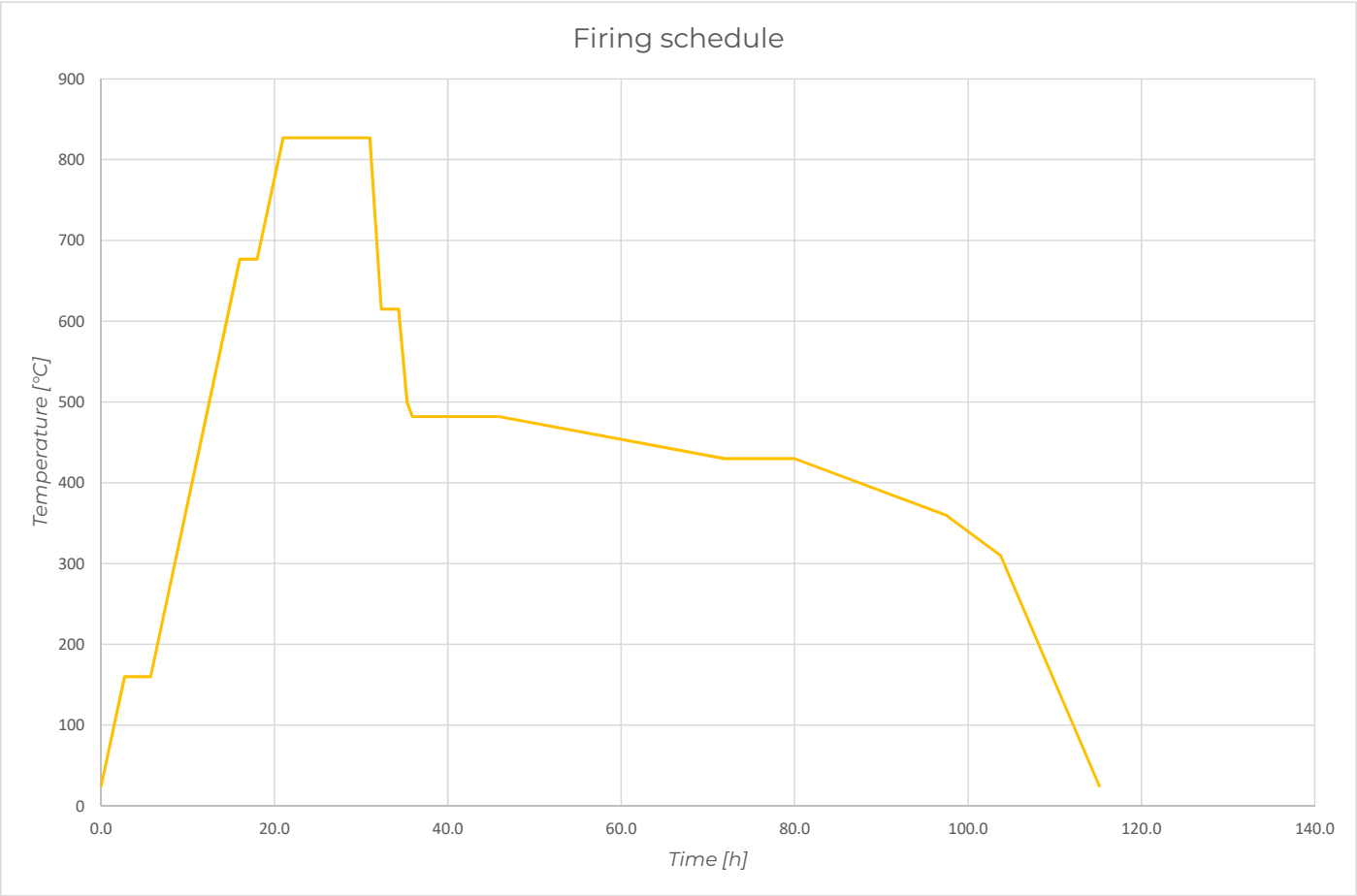
MOULD PREPARATION

CASTING PROCESS



(T. Bristogianni, et al. 2017)

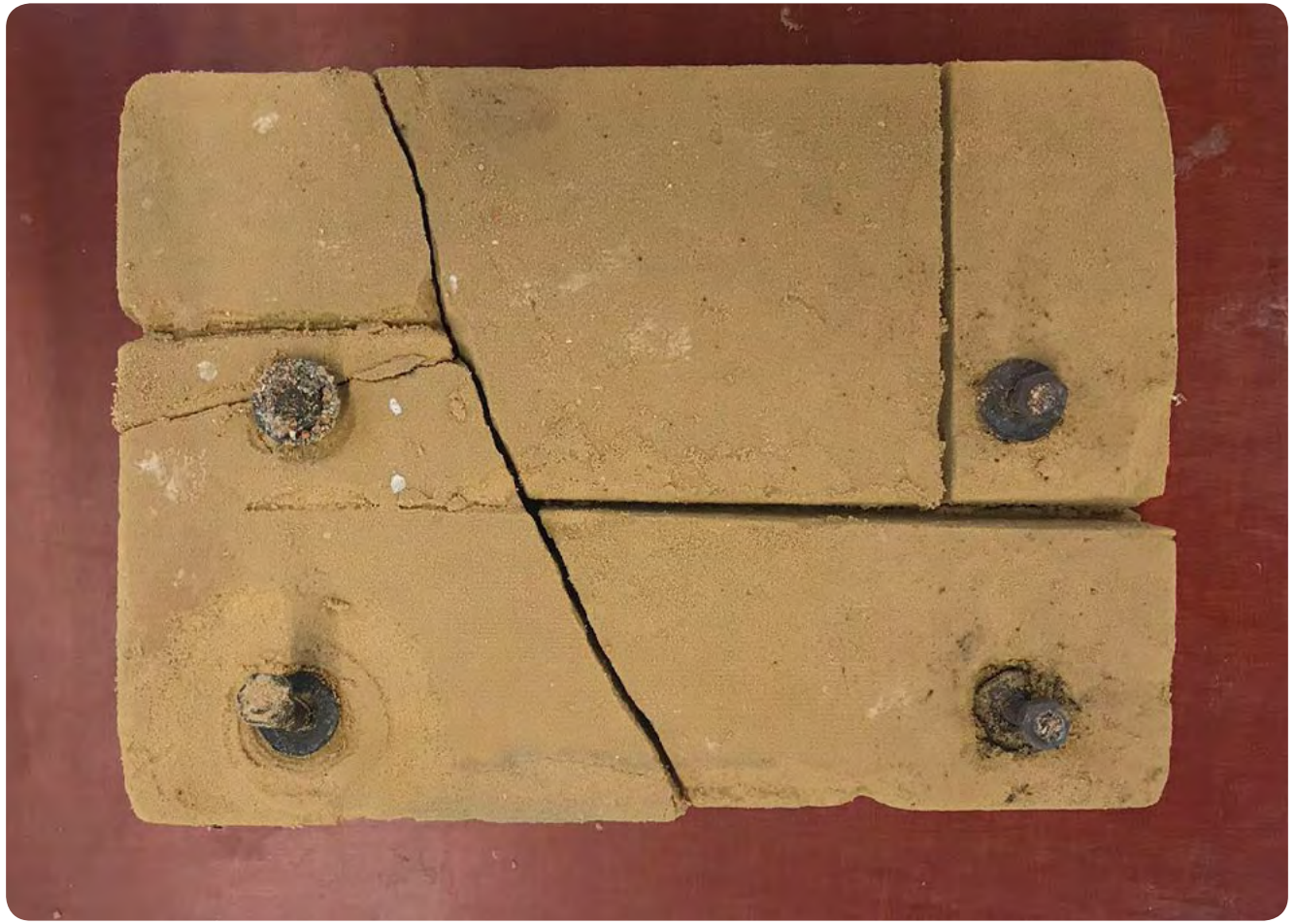
ANNEALING PROGRAM FOR KILN



CASTED MOULD

CASTED MOULD

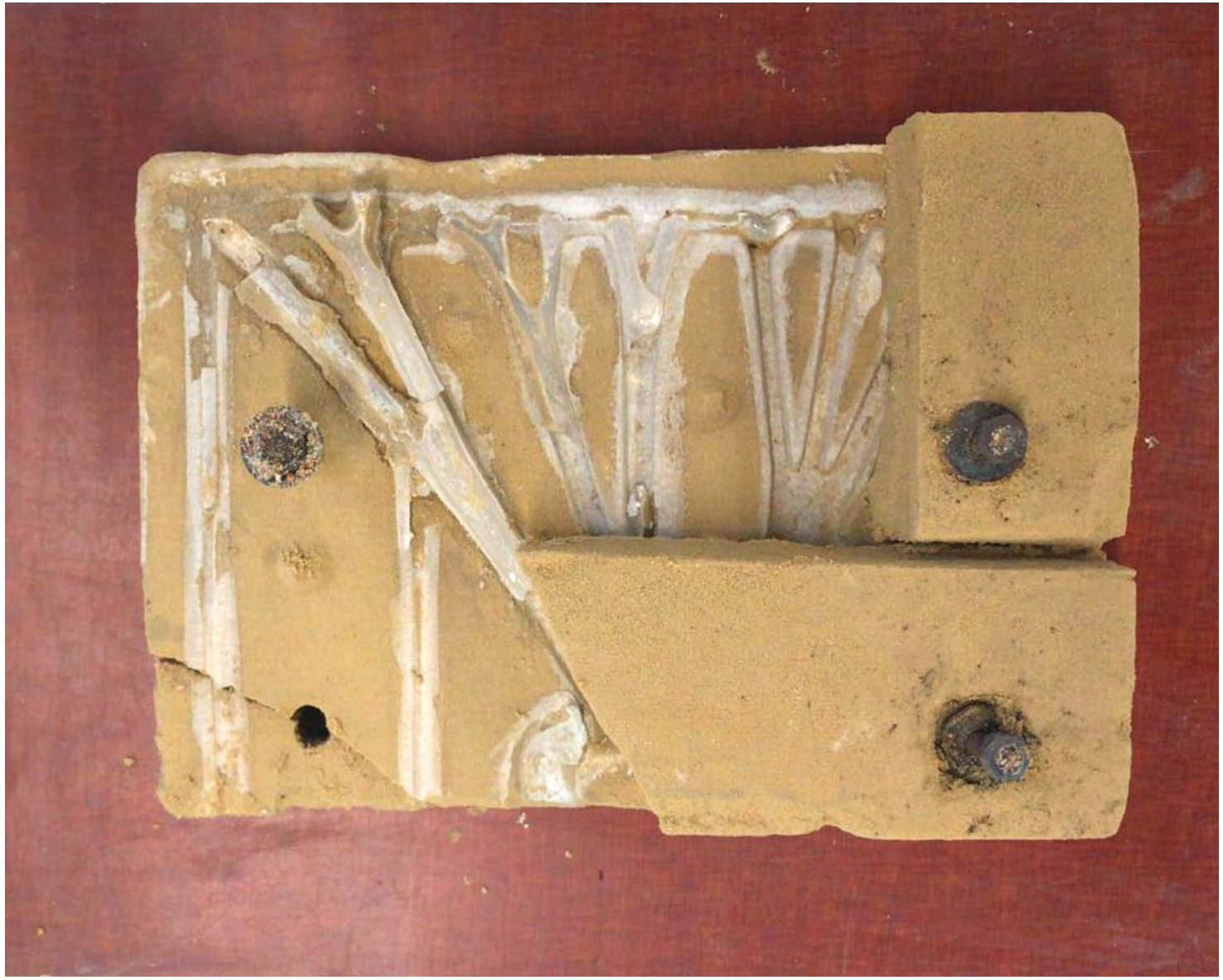
MOULD BREAKAGE



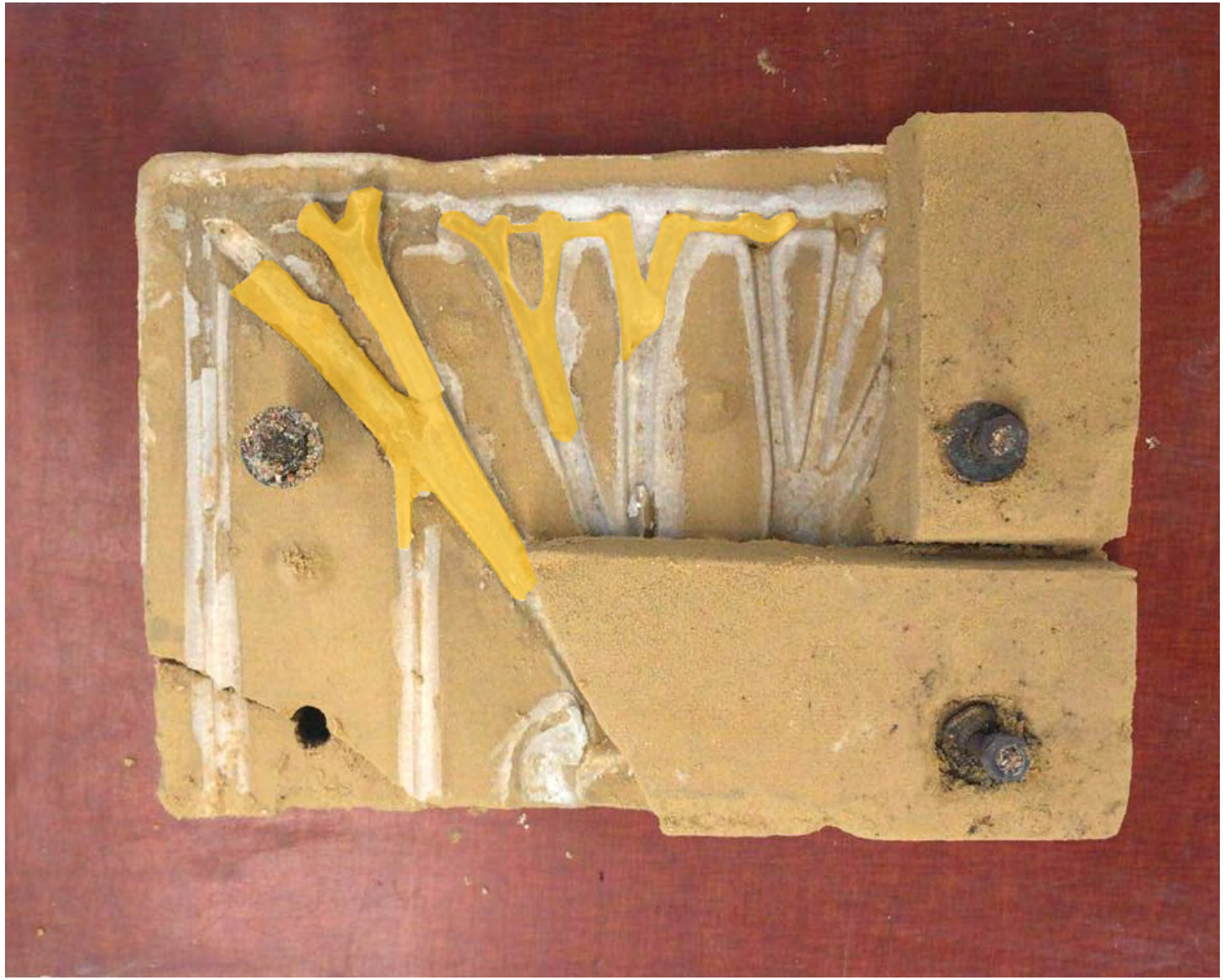
CASTED GLASS

ERRORS IN MOULD DESIGN

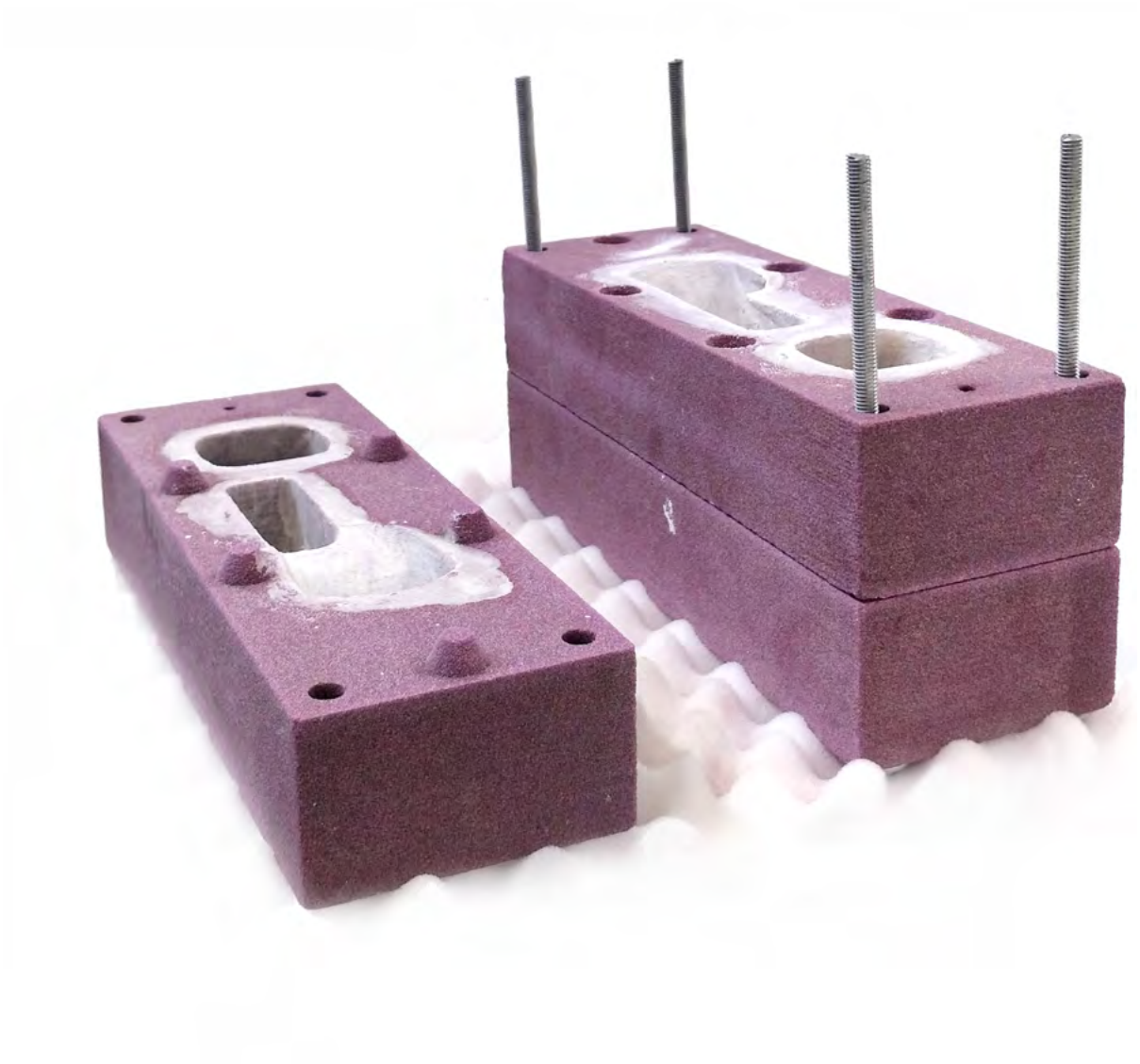
INCOMPLETE GLASS GEOMETRY



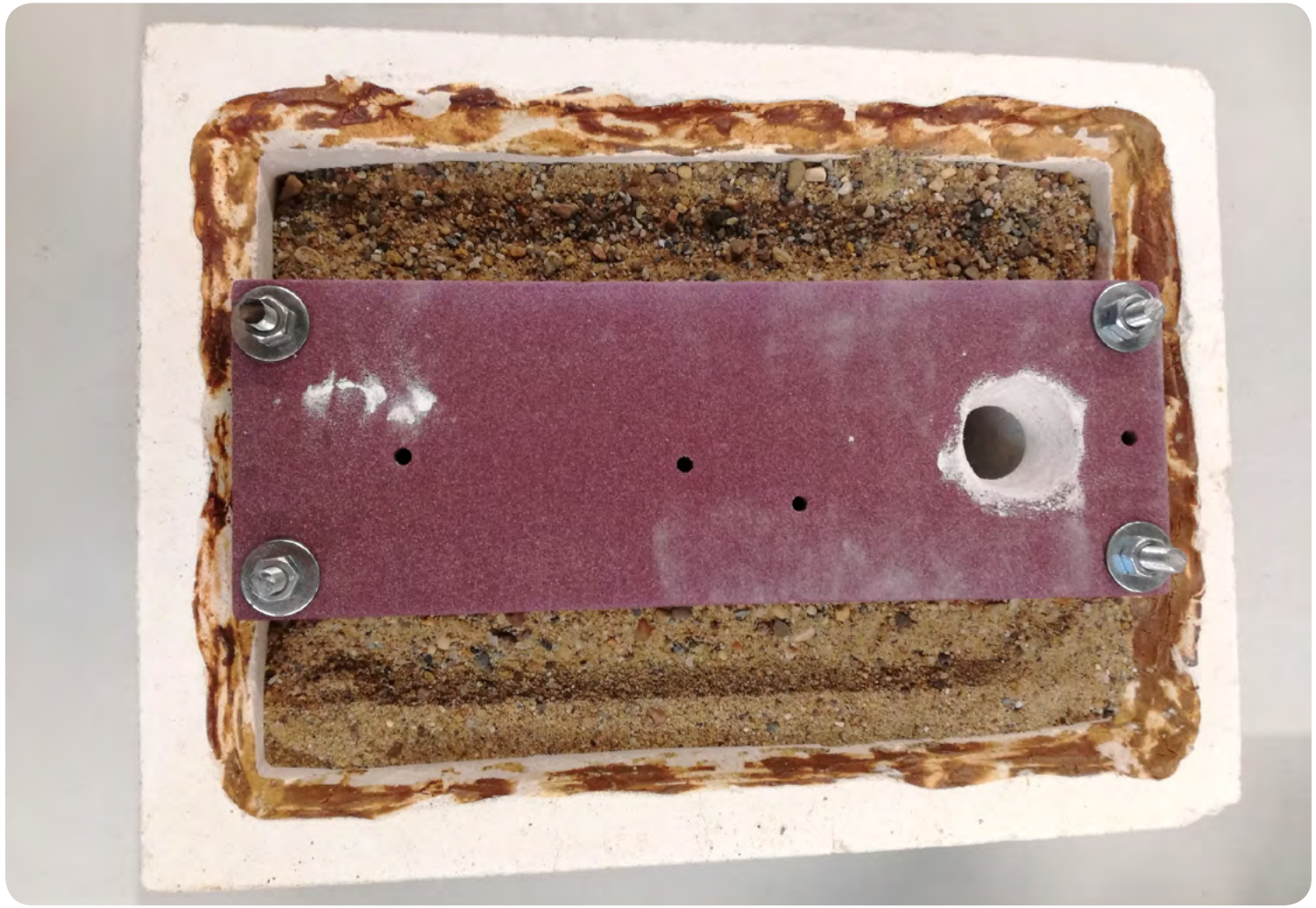
INCOMPLETE GLASS GEOMETRY



SAND MOULD- GEOMETRY 3



SAND MOULD- GEOMETRY 3

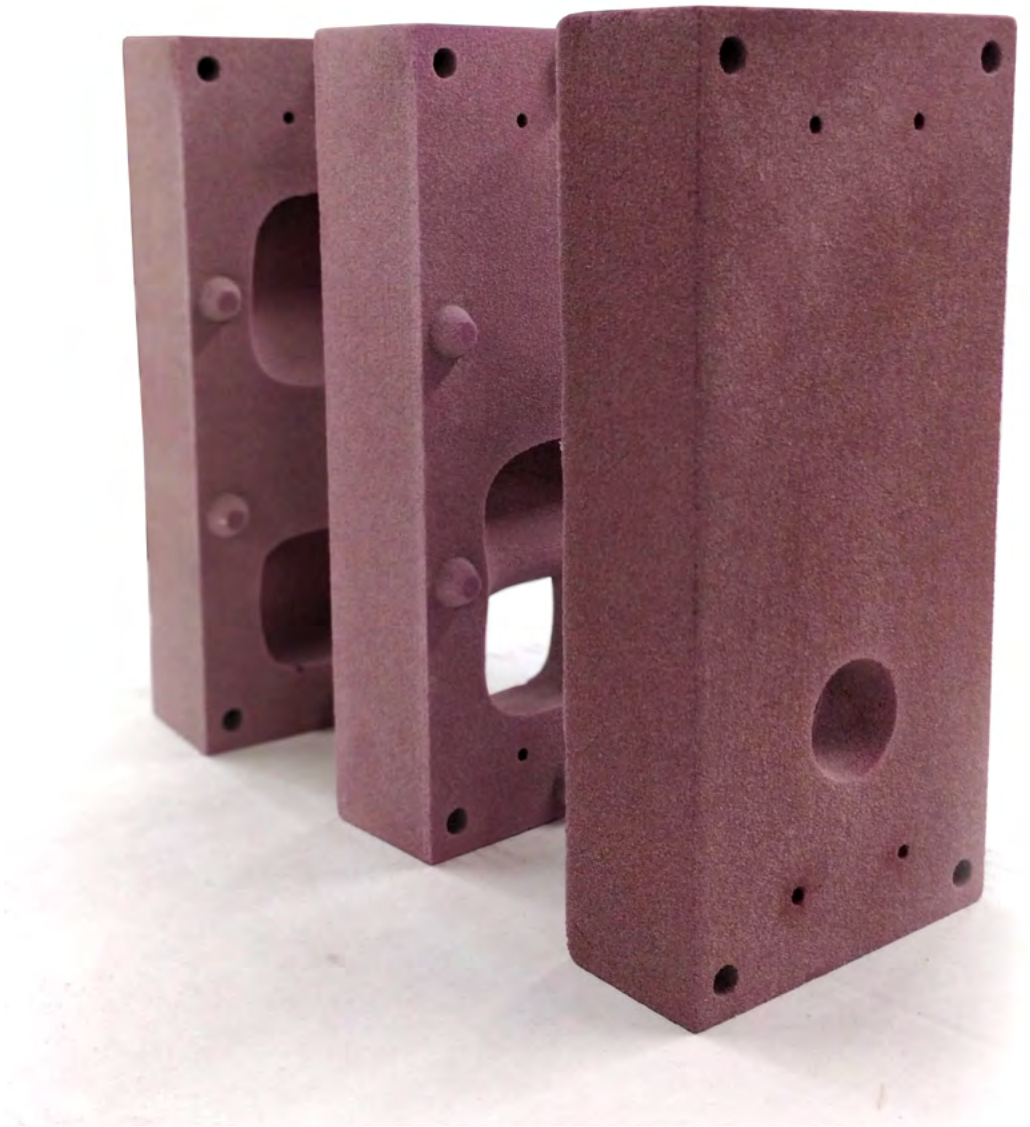


CASTED GLASS PROTOTYPE - GEOMETRY 3

CASTED GLASS PROTOTYPE - GEOMETRY 3

FINISHED GLASS PROTOTYPE - GEOMETRY 3

SAND MOULD- GEOMETRY 2

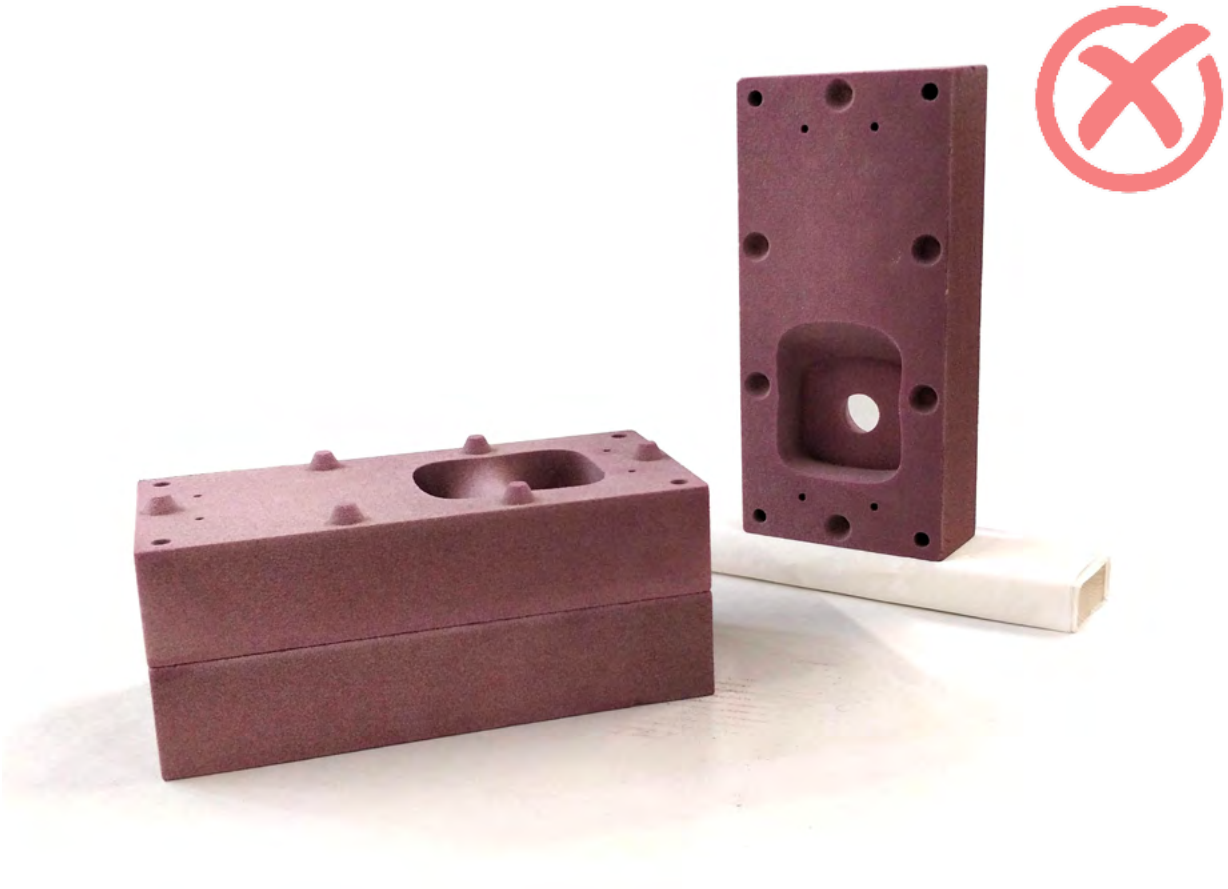


SAND MOULD- GEOMETRY 2

SAND MOULD- GEOMETRY 2

INFERENCE

Anorganik binder system

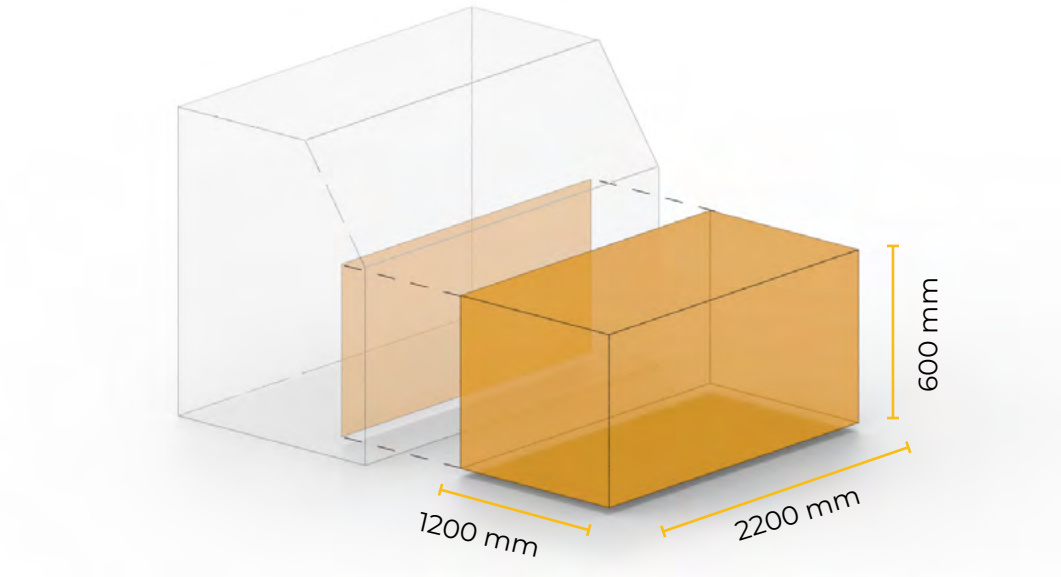


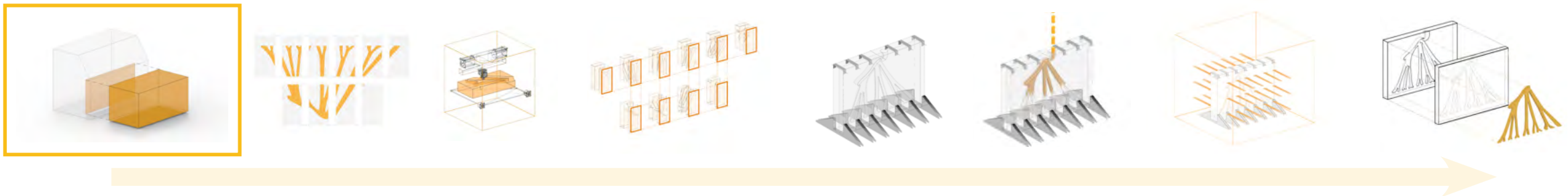
Cold hardening Phenolic

PRODUCTION TO ASSEMBLY

FABRICATION

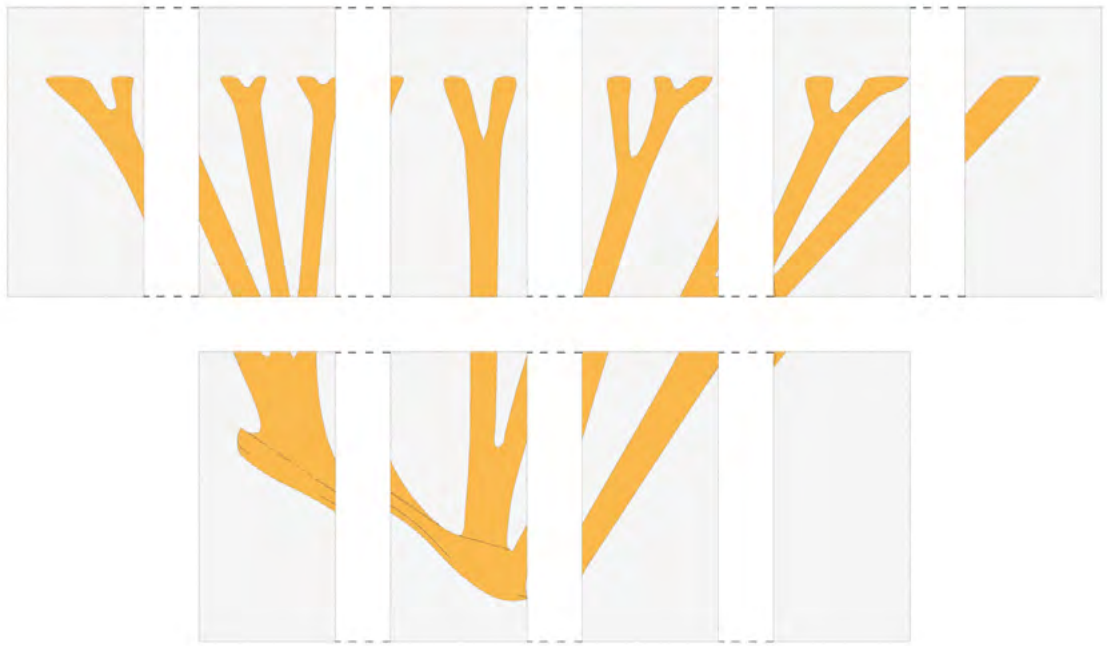
STEP 1:

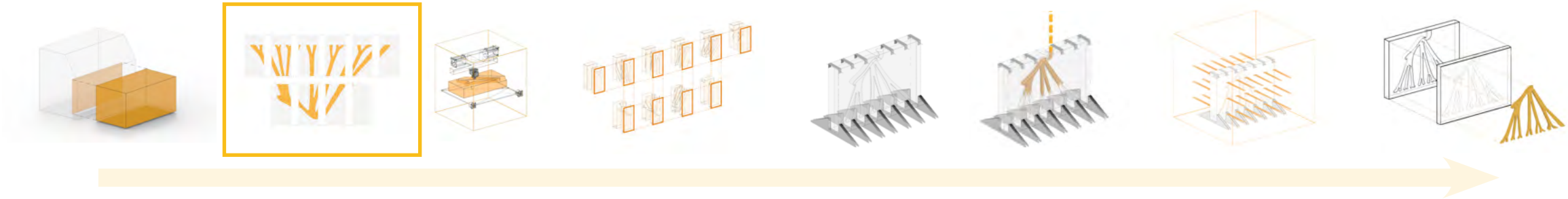




FABRICATION

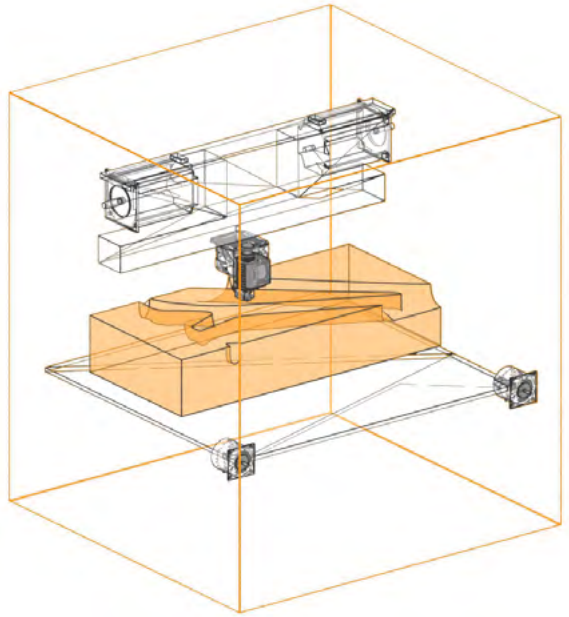
STEP 2:

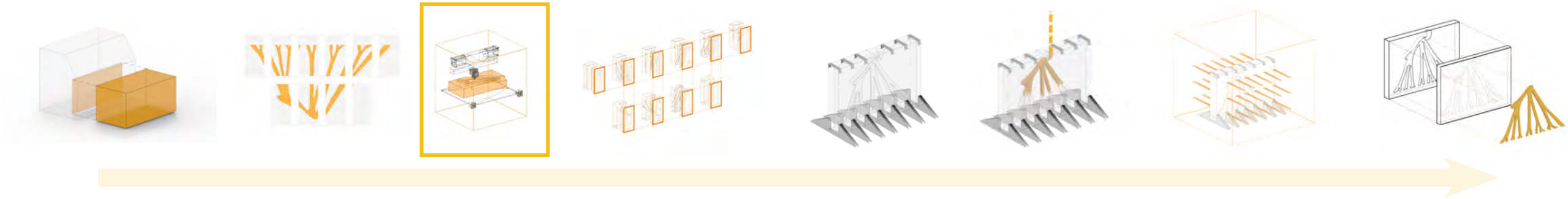




FABRICATION

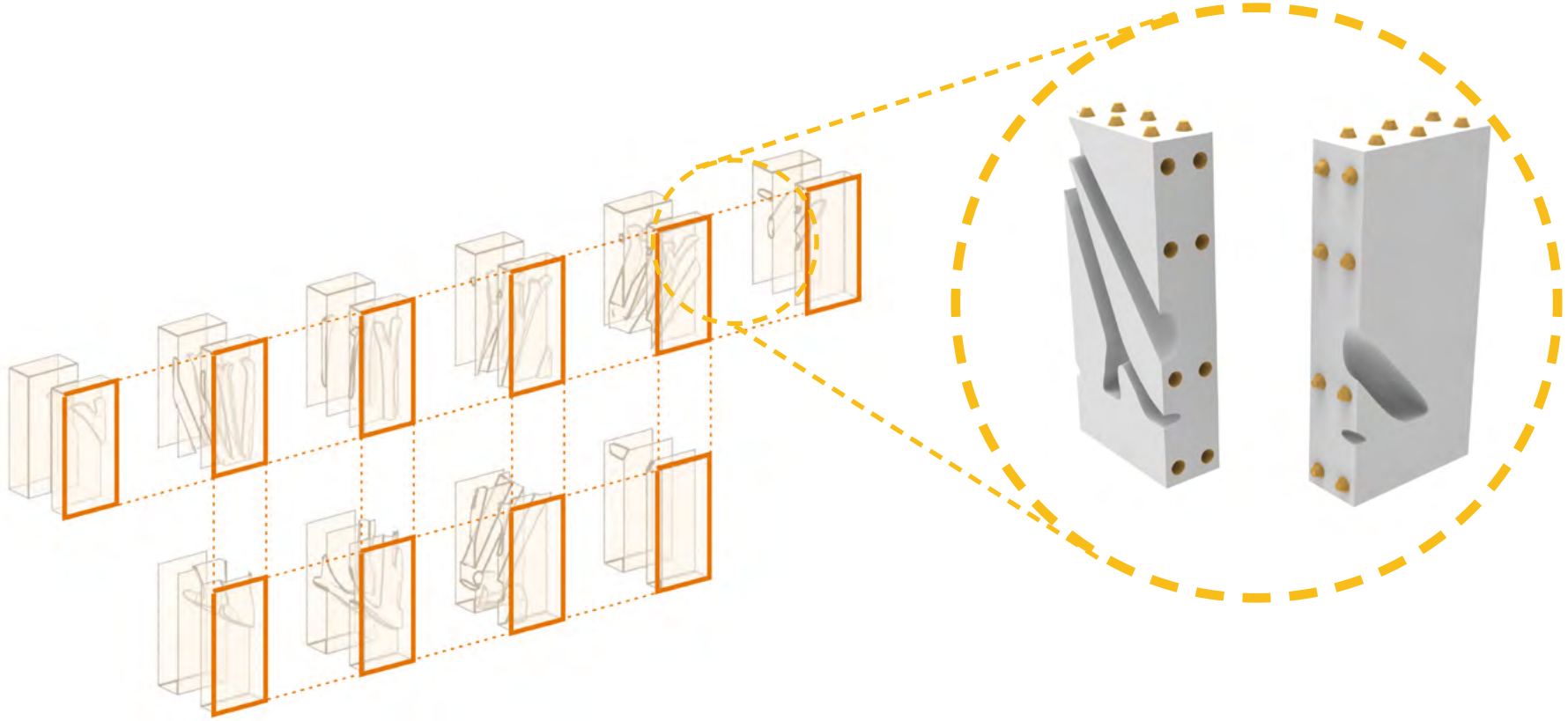
STEP 3:

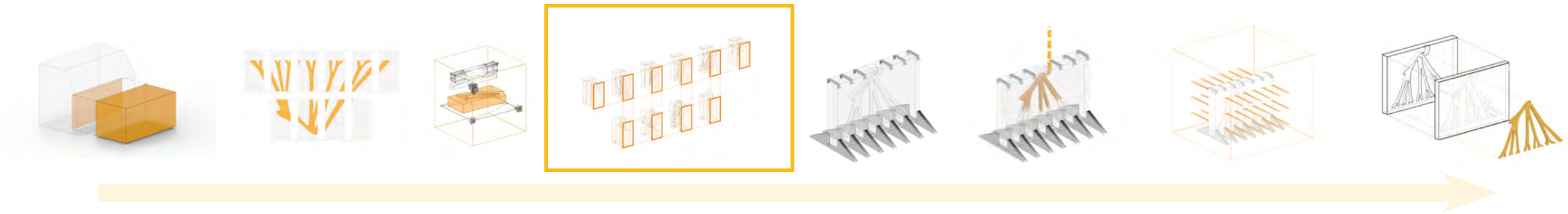




FABRICATION

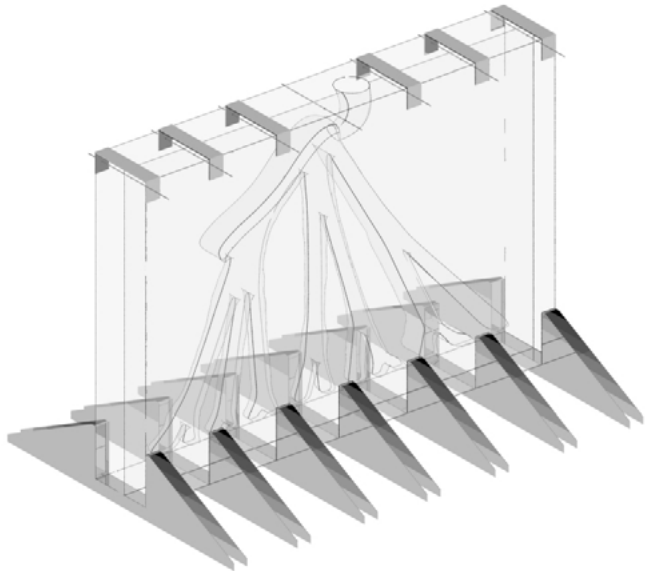
STEP 4:

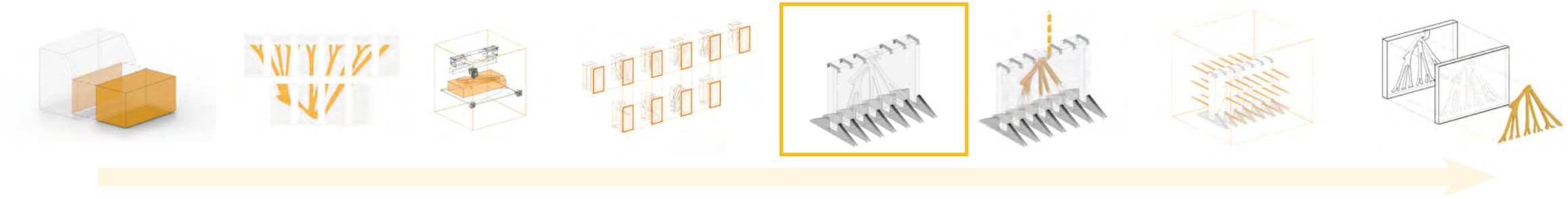




FABRICATION

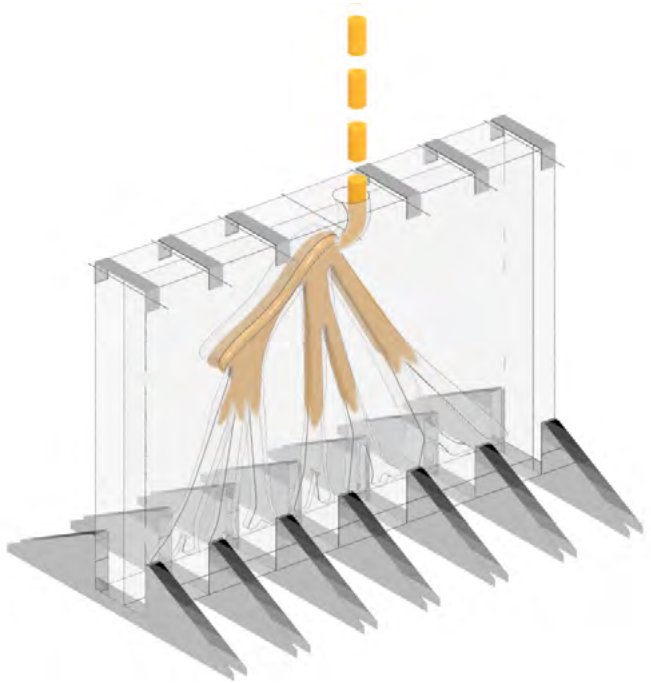
STEP 5:

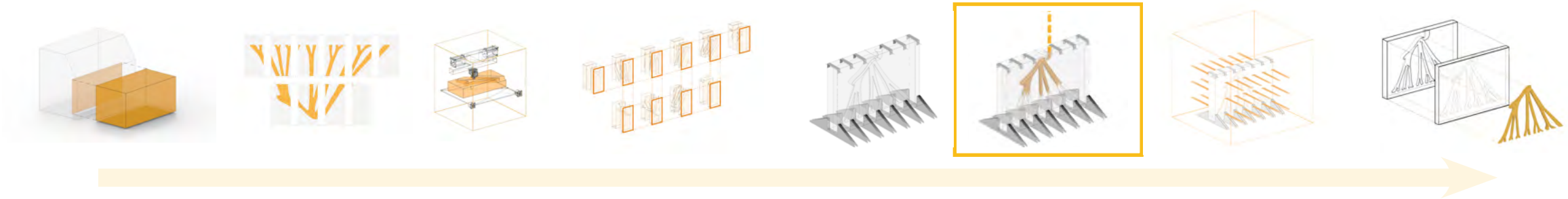




FABRICATION

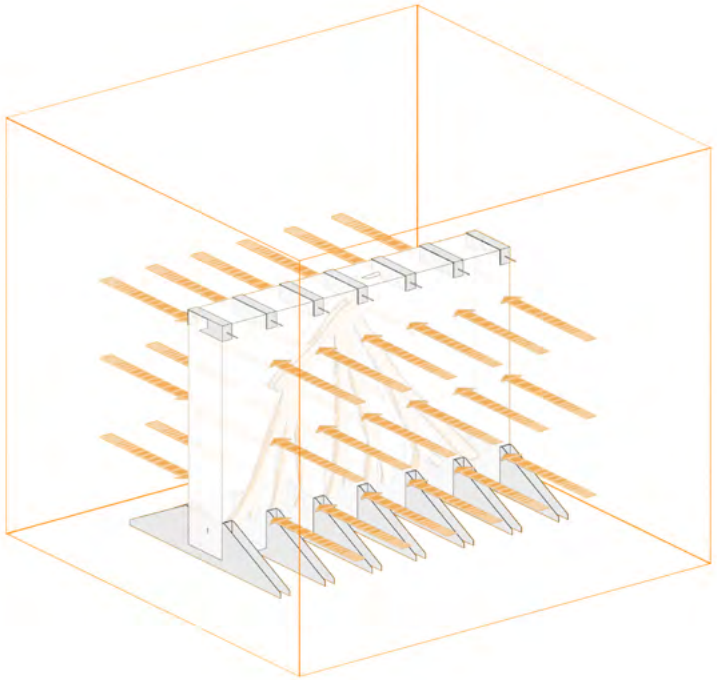
STEP 6:

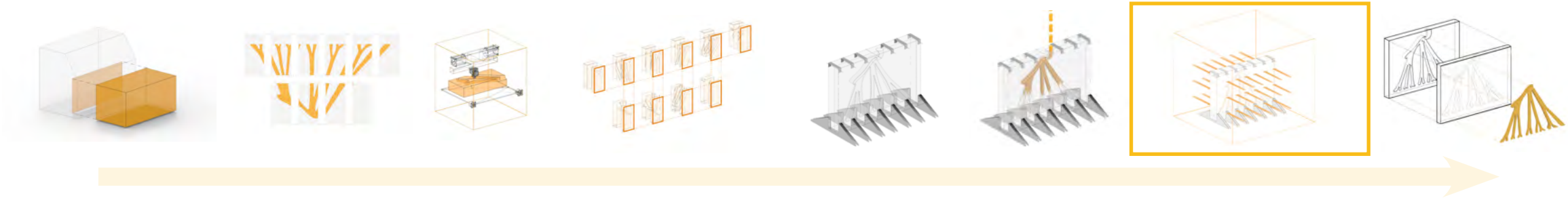




FABRICATION

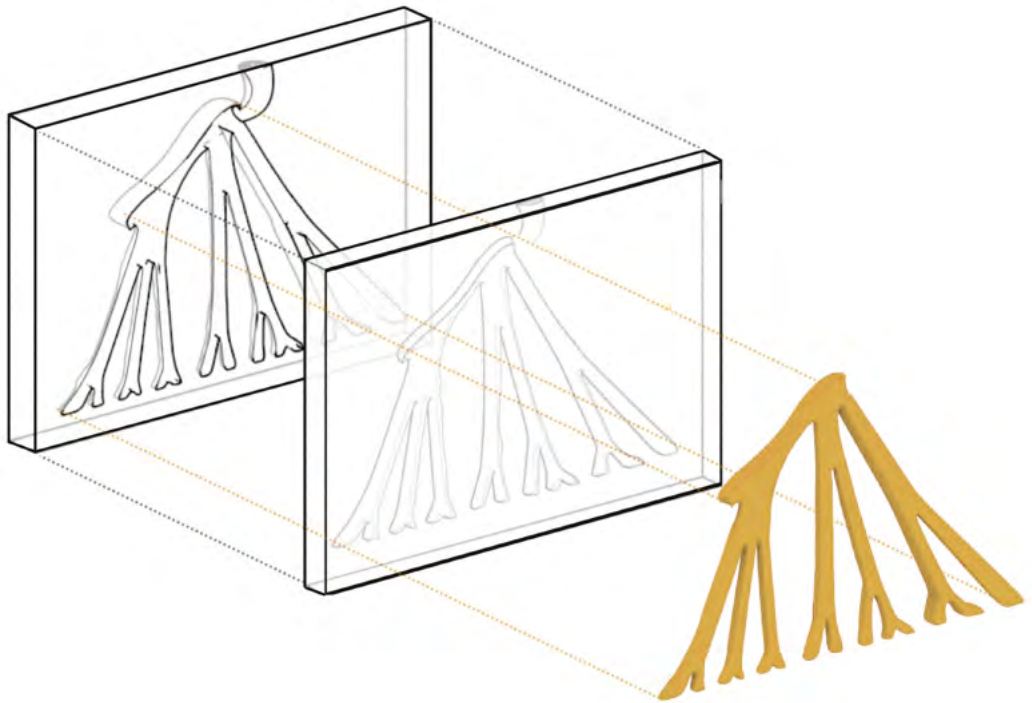
STEP 7:

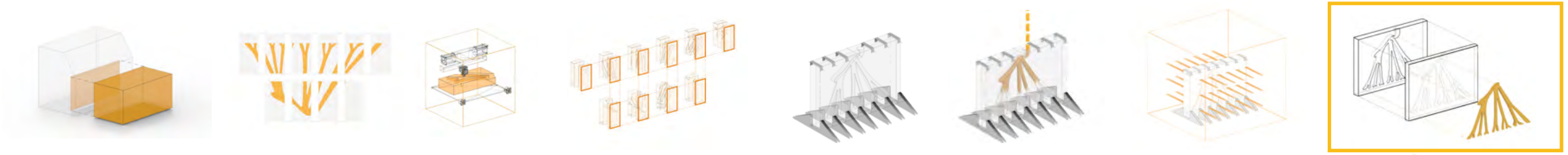




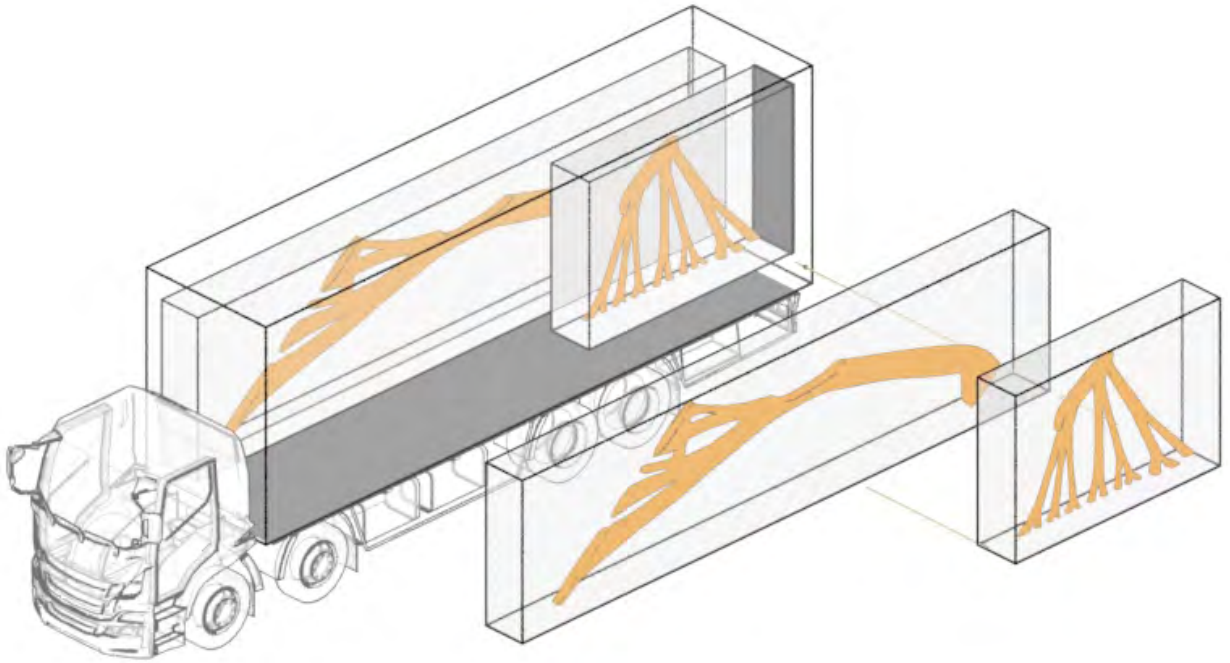
FABRICATION

STEP 8:



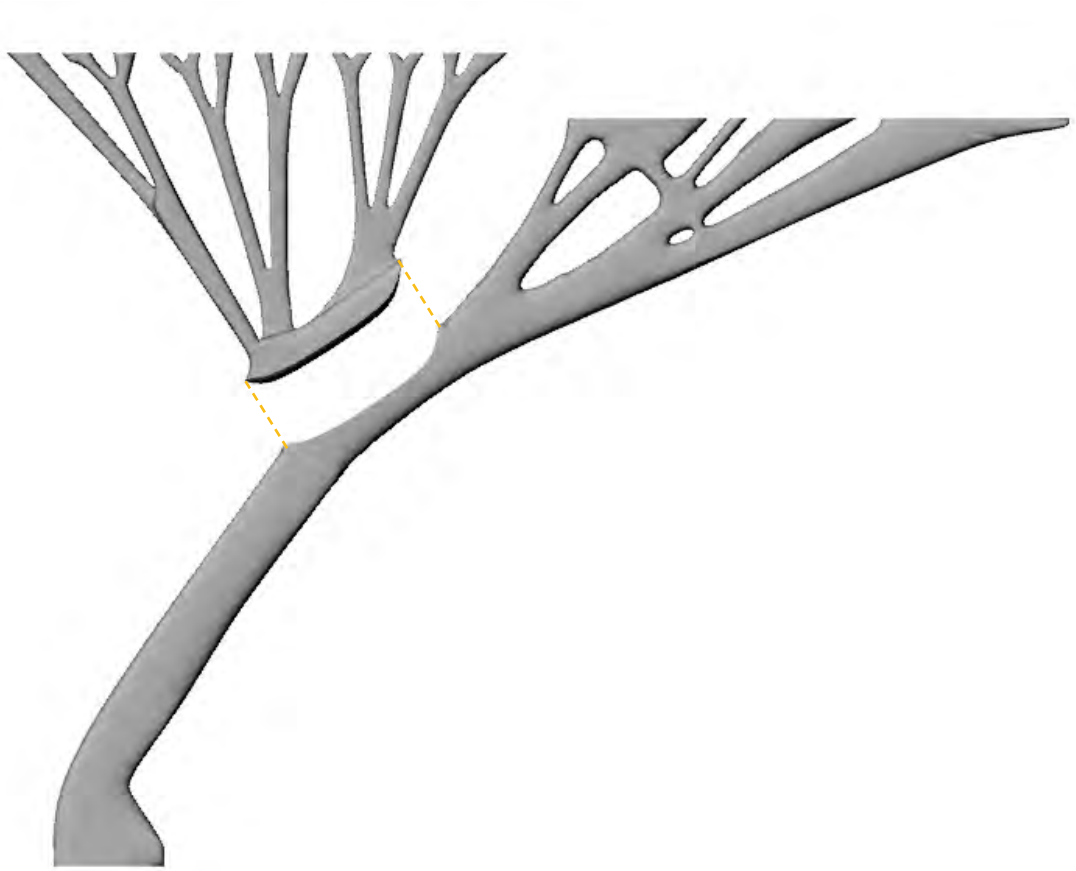


TRANSPORTATION



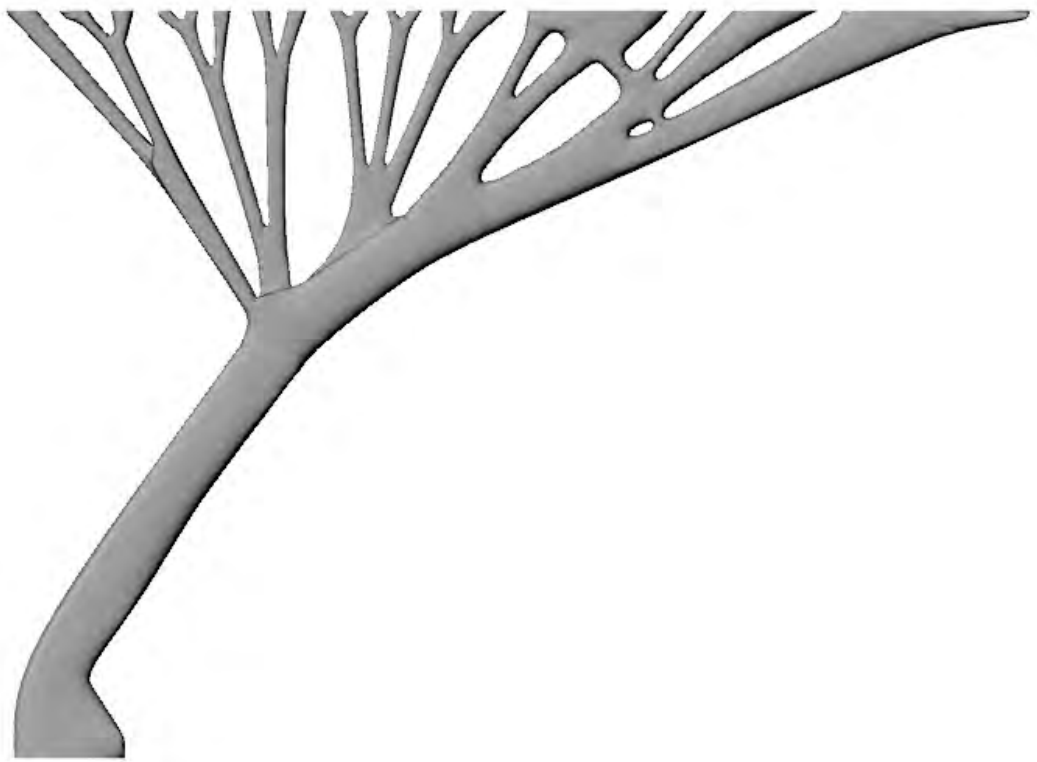
INSTALLATION

STEP 1:



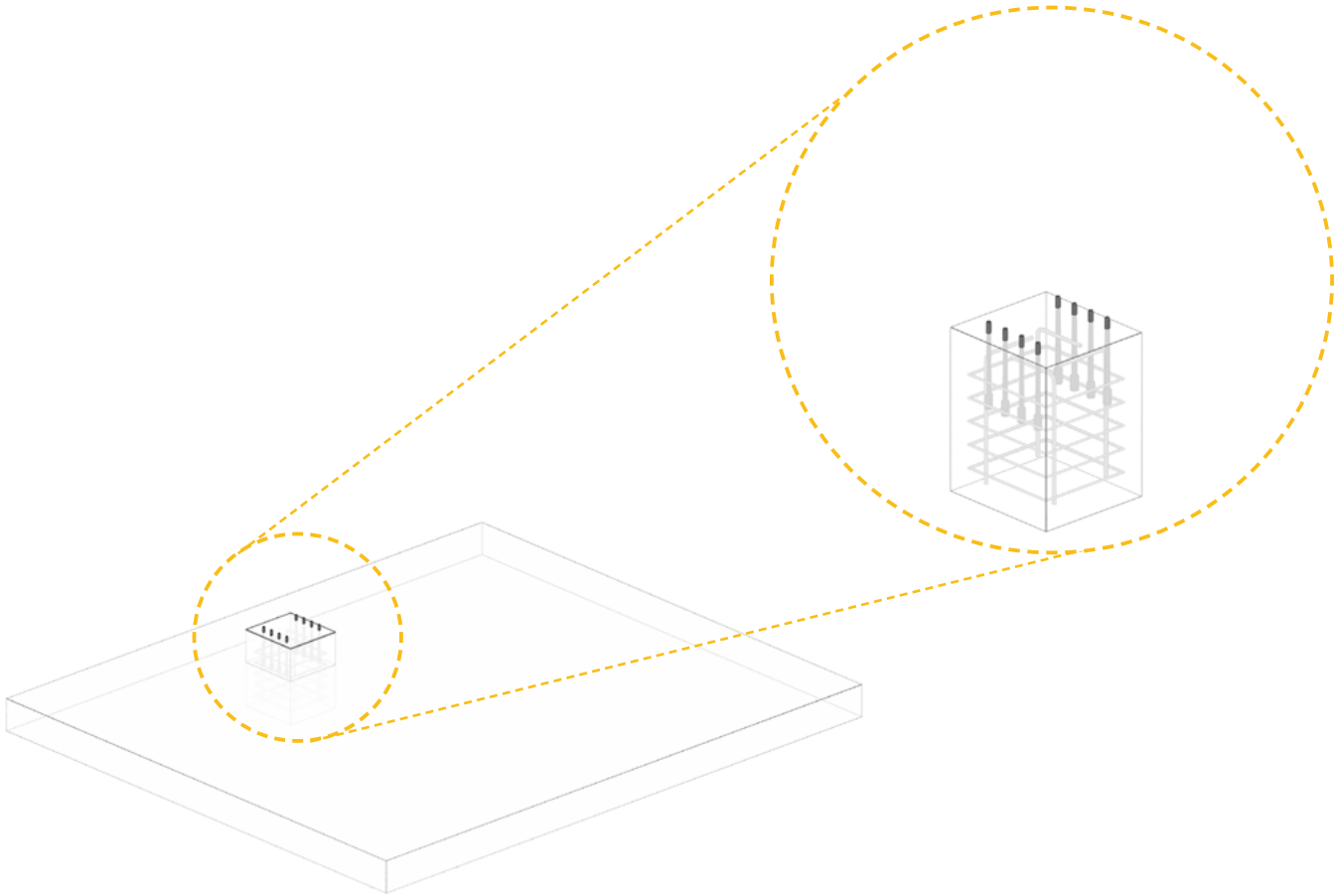
INSTALLATION

STEP 1:



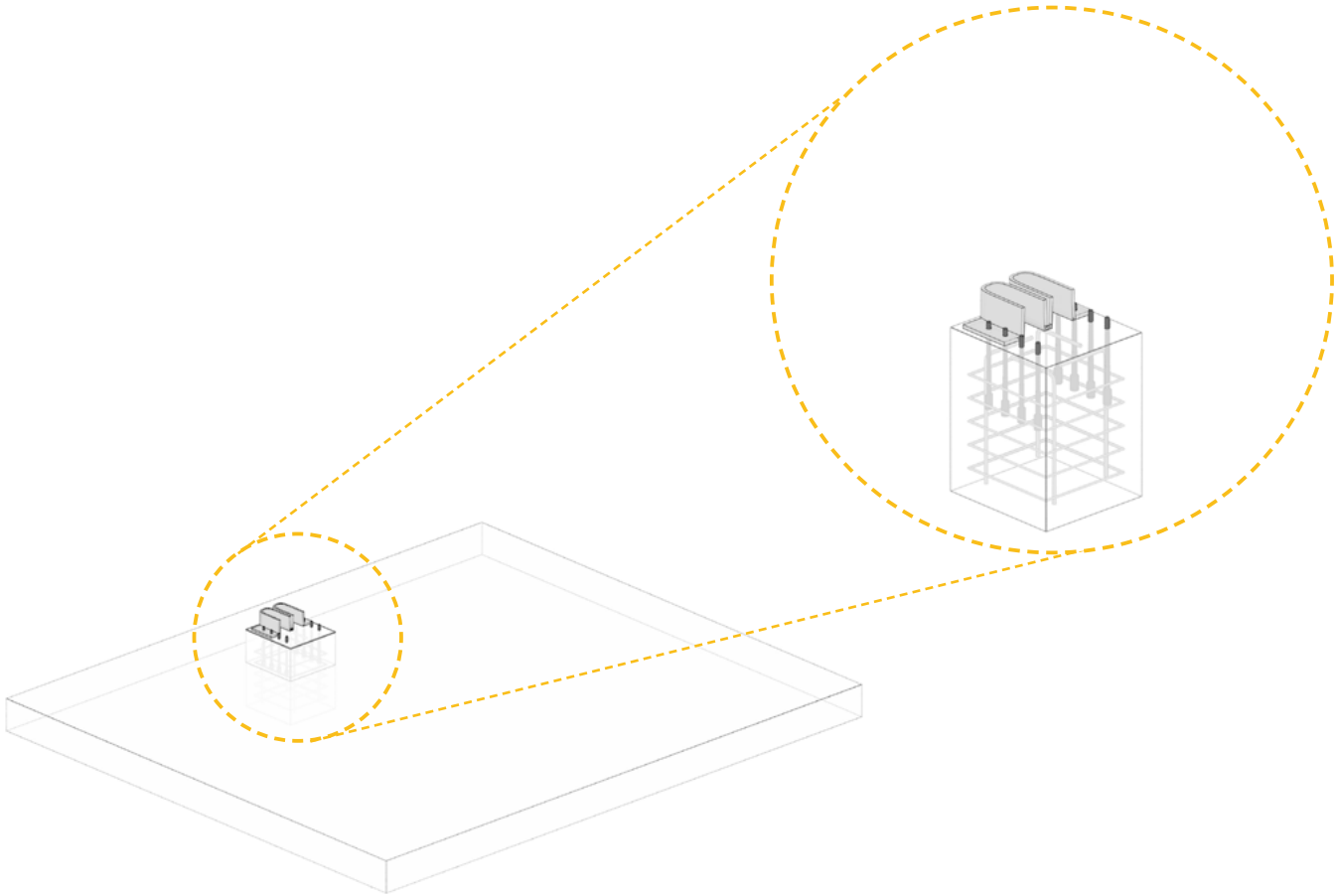
INSTALLATION

STEP 2:



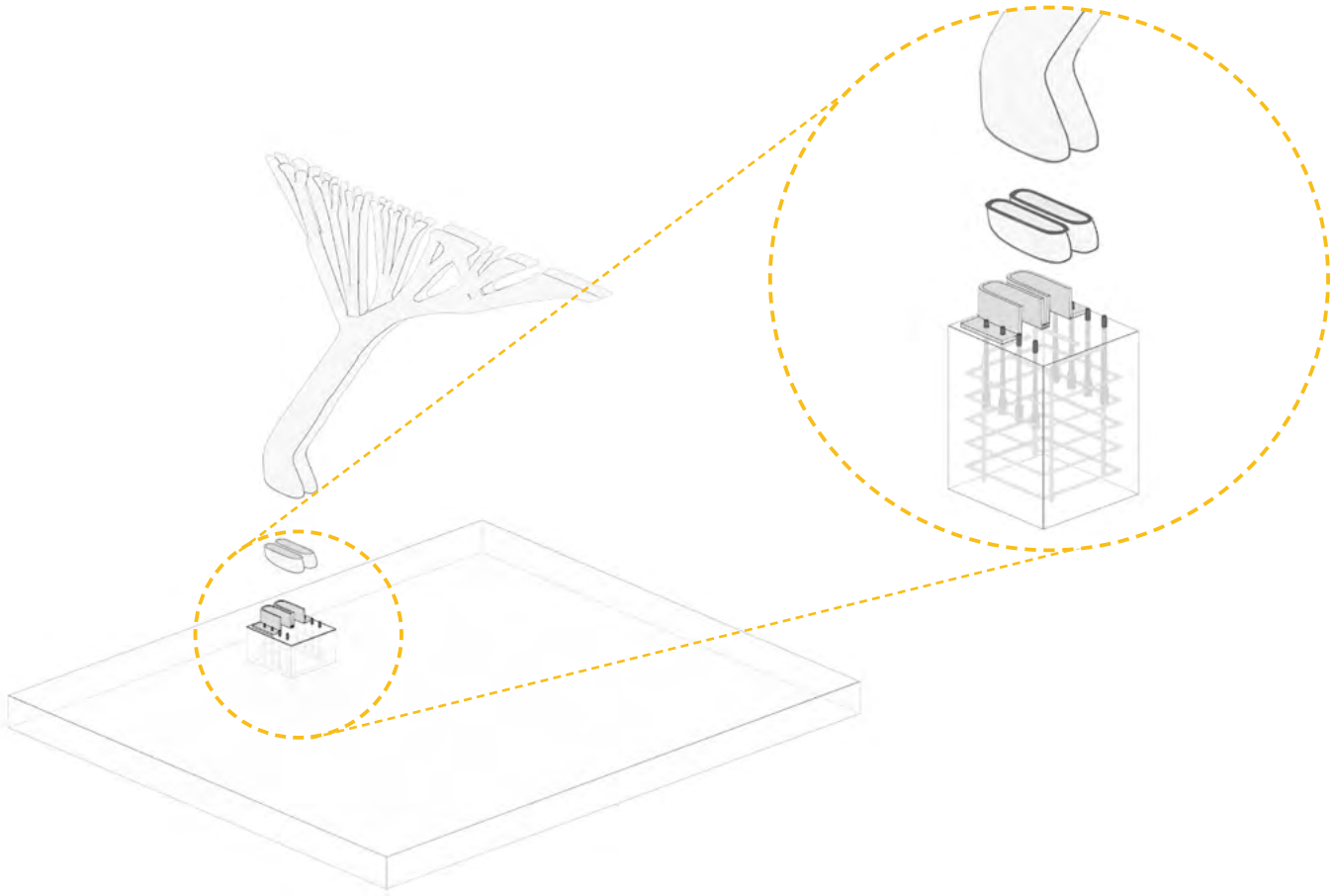
INSTALLATION

STEP 3:



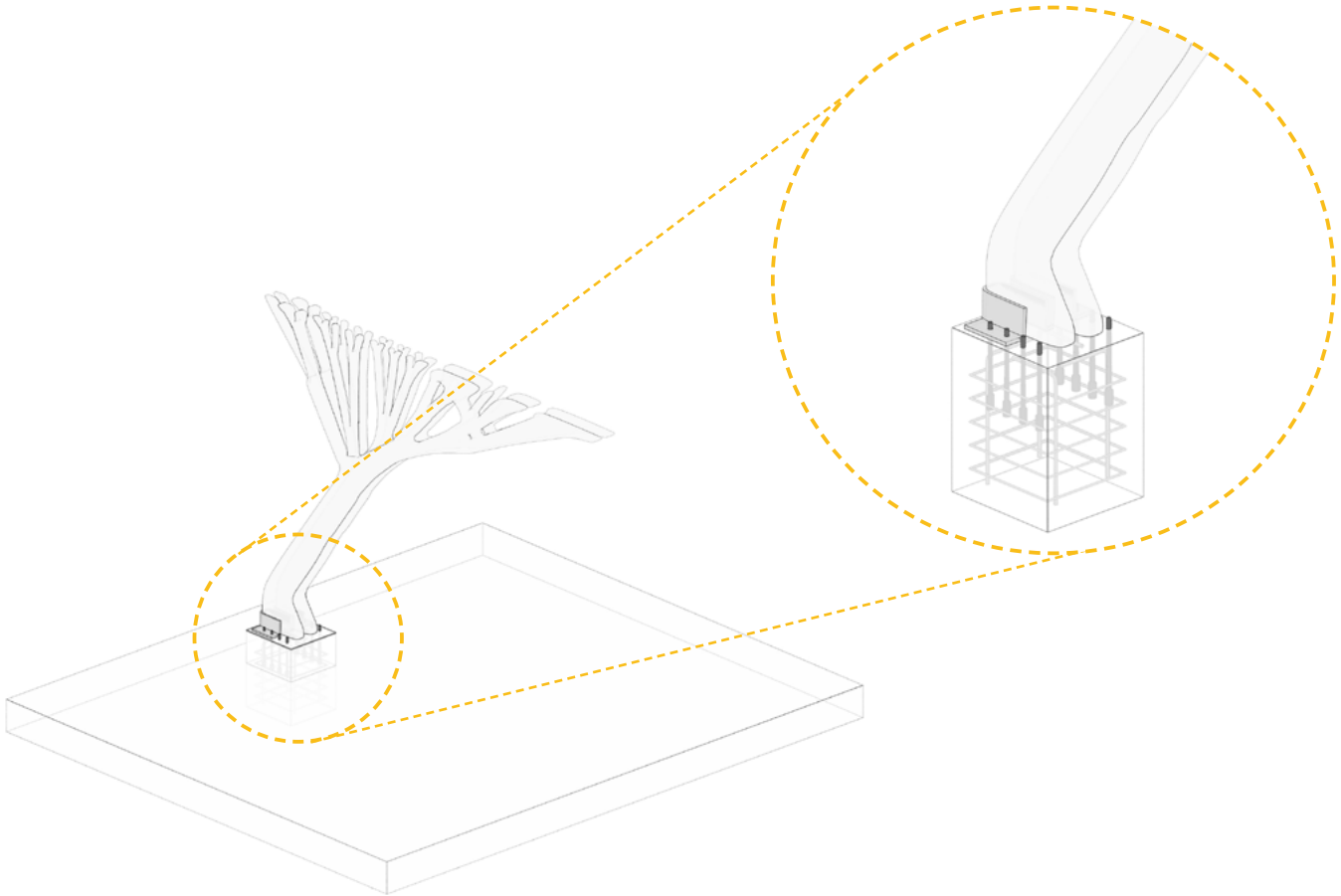
INSTALLATION

STEP 4:



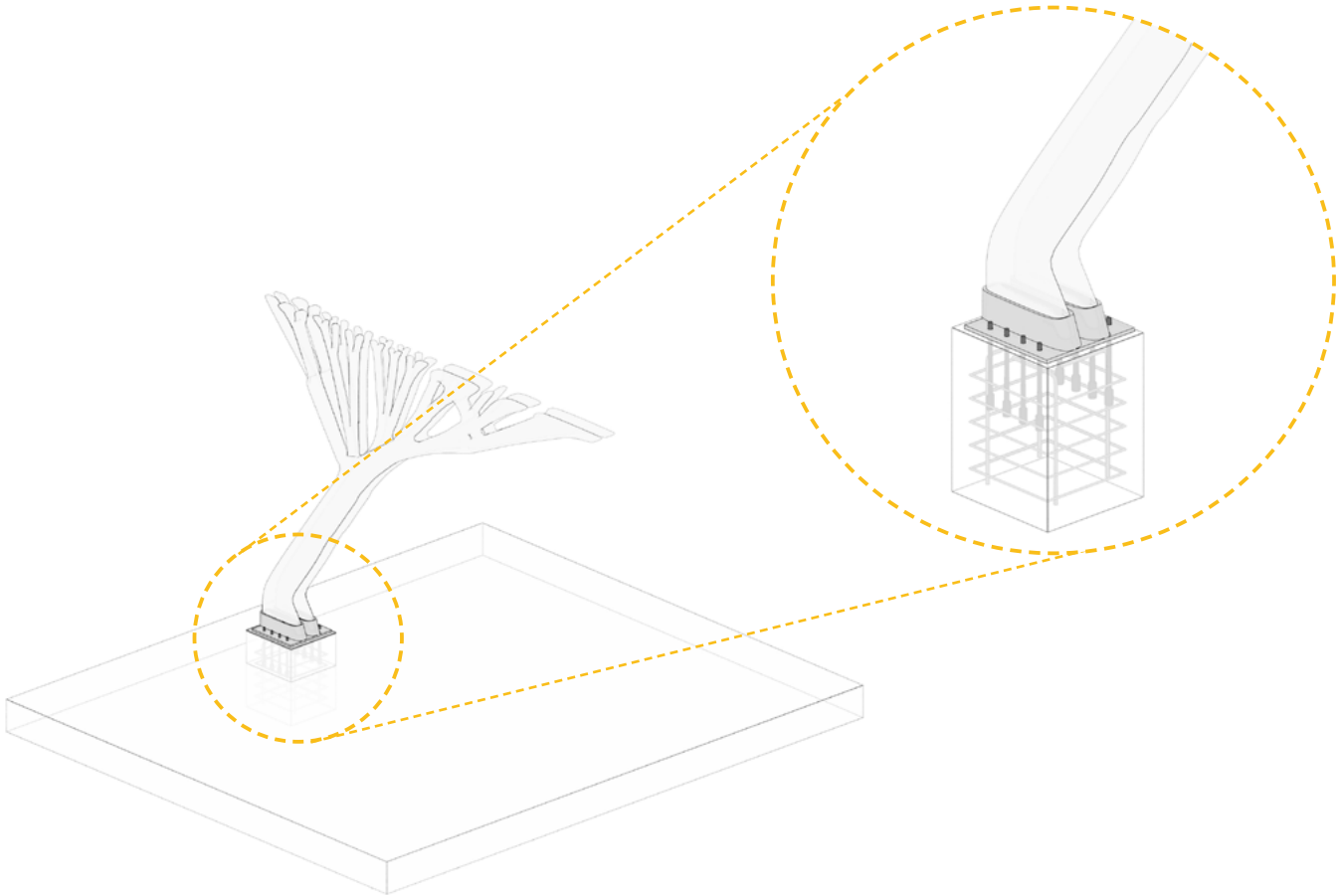
INSTALLATION

STEP 5:



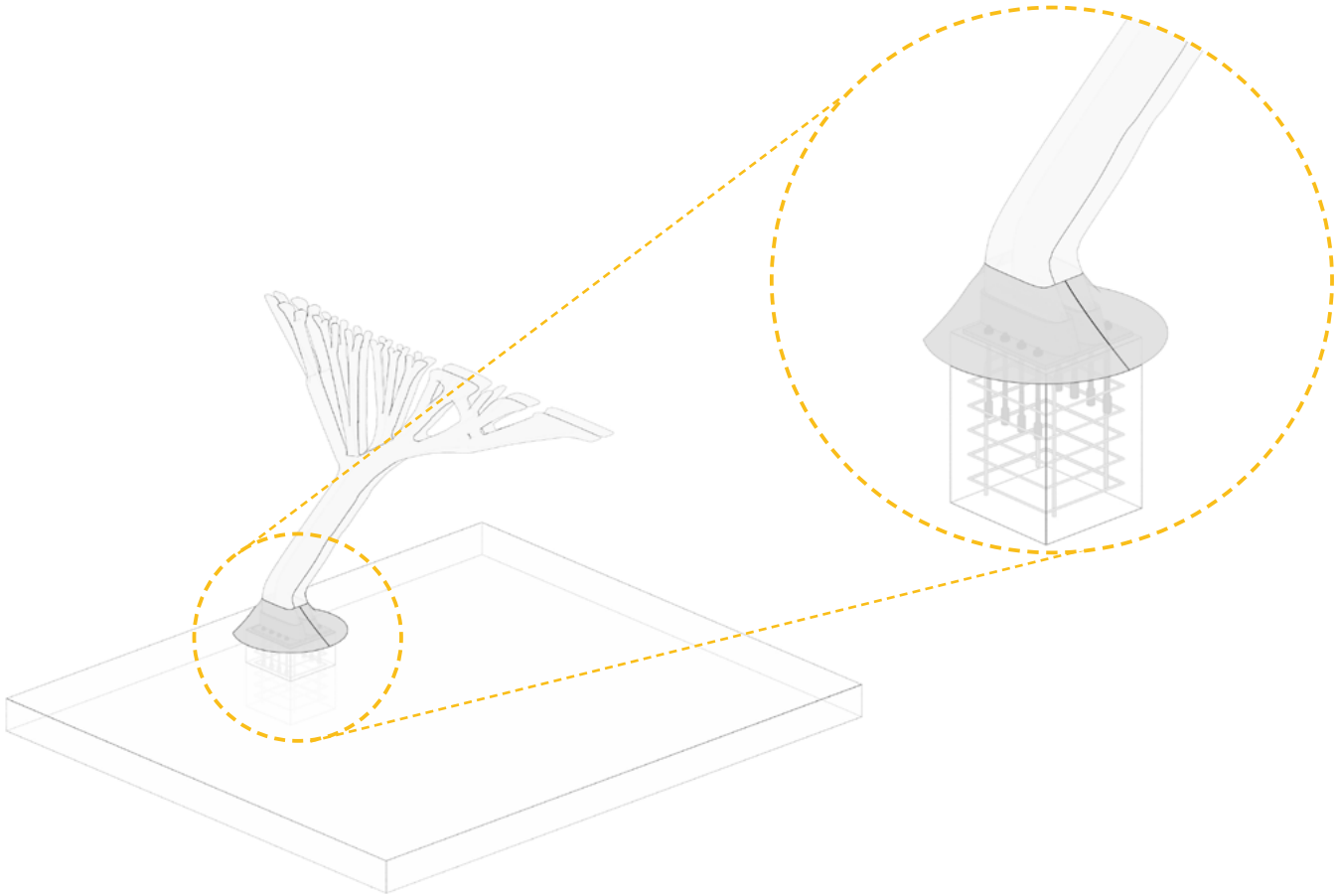
INSTALLATION

STEP 6:



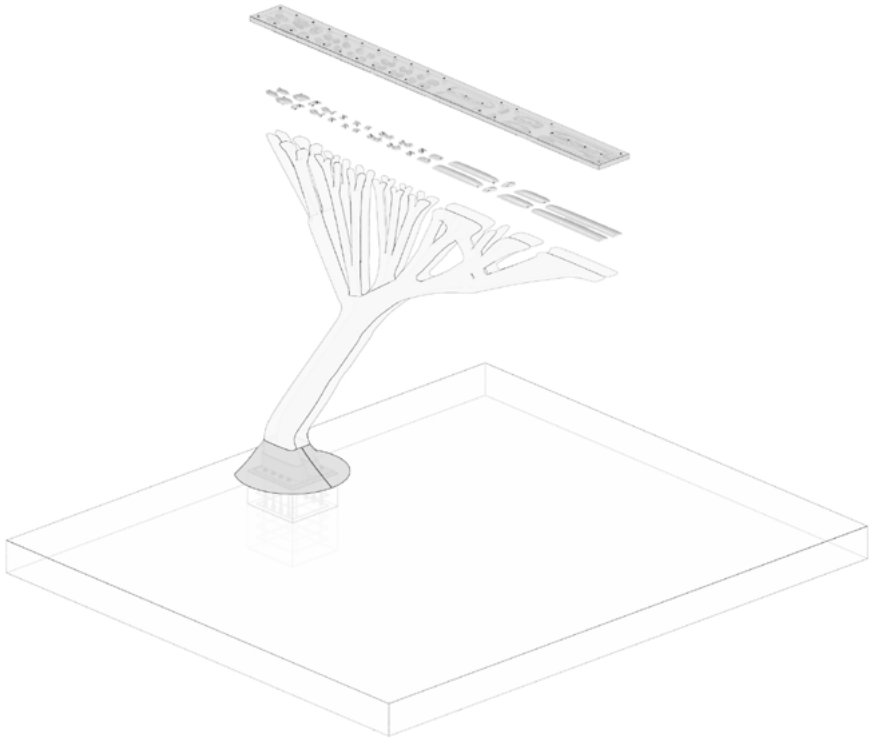
INSTALLATION

STEP 7:



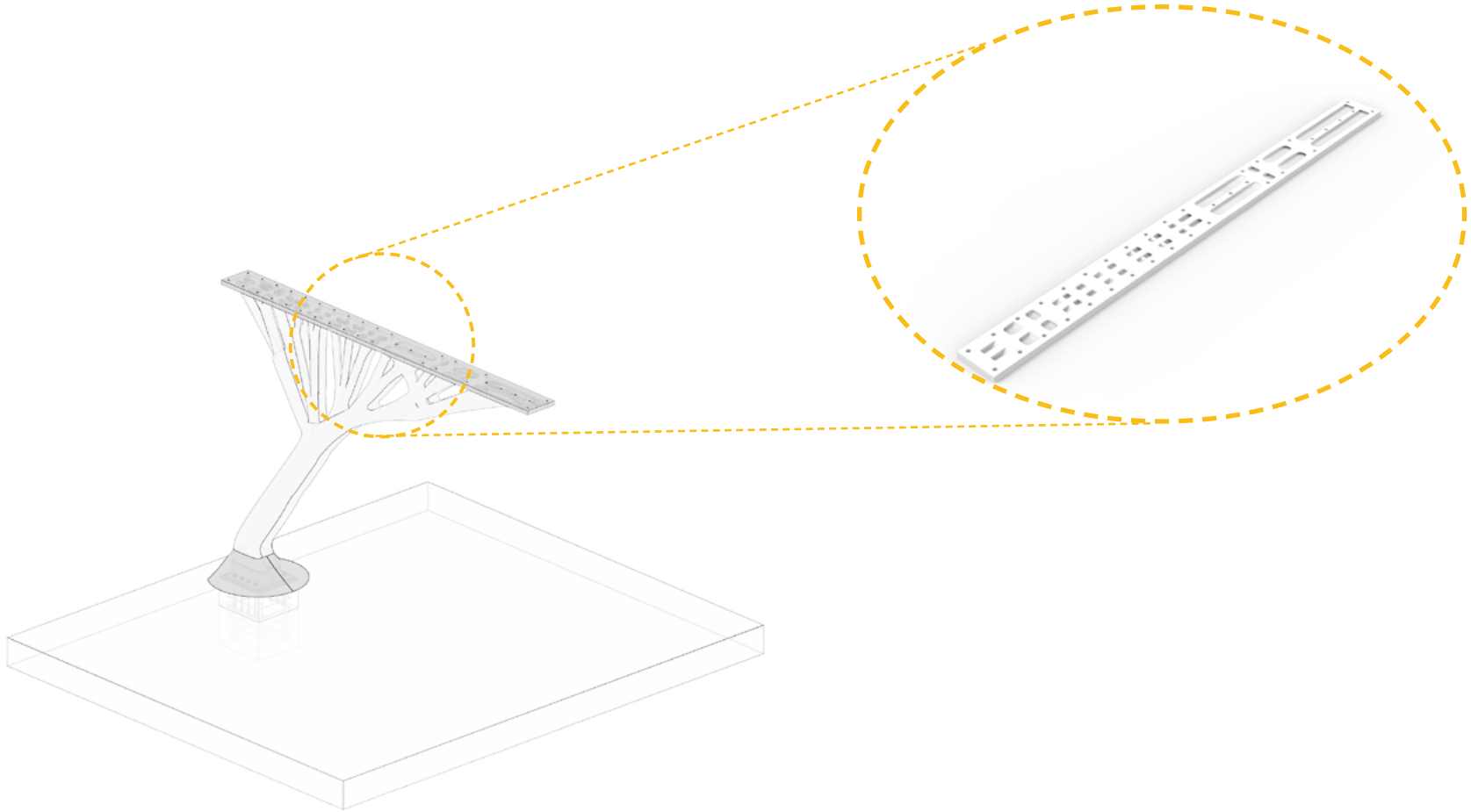
INSTALLATION

STEP 8:



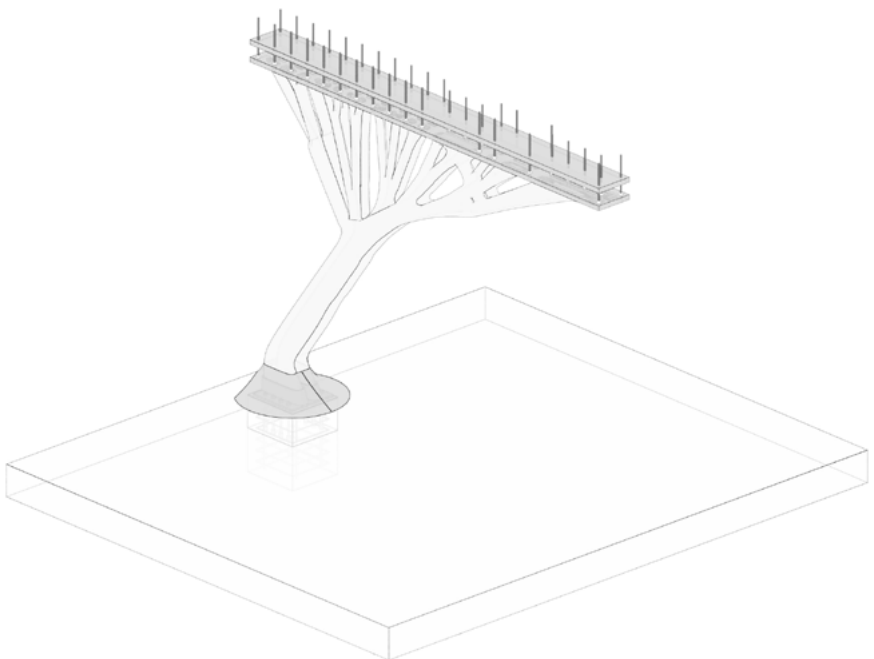
INSTALLATION

STEP 9:



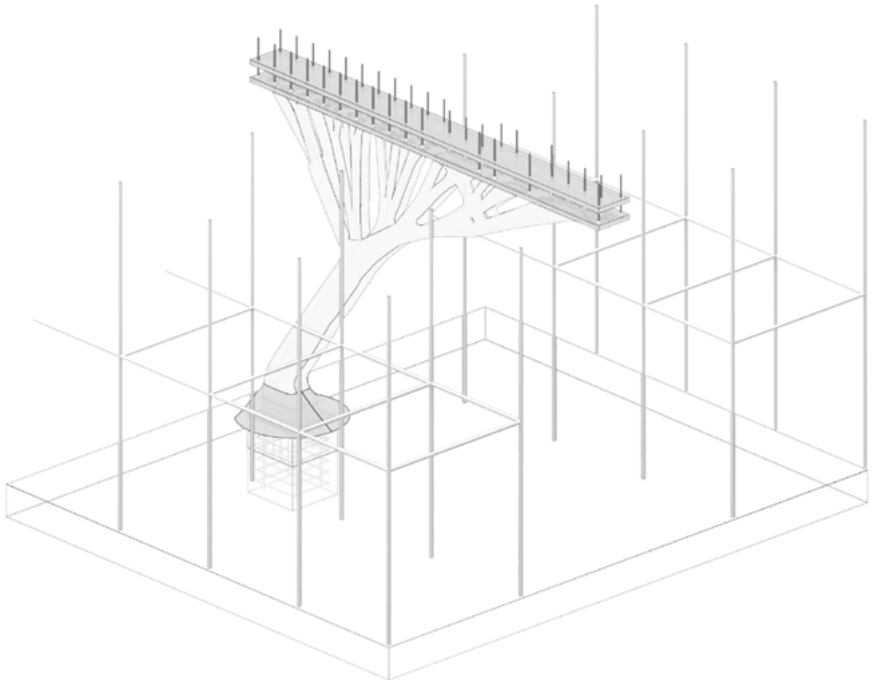
INSTALLATION

STEP 10:



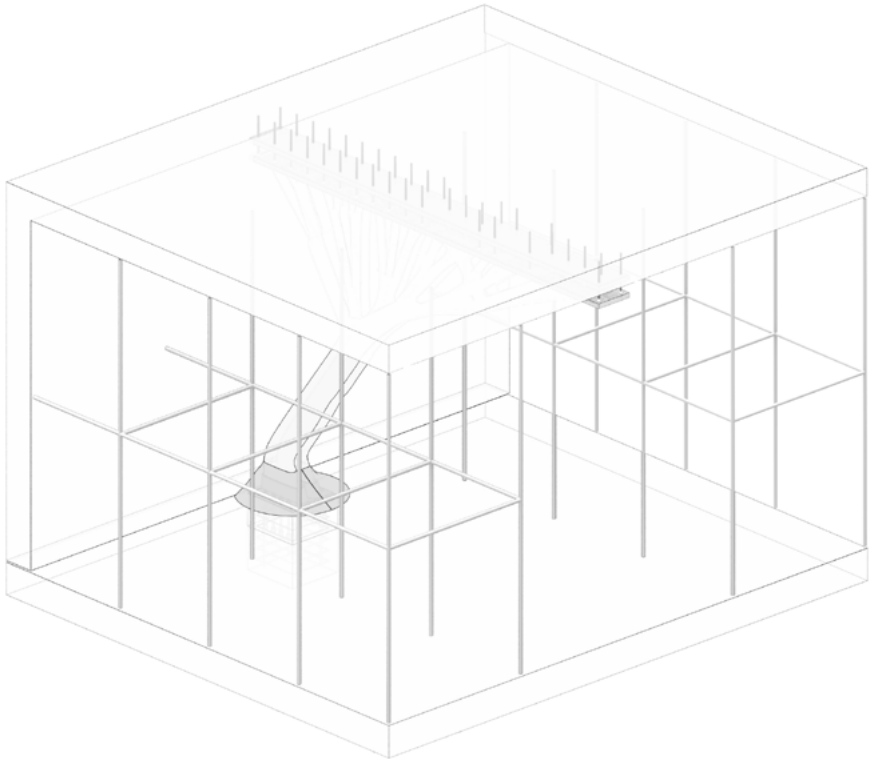
INSTALLATION

STEP 11:



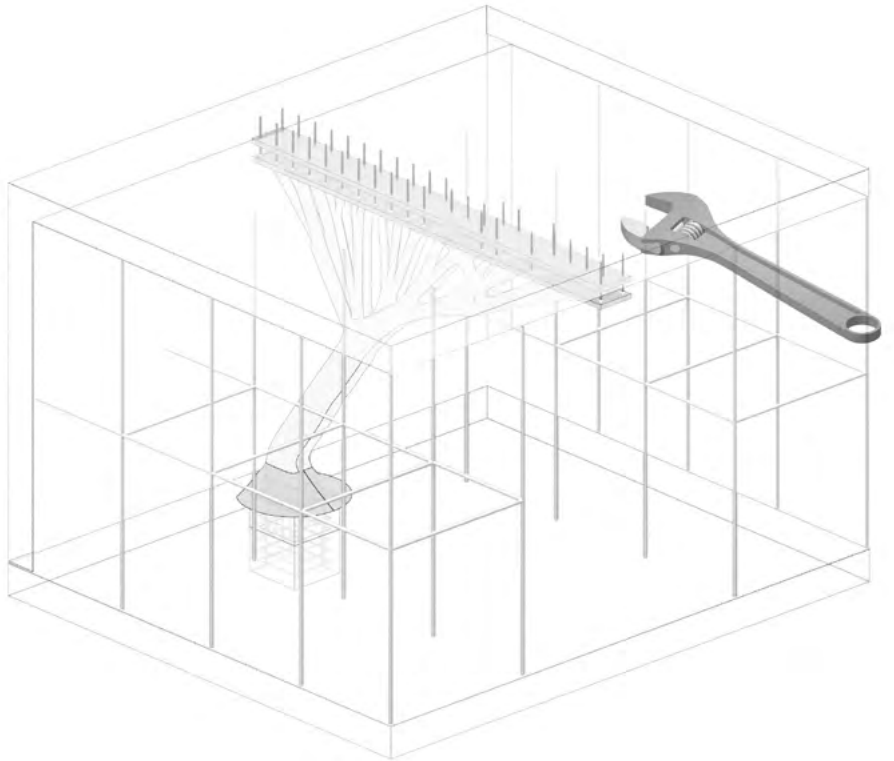
INSTALLATION

STEP 12:

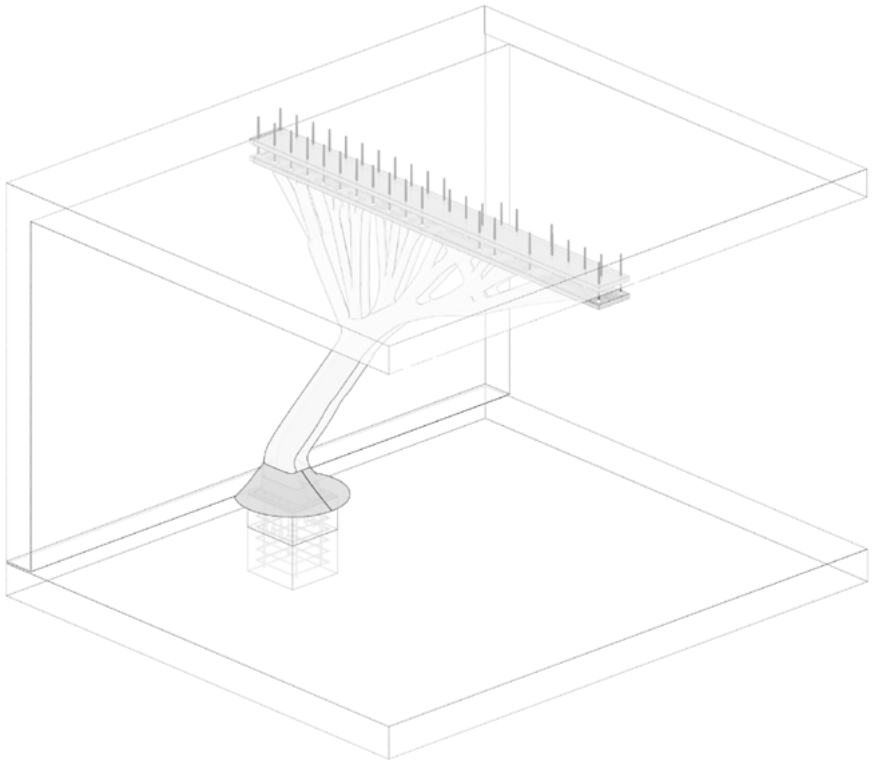


INSTALLATION

STEP 13:



STEP 14:



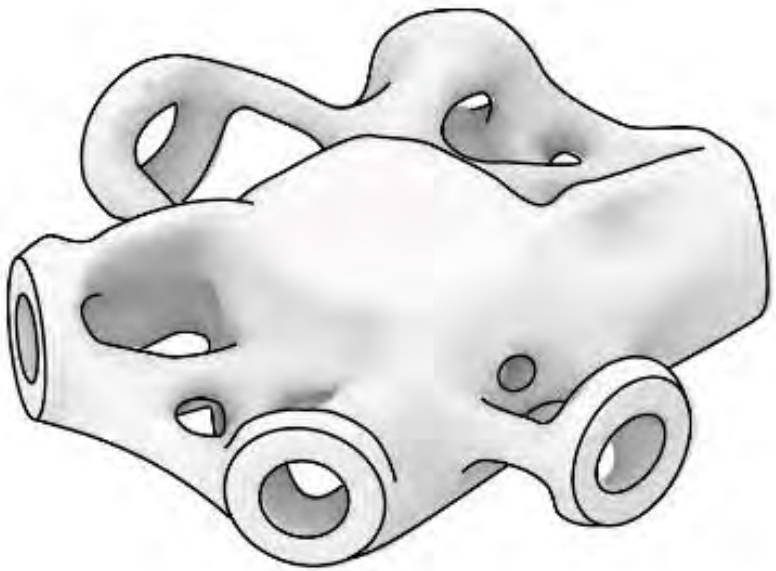
CONCLUSION

“How to fabricate a Topologically Optimized structural Glass Column using 3D printed Sand Moulds?”

CONCLUSION

“How to fabricate a Topologically Optimized structural Glass Column using 3D printed Sand Moulds?”

Topological Optimization

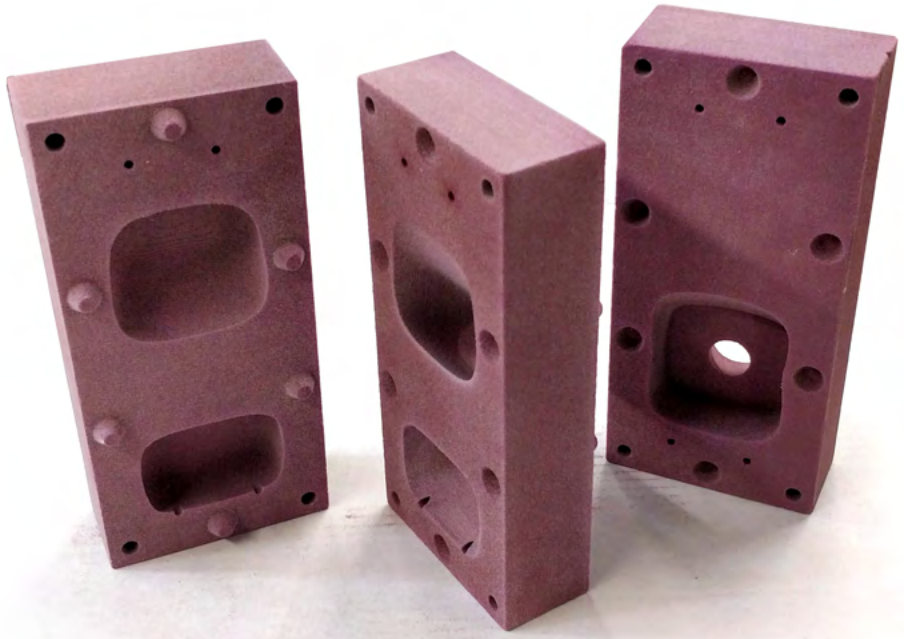


Topologically Optimized Glass shell node(W. Damen 2019)

CONCLUSION

“How to fabricate a Topologically Optimized structural Glass Column using 3D printed Sand Moulds?”

Advantages & Limitations



CONCLUSION

“How to fabricate a Topologically Optimized structural Glass Column using 3D printed Sand Moulds?”

Comparison with current Disposable Mould technique

CONCLUSION

“How to fabricate a Topologically Optimized structural Glass Column using 3D printed Sand Moulds?”

Sand mould binder: Anorganik binder system

CONCLUSION

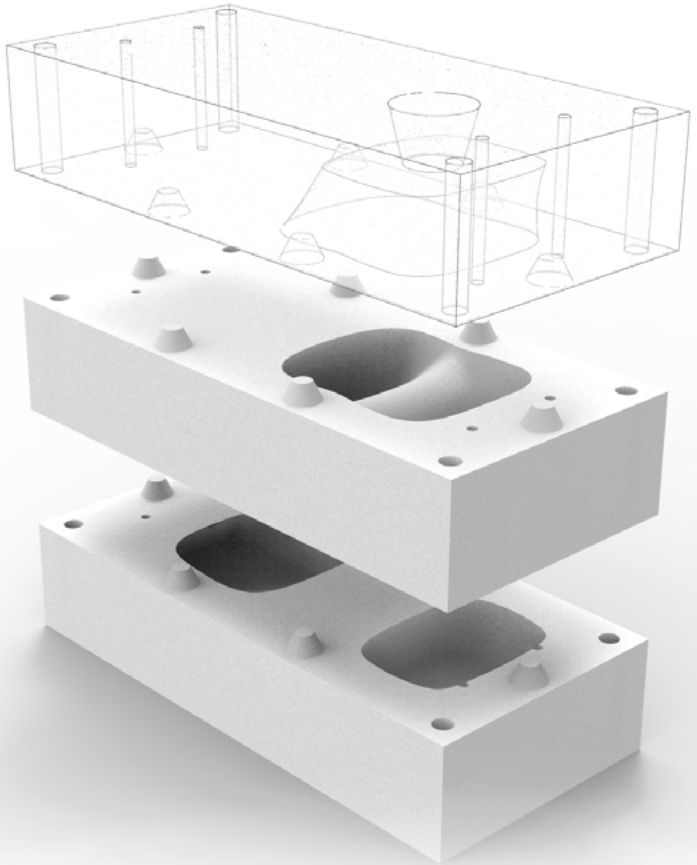
“How to fabricate a Topologically Optimized structural Glass Column using 3D printed Sand Moulds?”

Finishing: Crystal Cast

CONCLUSION

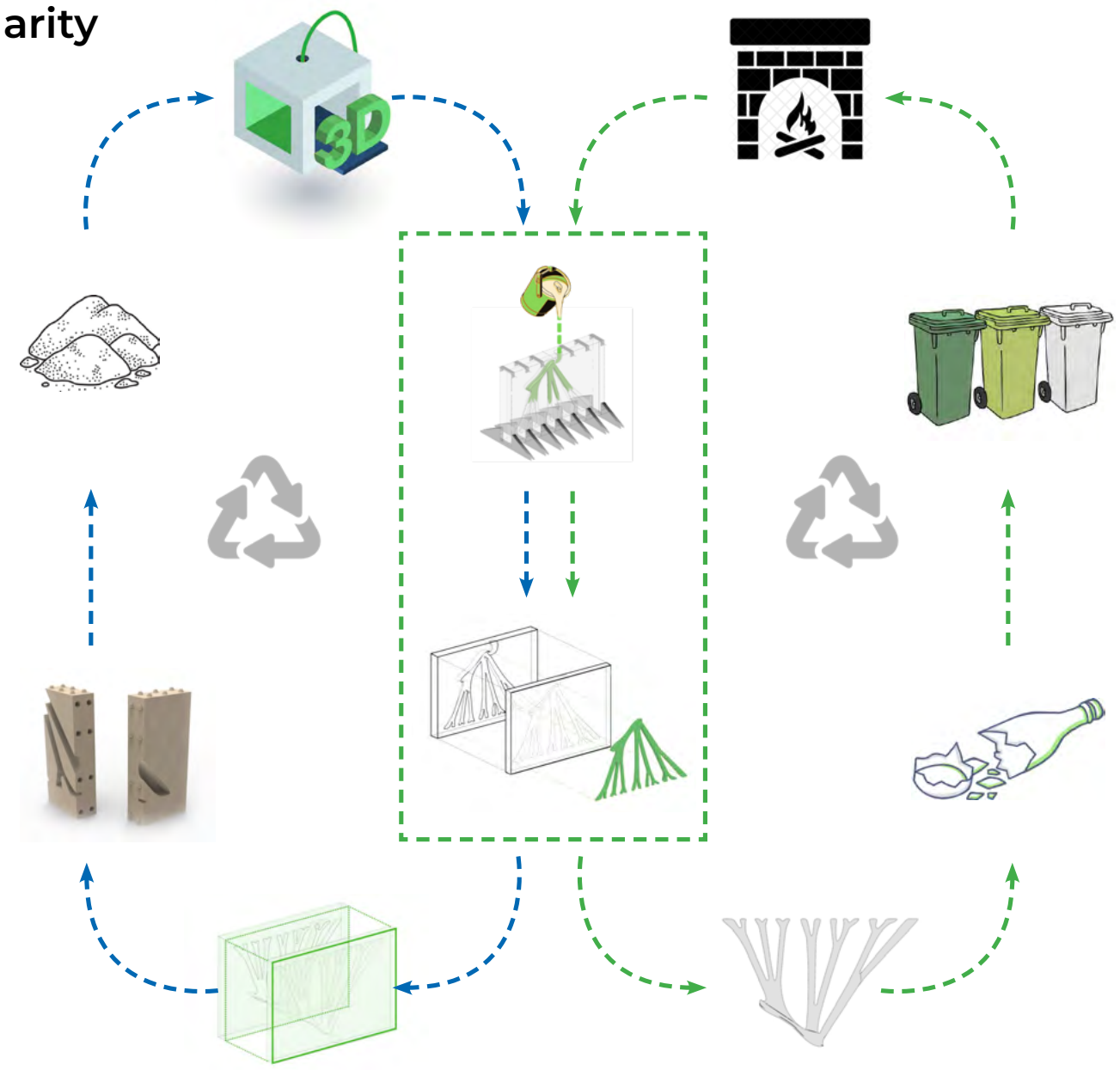
“How to fabricate a Topologically Optimized structural Glass Column using 3D printed Sand Moulds?”

Computational Tools- Automation



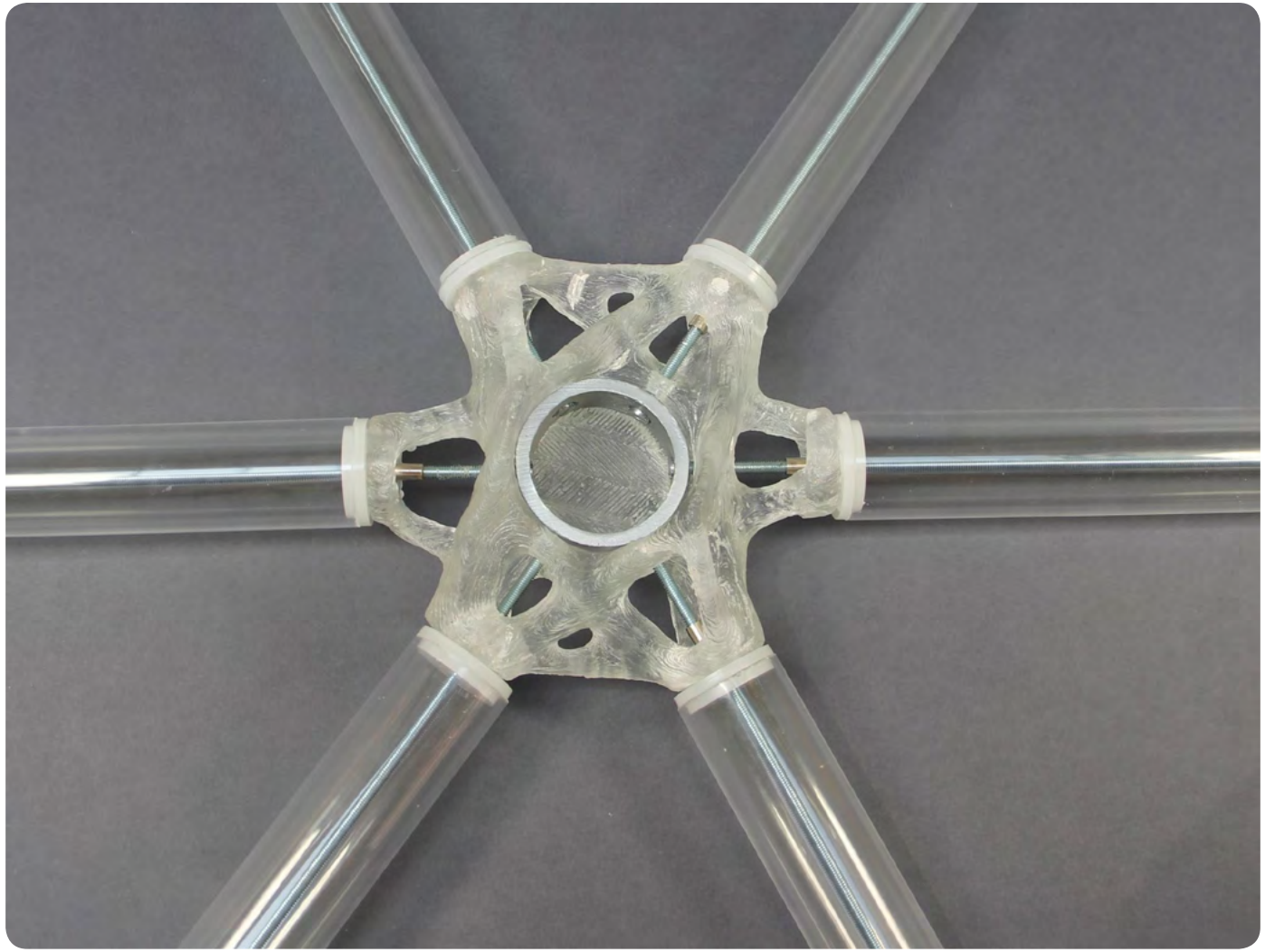
DISCUSSIONS

- **Sustainability & Circularity**



DISCUSSIONS

- **Shell Nodes & Hybrid Structures**



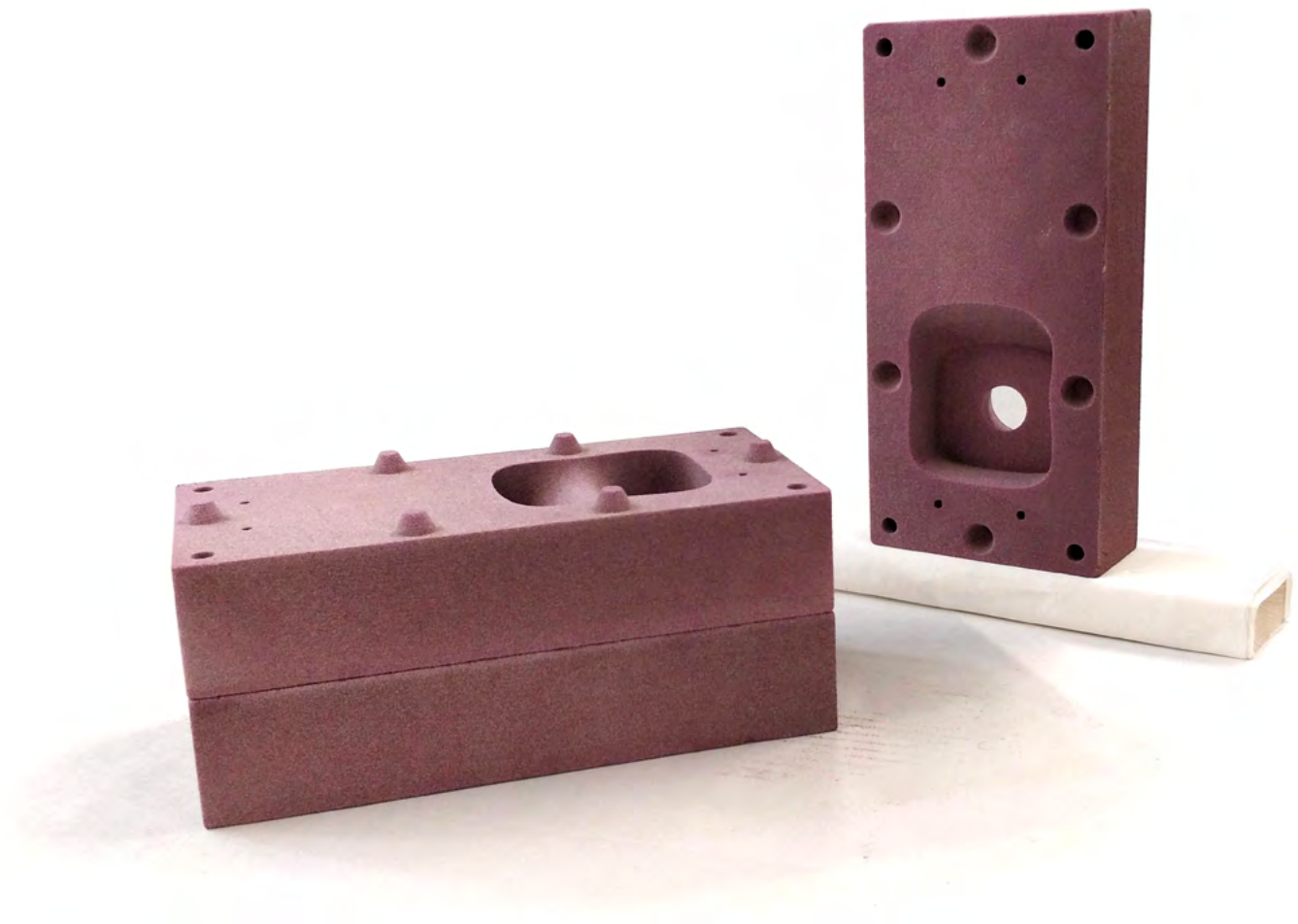
Topologically Optimized Glass shell node(W. Damen 2019)

DISCUSSIONS

- **Ornamentation**

SHAPING TRANSPARENT SAND IN SAND

FABRICATING TOPOLOGICALLY OPTIMIZED CAST GLASS COLUMN USING SAND MOULDS



IVNEET SINGH BHATIA | 4724518 | TU DELFT 2018-19