P5 Presentation

MSc Building Technology - Faculty of Architecture

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June 22th, 2016 | TU Delft

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Final graduation presentation

Topic:

Transparent restoration of a historic building by use of structural glass elements

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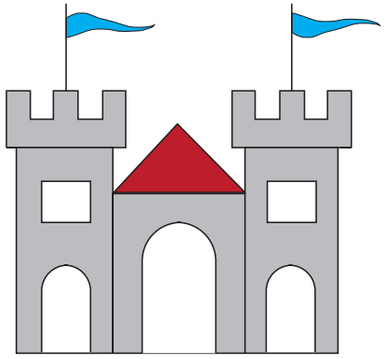
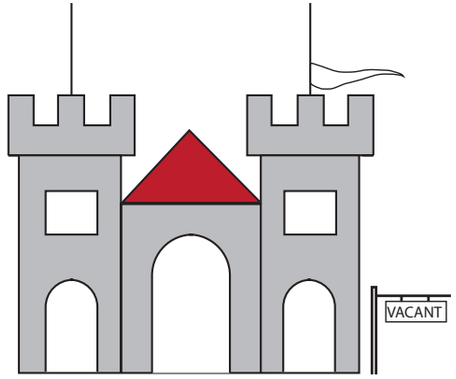
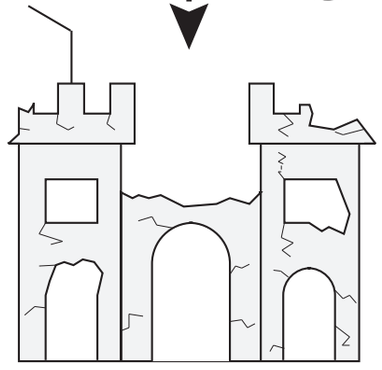
RESEARCH PLAN

BACKGROUND

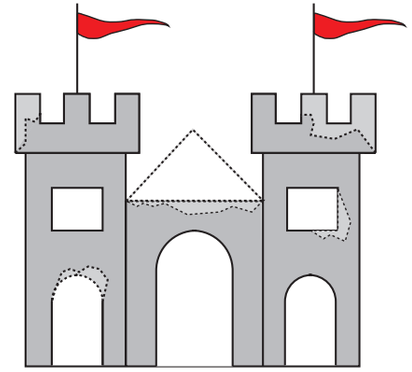


Historic **monumental buildings** are often of **great** architectural - cultural - historical **value**, and unique.



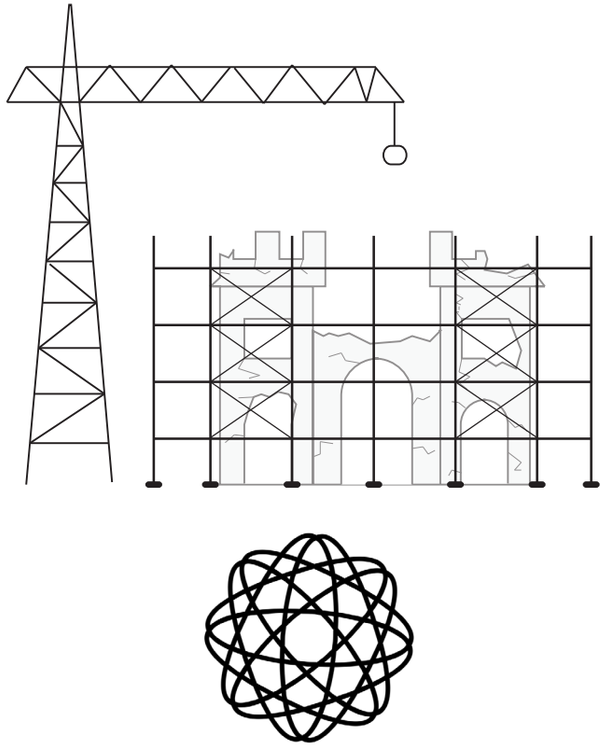


However monuments become **vacant**, leading over-time to **deterioration**

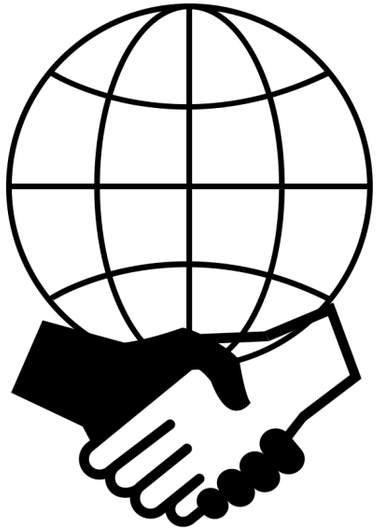


Possibility to **restore** building, repurposing with **new function** to **protect** and **maintain** building

RESTORATION PHILOSOPHY



Restoration is **complex**
due to high demands



International agreements
regarding restoration
requirement:
Venice Charters

(International Council on Monuments and Sites, 1964) citation:

''..... the aim should be to preserve and reveal the aesthetic and historic value of the monument Restoration should be based on respect for the original material and authentic documents. .....replacement of missing original parts of a building must integrate harmoniously with the whole, but at the same time be distinguishable from the original so that restoration does not falsify the artistic or historic evidence. Also, additions cannot be allowed except in so far that they do not detract from the interesting parts of the building, its traditional setting, the balance of its composition and its relation with its surroundings.....''

Requirements in Venice
Charters

VENICE CHARTERS

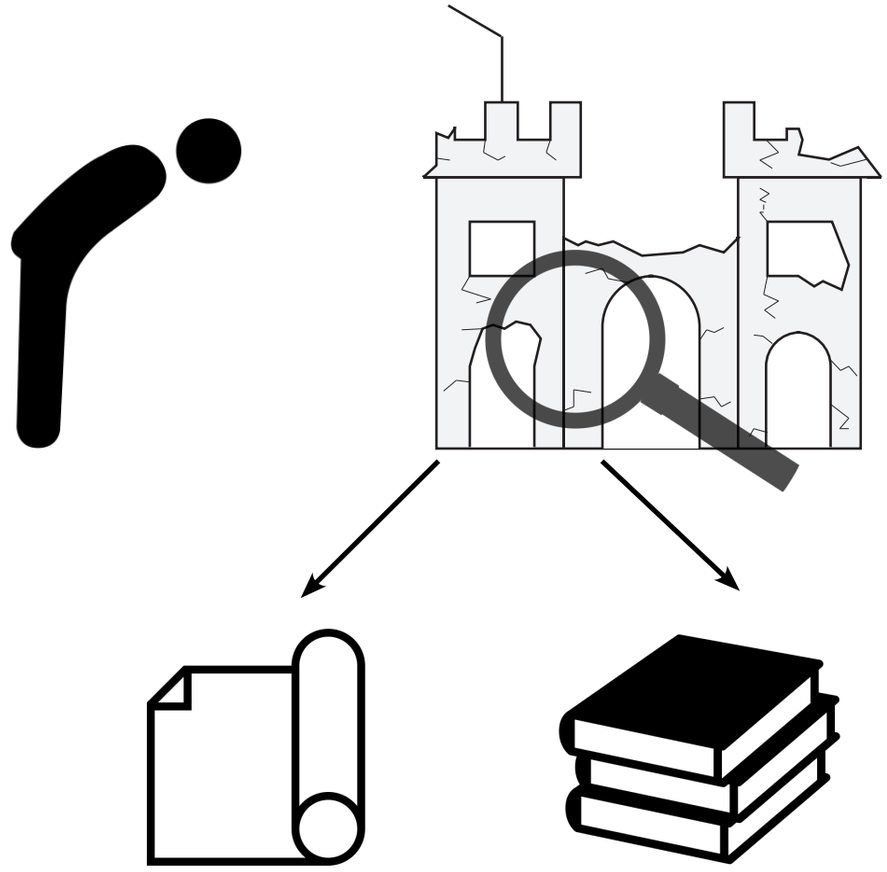
‘‘The **aim of restoration** should be to **preserve** and **reveal** aesthetic and historic **value of monument**’’

Any replacing element **must**:

‘‘be **distinguishable** from the original structure and bear a contemporary stamp.’’

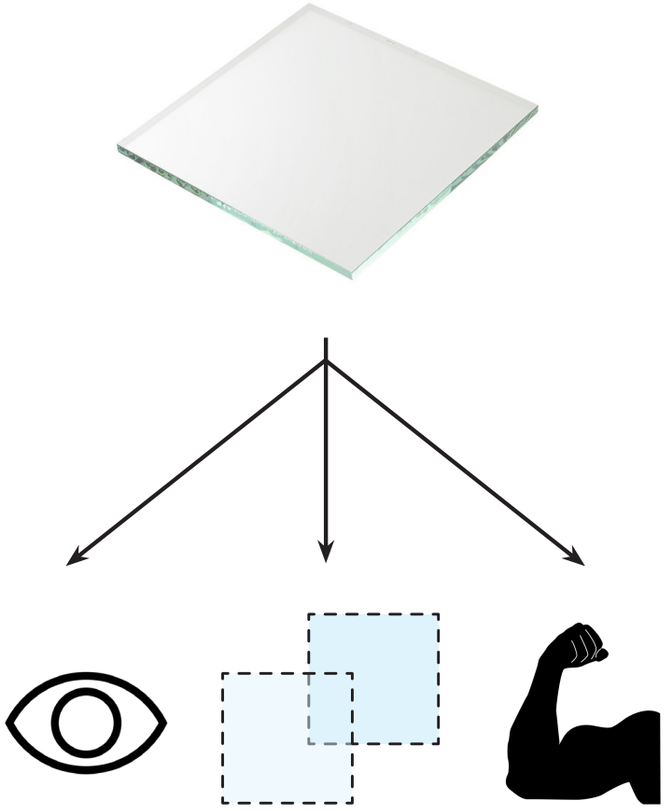
‘‘**integrate harmoniously** in the original structure..’’

‘‘...**not detract** from the **interesting parts** of the buildings, the setting, balance in composition and relation to its surrounding’’



- Respect for the ruin
- Restoration requires proper research into history, documentation and drawings

SOLUTION

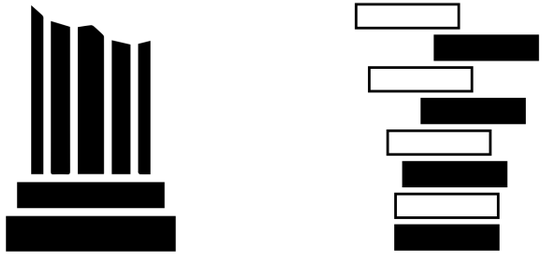


Solution of debate is **Glass**!

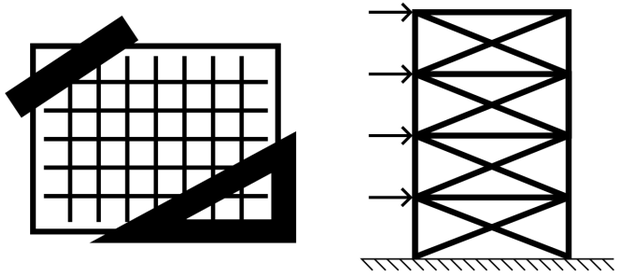
Unique properties:
Contemporary look
Transparent
Structural material

PROBLEM

Subproblem 1



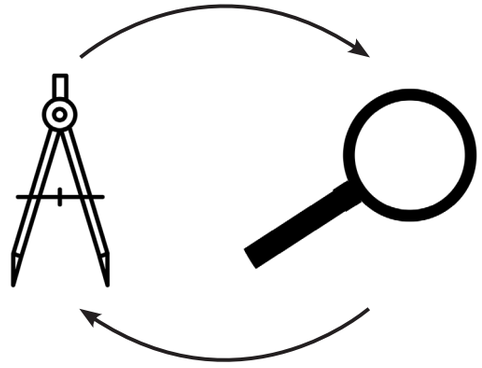
Subproblem 2

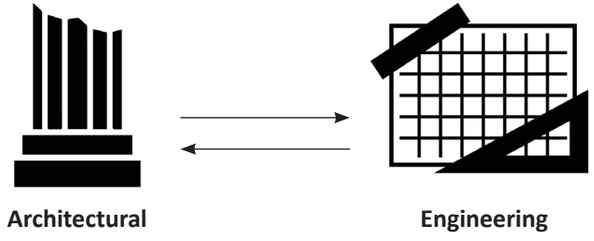


Restorations with **glass** replacements **uncommon**

Architectural & **Engineering** problems:
Integration of old & new
Making the glass structure

OBJECTIVE

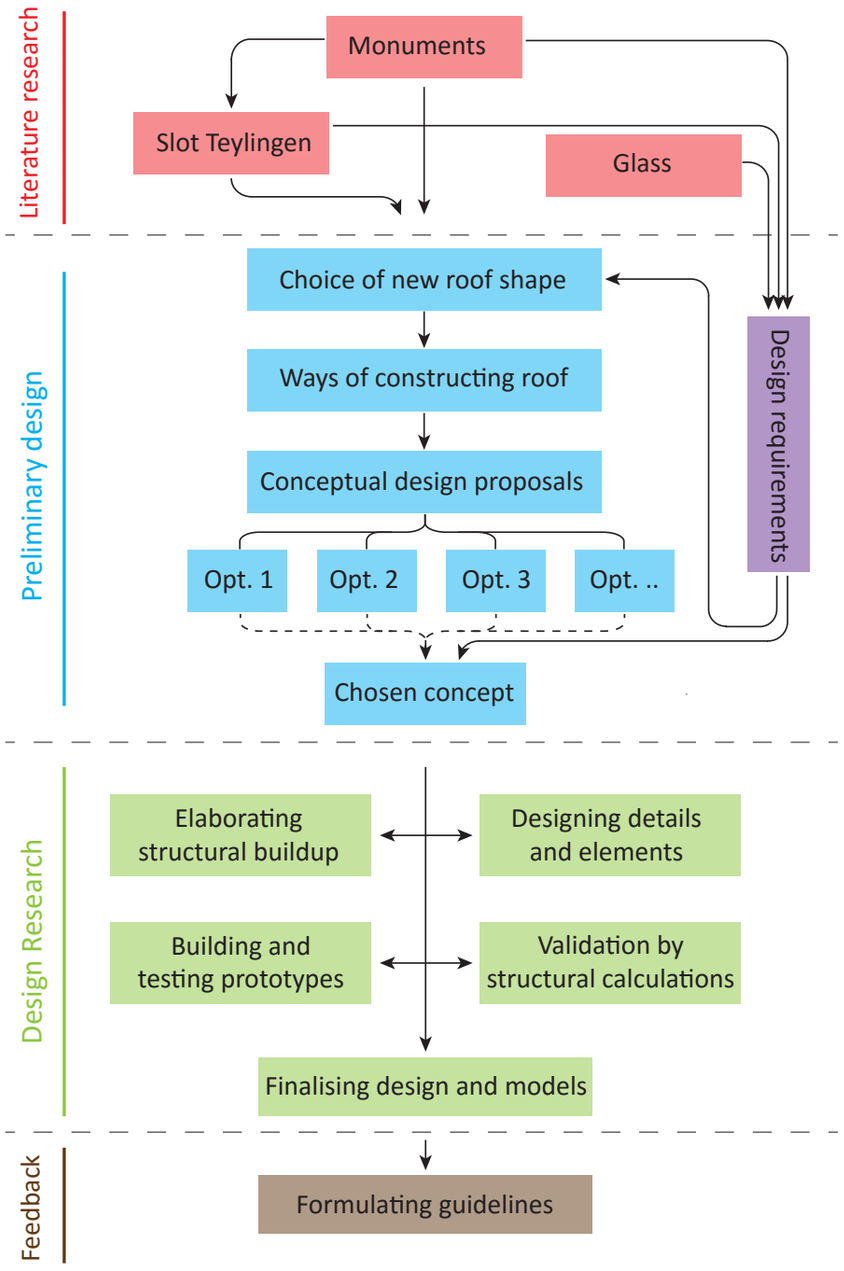




Design Research where **original element** is **replaced** by **glass structure** for a **case study**

METHODOLOGY

- Four phases
- Literature research -> design requirements and background info
- Design requirements guiding in preliminary design and design research



CASE STUDY CHOICE
Slot Teylingen

Moated round encircled fortress

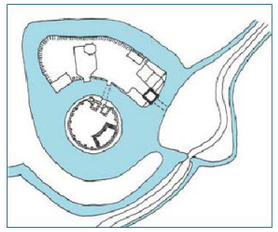
Missing roof element

SLOT TEYLINGEN
Location

Voorhout, 10 km above Leiden, Zuid-Holland

Surrounded by agricultural, residential buildings

SLOT TEYLINGEN
Past - pathology







1230 Built
1572 Destroyed
1605 Re built
1676 Burned out
1800 Deterioration
1888 Minor repairs
Now

- Long and rich history
- Roof destroyed twice: in war times and during fire
- Minor restorations haven taken place last 150 years

SLOT TEYLINGEN

Present - current state

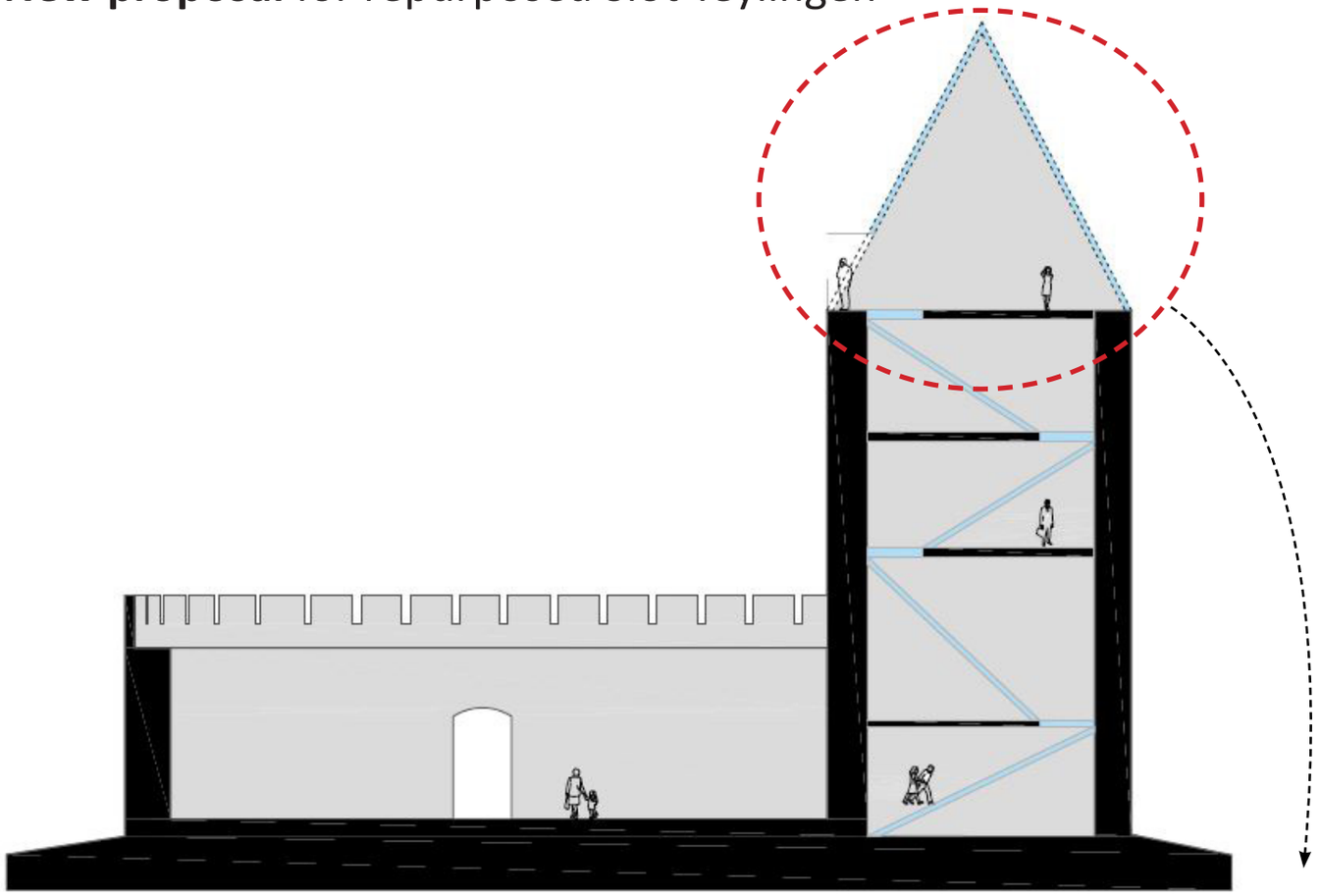
Empty donjon, authentic indentations in walls

Damaged top surface walls -> uneven

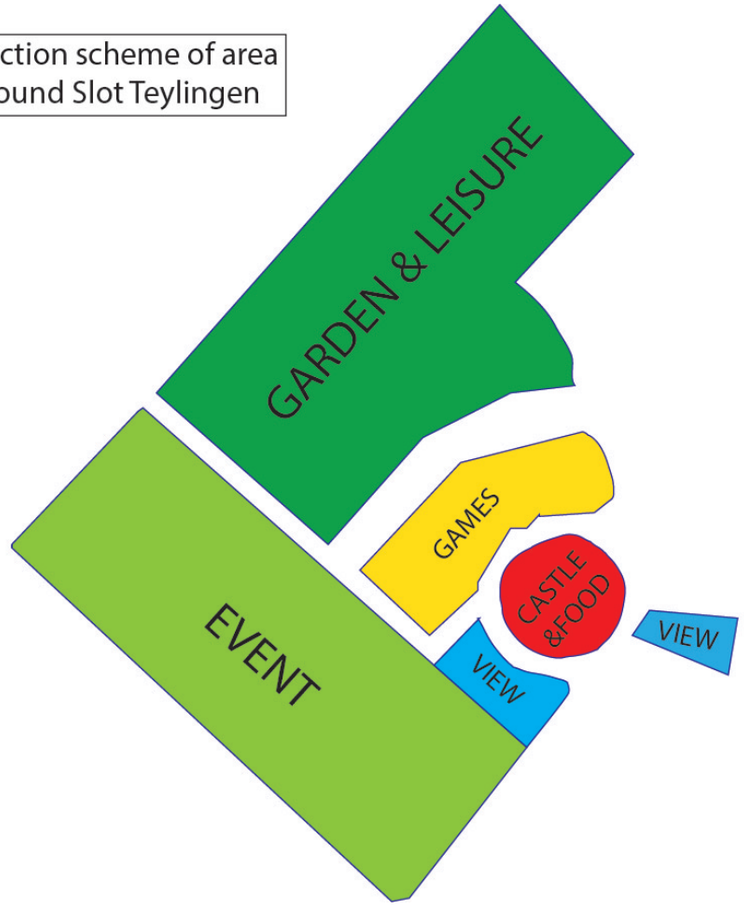
DESIGN CONTEXT = REFURBISHING PROPOSAL

Future - refurbishment

New proposal for repurposed Slot Teylingen

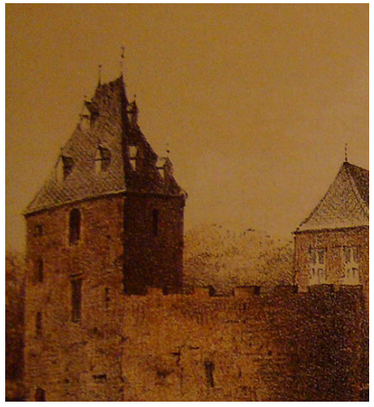


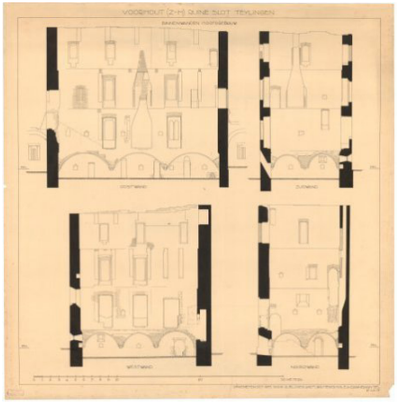
Function scheme of area around Slot Teylingen

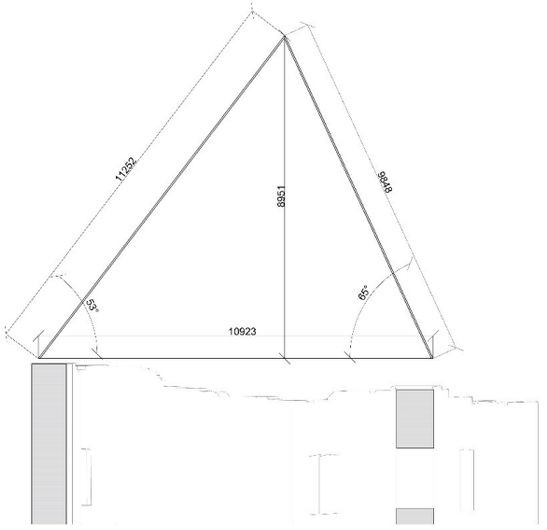


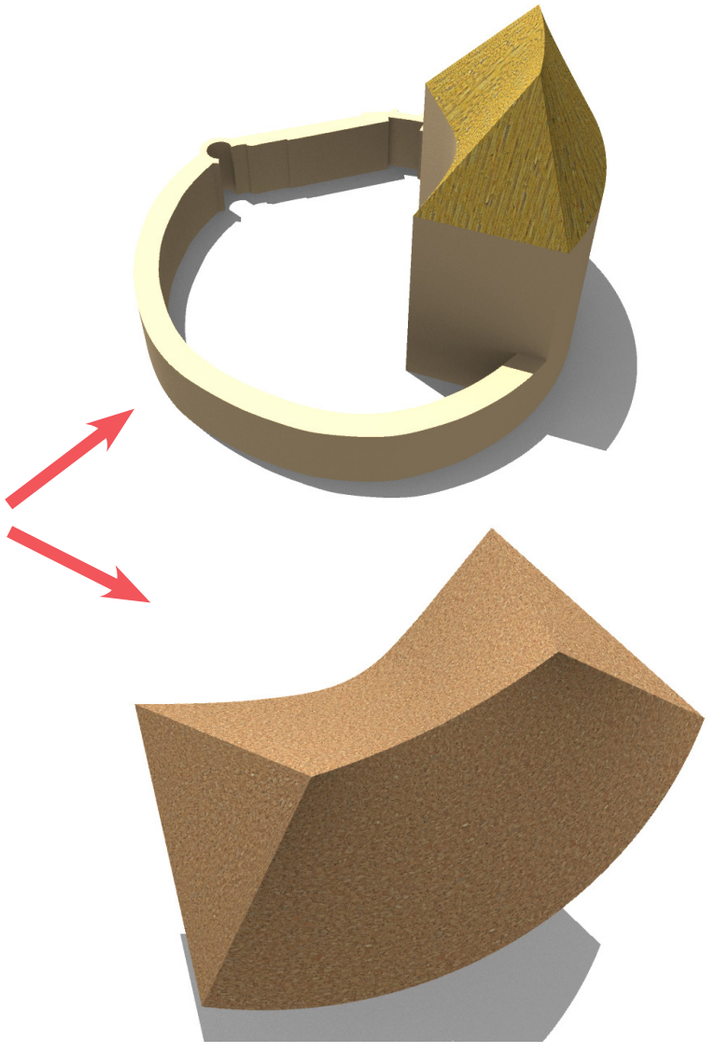
Focus on glass roof design

ORIGINAL ROOF
Shape and size



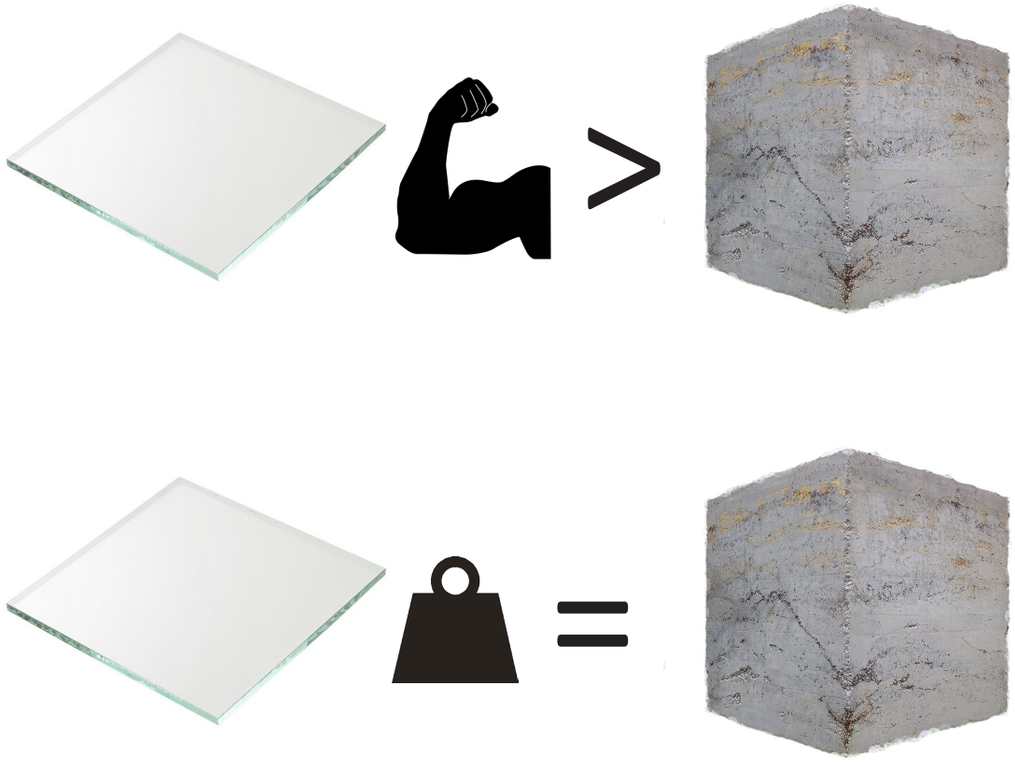




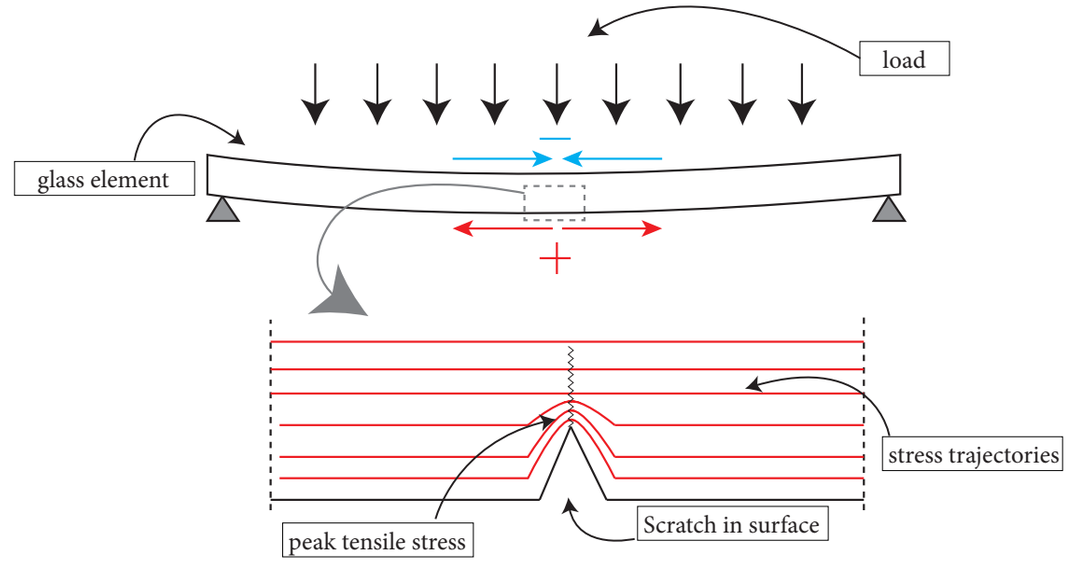


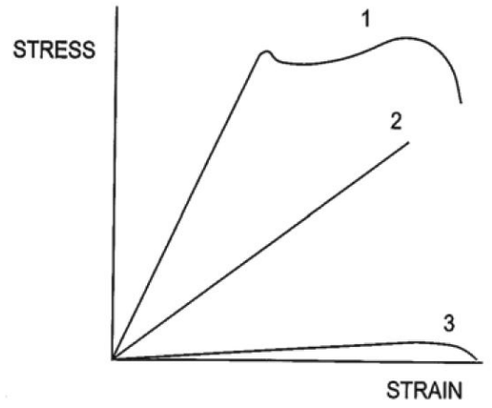
Based on research of documentation, original shape, size of roof was determined

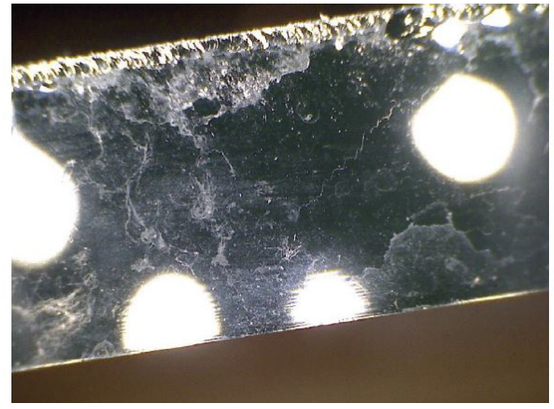
GLASS
Structural capacity



If used right, glass is as strong,
(or stronger) than concrete







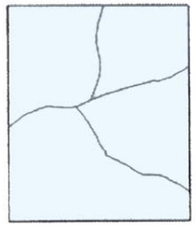
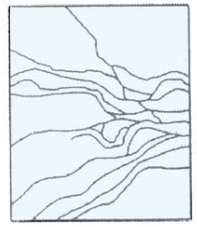
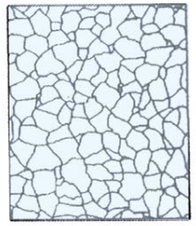
Hard and brittle material -> avoid peak stresses!

Detailling is very important

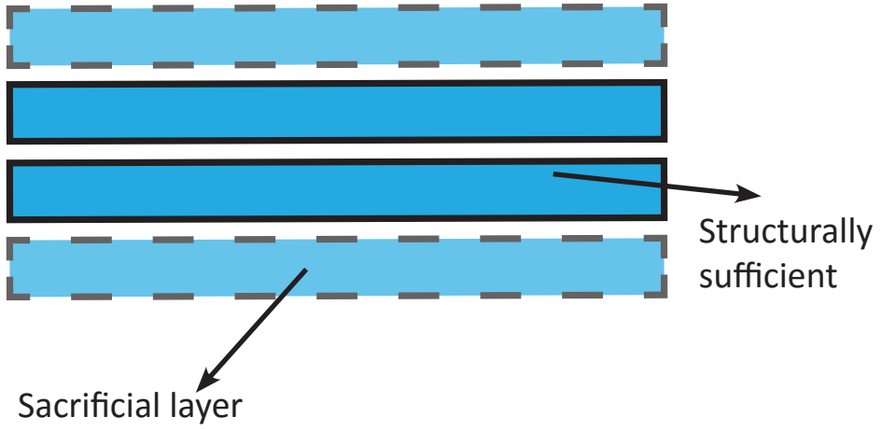
GLASS
Strength and safety

Measure to **minimize probability** of failure of the glass

Heat treating glass

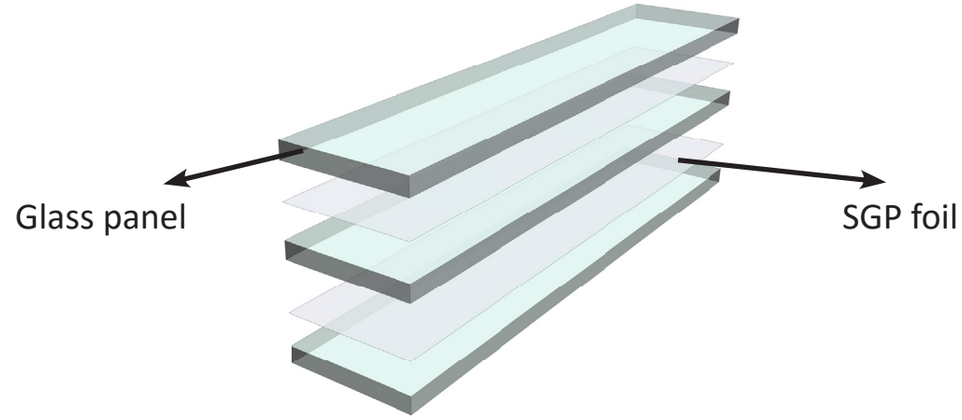
Glass type	Annealed Glass	**Heat strengthened Glass**	Fully tempered Glass
Breaking pattern			
Characteristic value of tensile bending strength	20 Mpa	40 Mpa	80 Mpa

Over - dimensioning



Measure to **minimize consequences** in case of total failure of the glass

Laminating with SGP interlayer

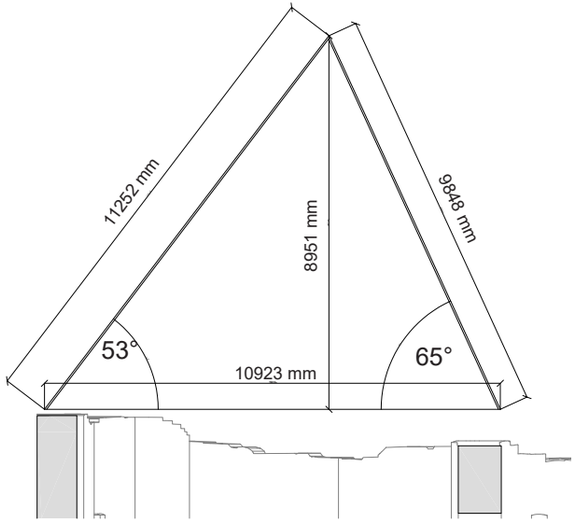


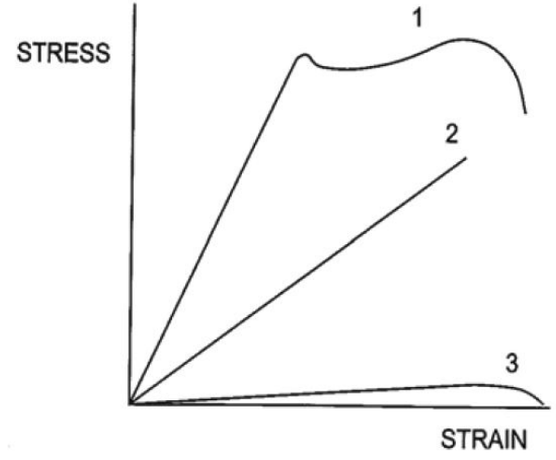
Post-breaking structural capacity of panel

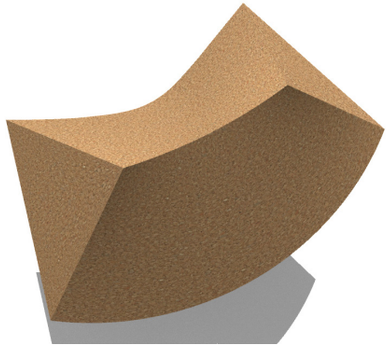
Main research question:

"How can structural glass be used in order to make a transparent roof restoration for Slot Teylingen?"

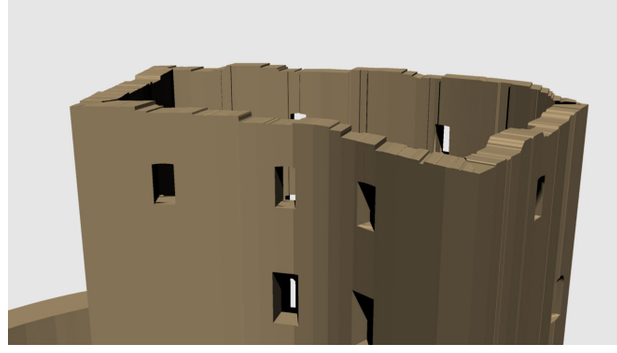
Design challenges



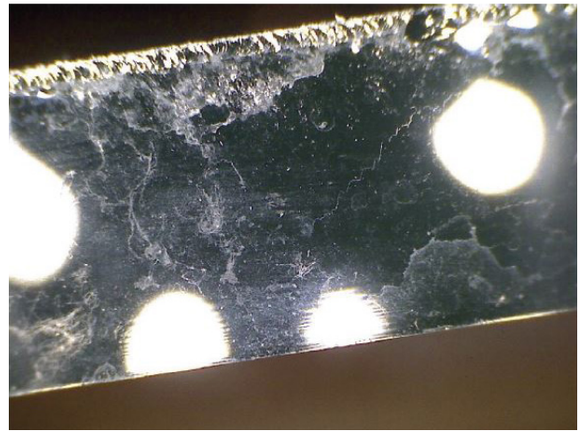




Complex **shape** and large **size**

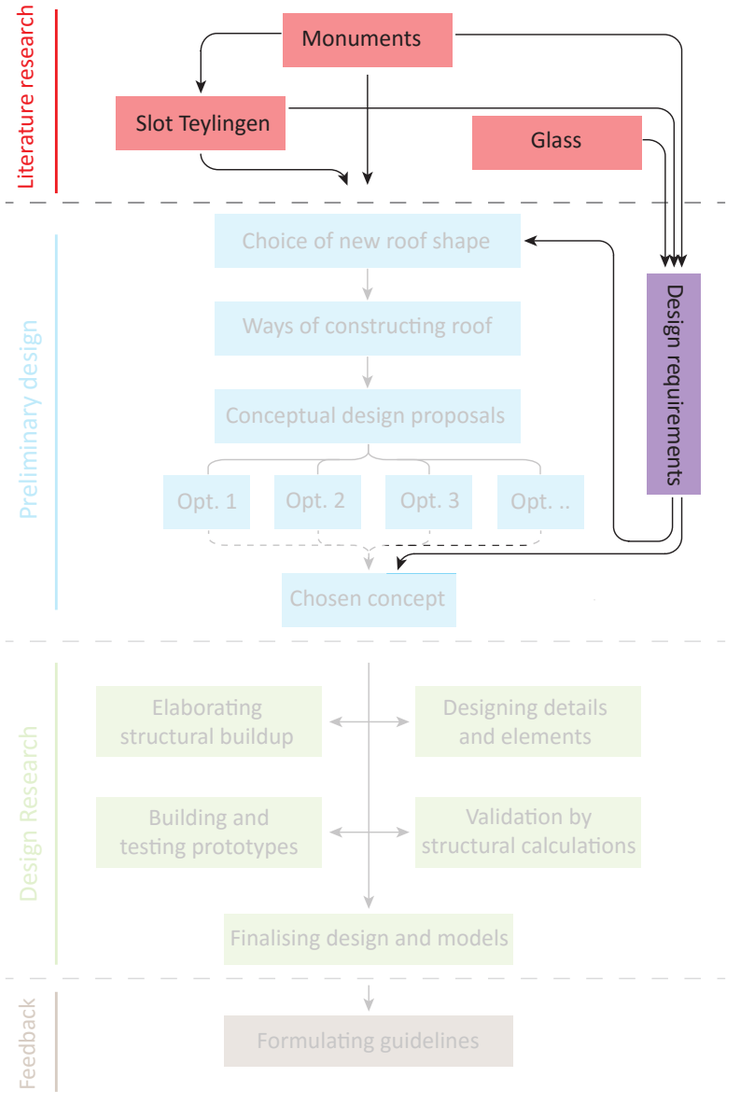


Old **weakened** and damaged **masonry**



Typical **glass properties**

DESIGN REQUIREMENTS



The new glass roof should be:

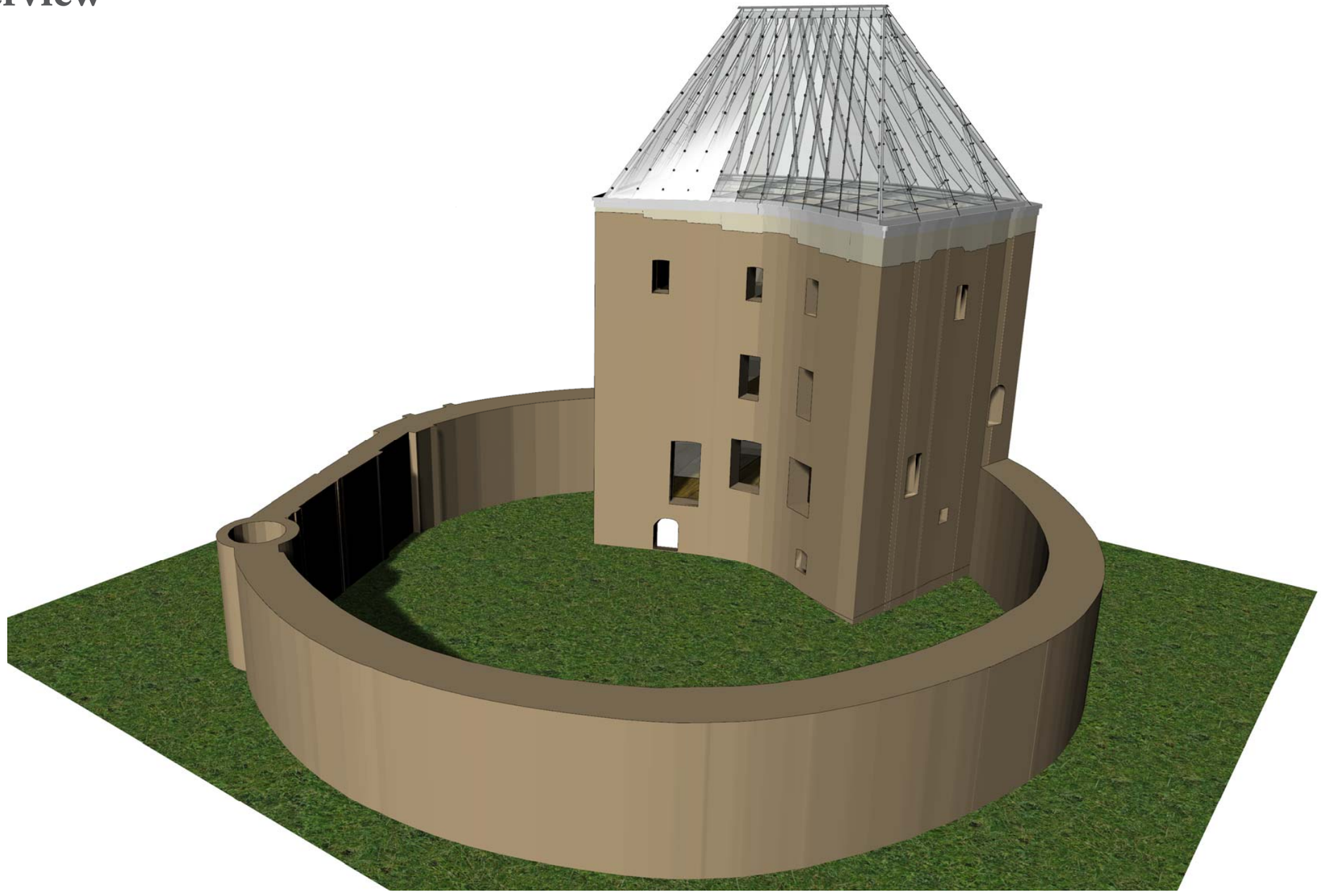
- ◊ Reversible
- ◊ Optimized amount of transparency
- ◊ Structure with maximum application of glass
- ◊ Fitting in the original building, with respect to history and context
- ◊ Preventing large unwanted forces on old structure
- ◊ Designed to minimize probability of failure of glass
- ◊ Designed to minimize consequences of failure of glass
- ◊ Use steel components and glued connections where needed to prevent drilling in the glass

ARCHITECTURAL DESIGN

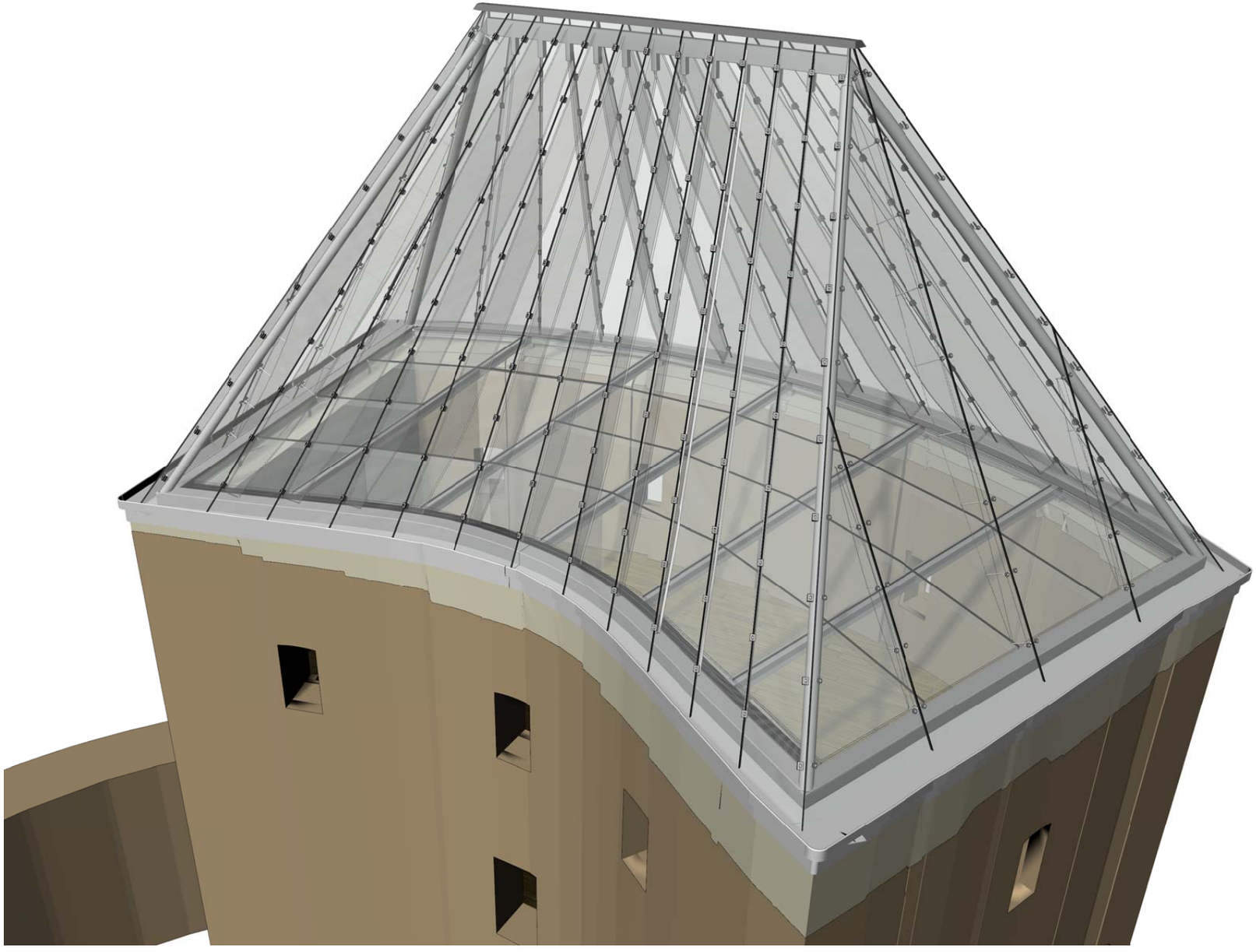
3D RENDER

3D RENDER

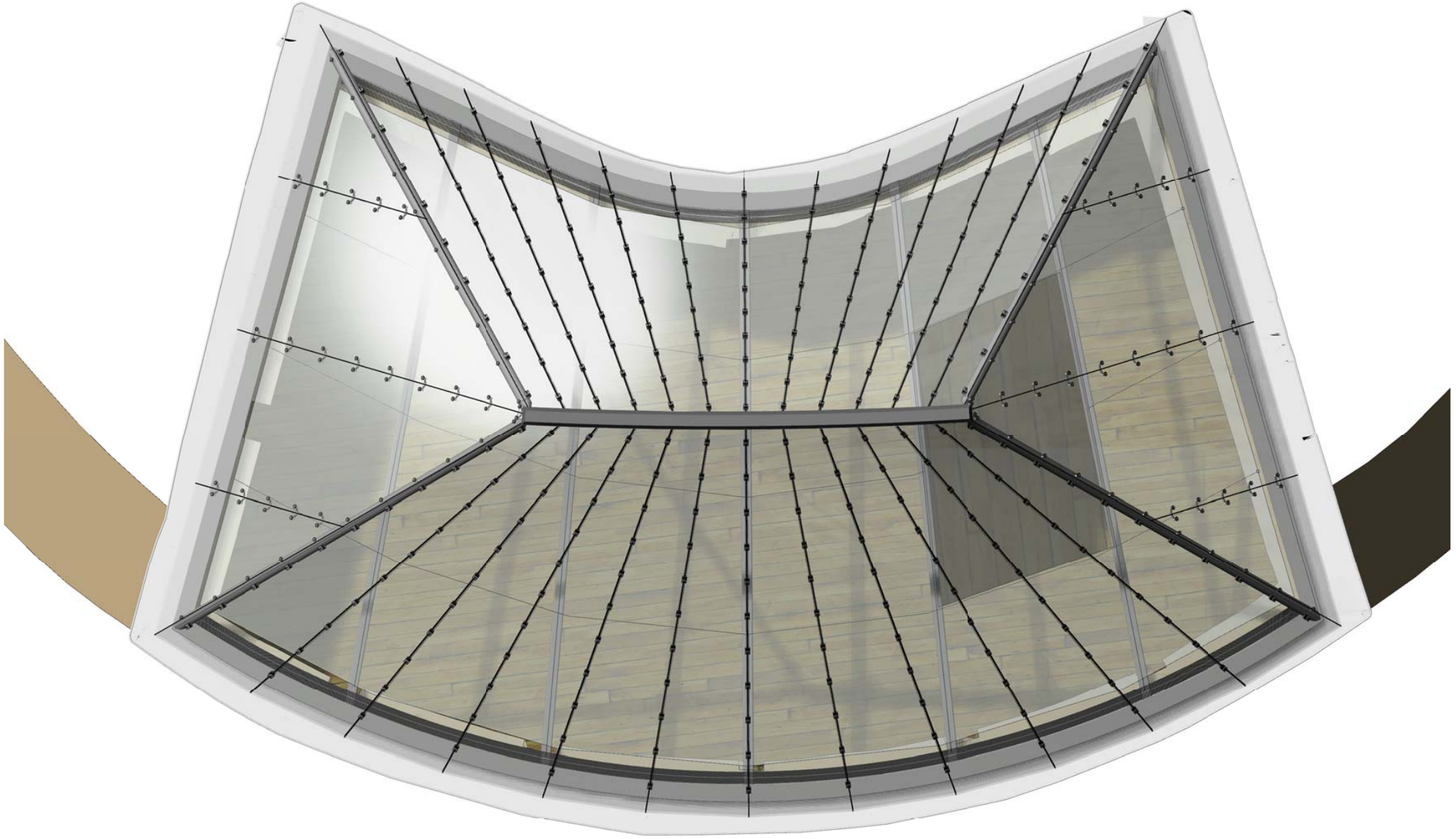
3D - overview



3D - roof close up

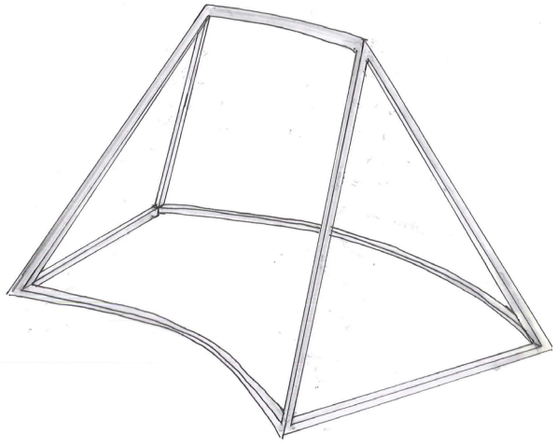


TOP VIEW

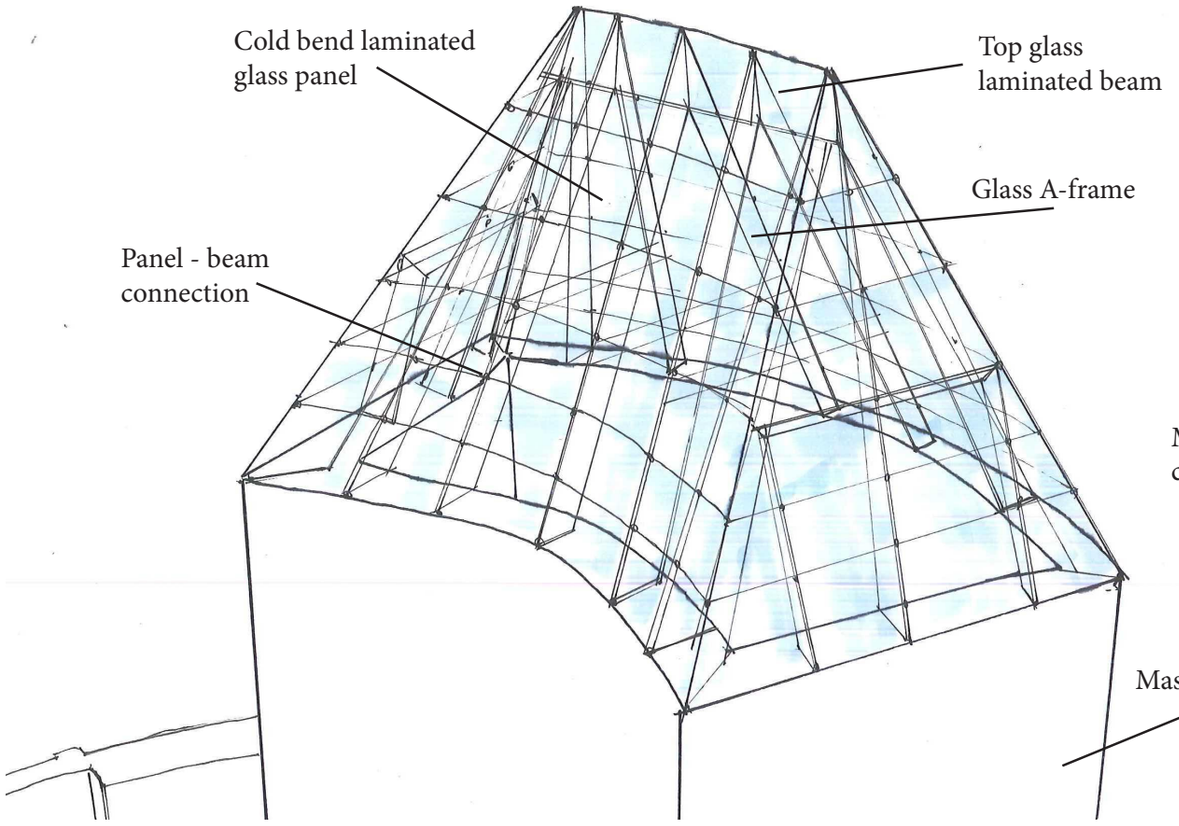


MAIN PRINCIPAL

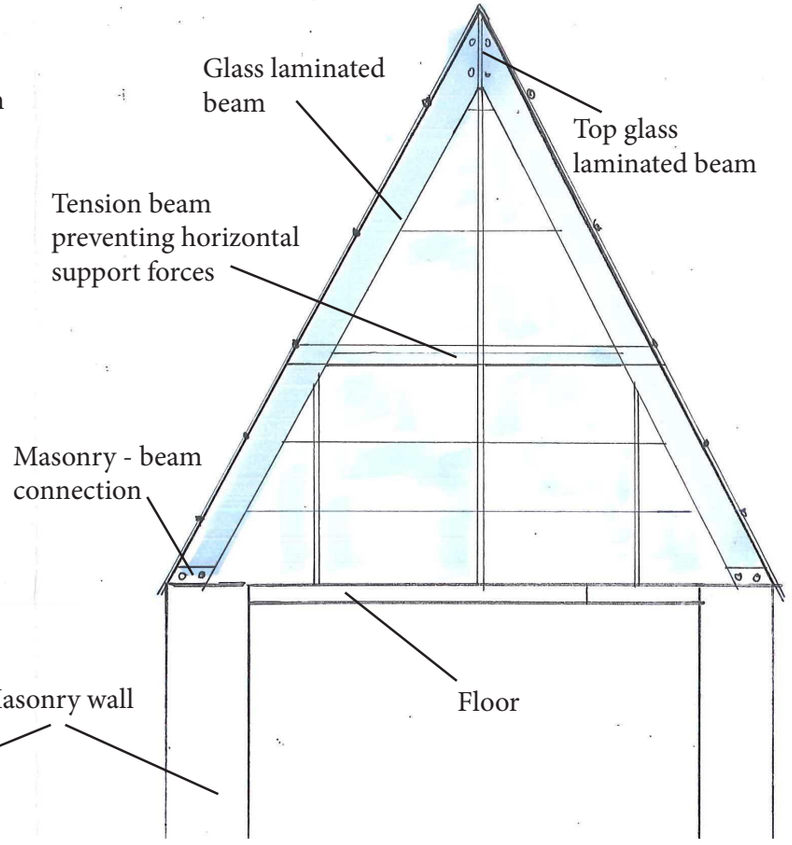
Glass beam structure + steel contour frame



3D Impression



2D Section



STRUCTURAL DESIGN

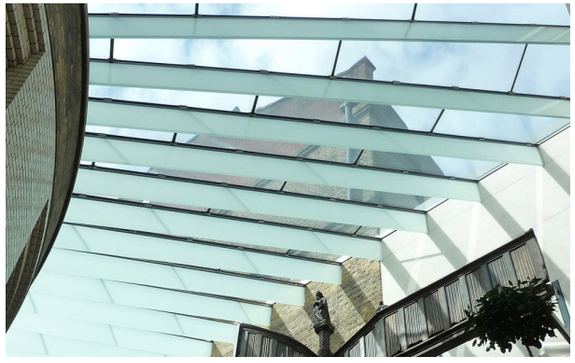
RESEARCH

Glass structural systems

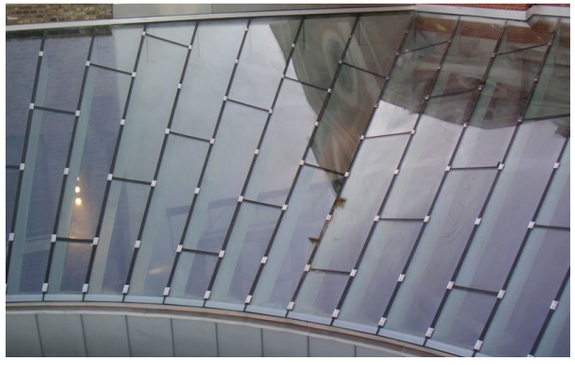
Structure systems

Beams

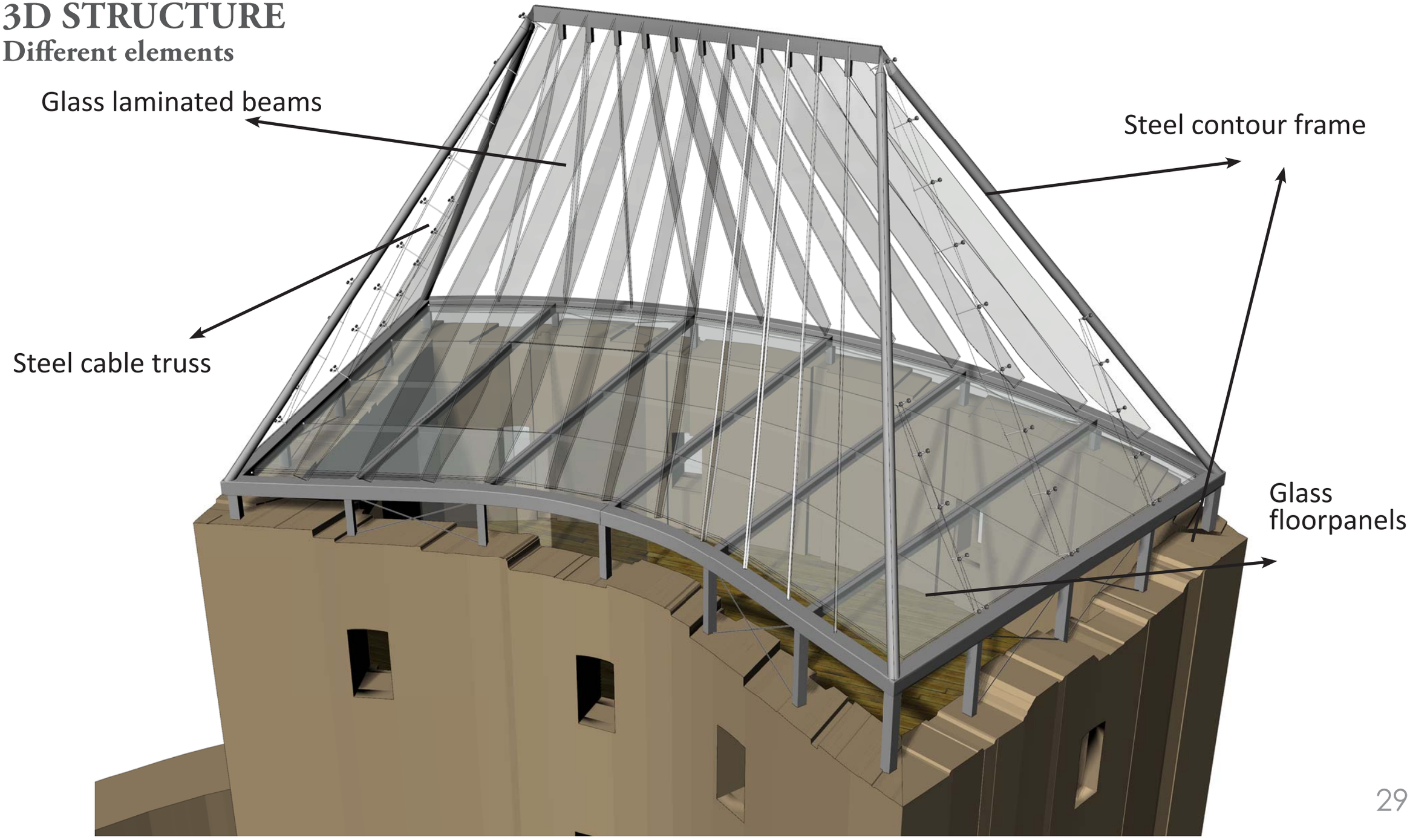
Truss








3D STRUCTURE
Different elements



STRUCTURAL ELEMENTS

Steel contour frame

Steel structure fullfils
Architectural + Structural
function

Architecture

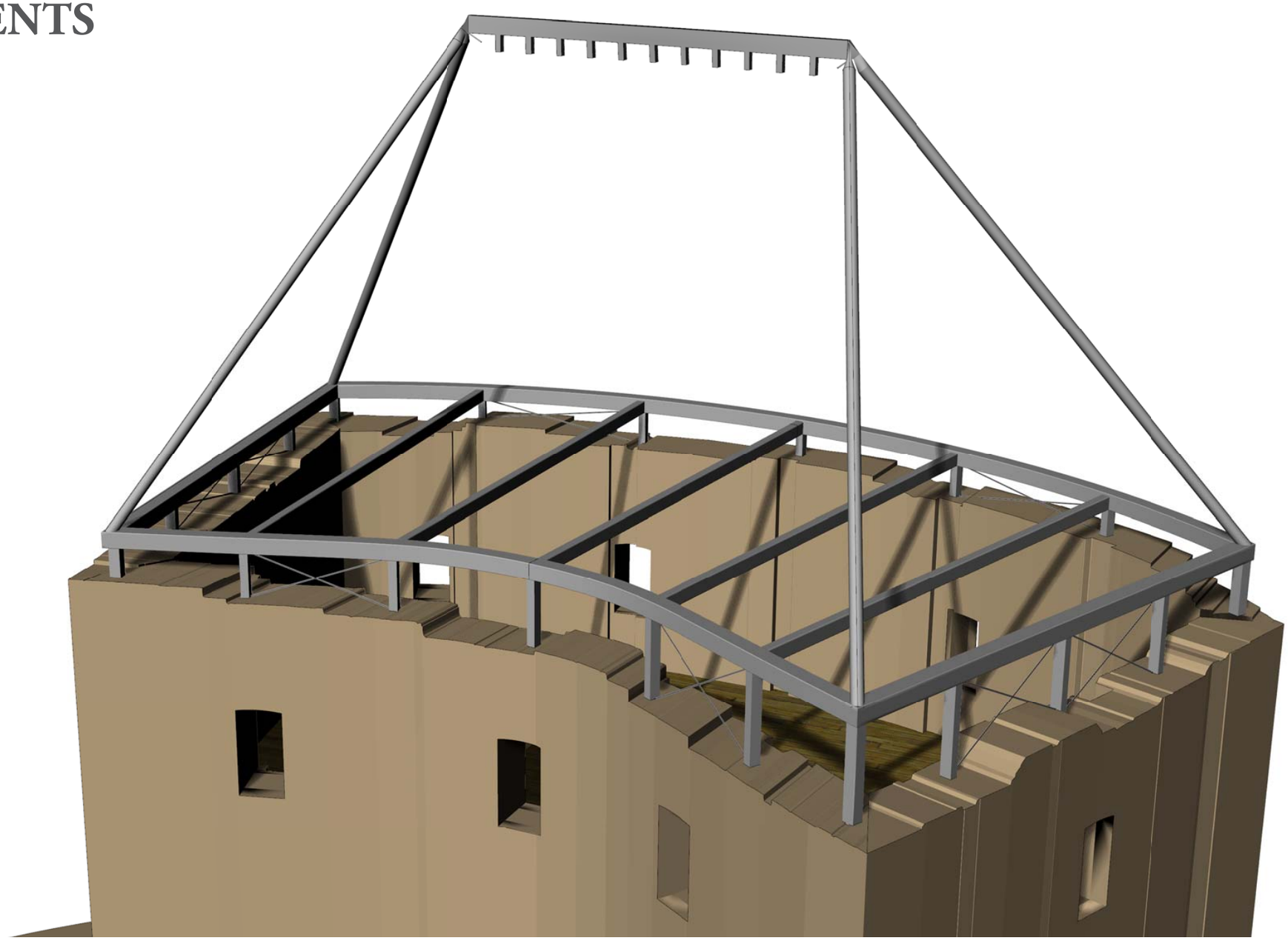
◊ Structure emphazises contour of original roof

Structural

◊ Structure prevents large unwanted tensile forces and bending moment on the masonry

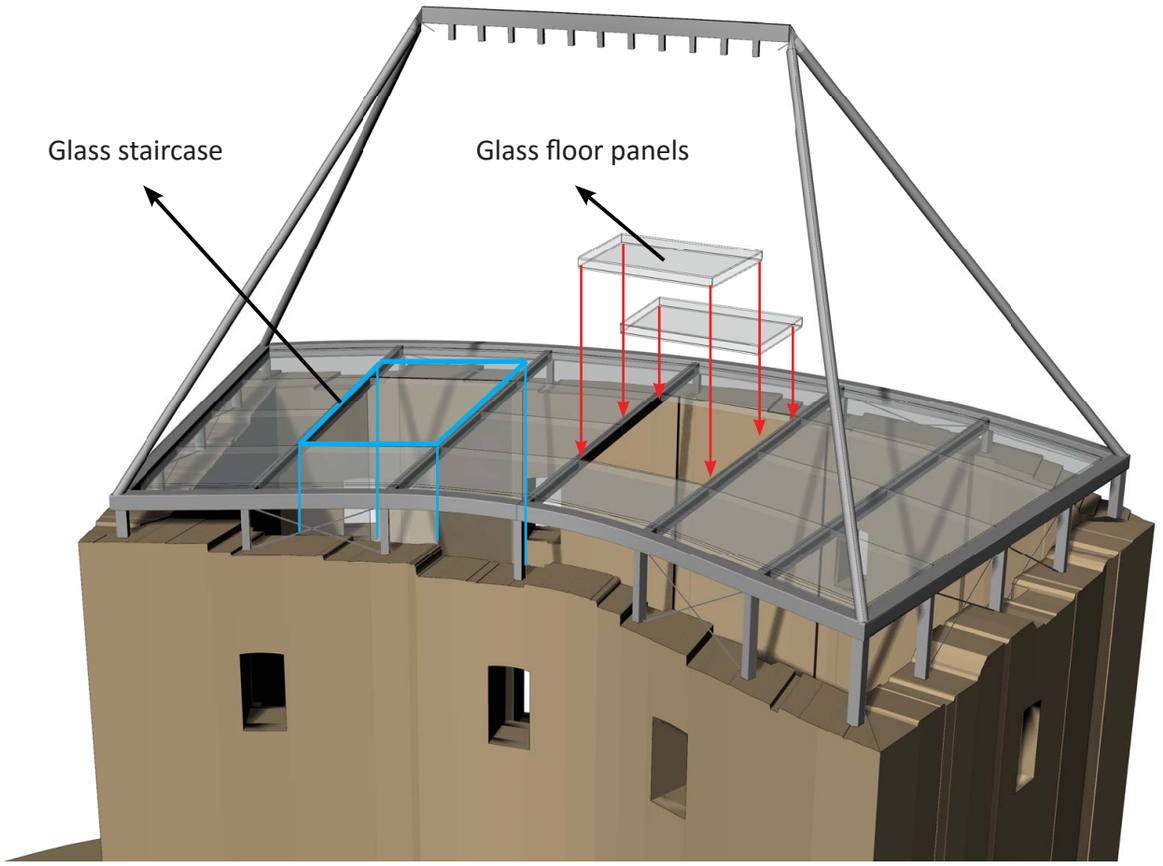
◊ Provides flat surface for new roof

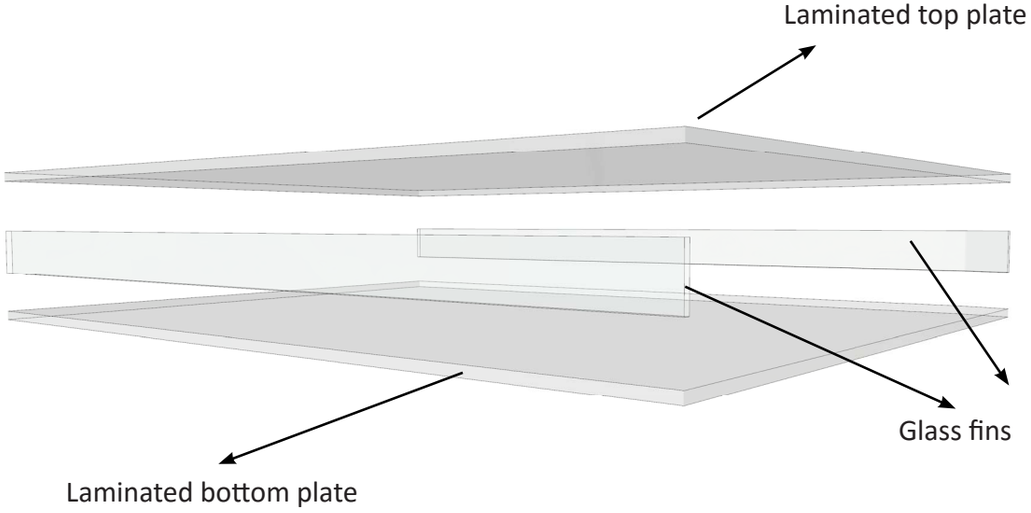
◊ Allows for easier connections

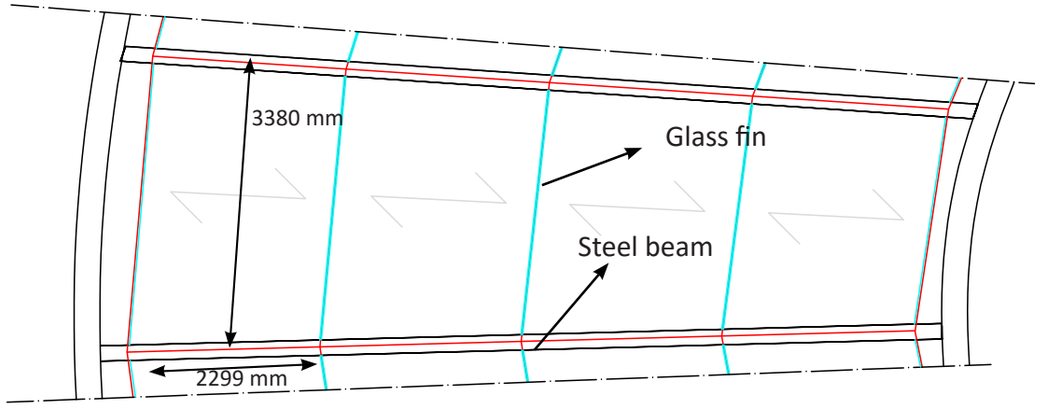


STRUCTURAL ELEMENTS
Glass floor panels

- Structural glass floor panels
- Designed to carry over 500 kg/m2
- Panels resting on glass fin, connected to the steel beams
- Bottom and top plate create hollow panel -> insulating properties







STRUCTURAL ELEMENTS
Glass beam structure

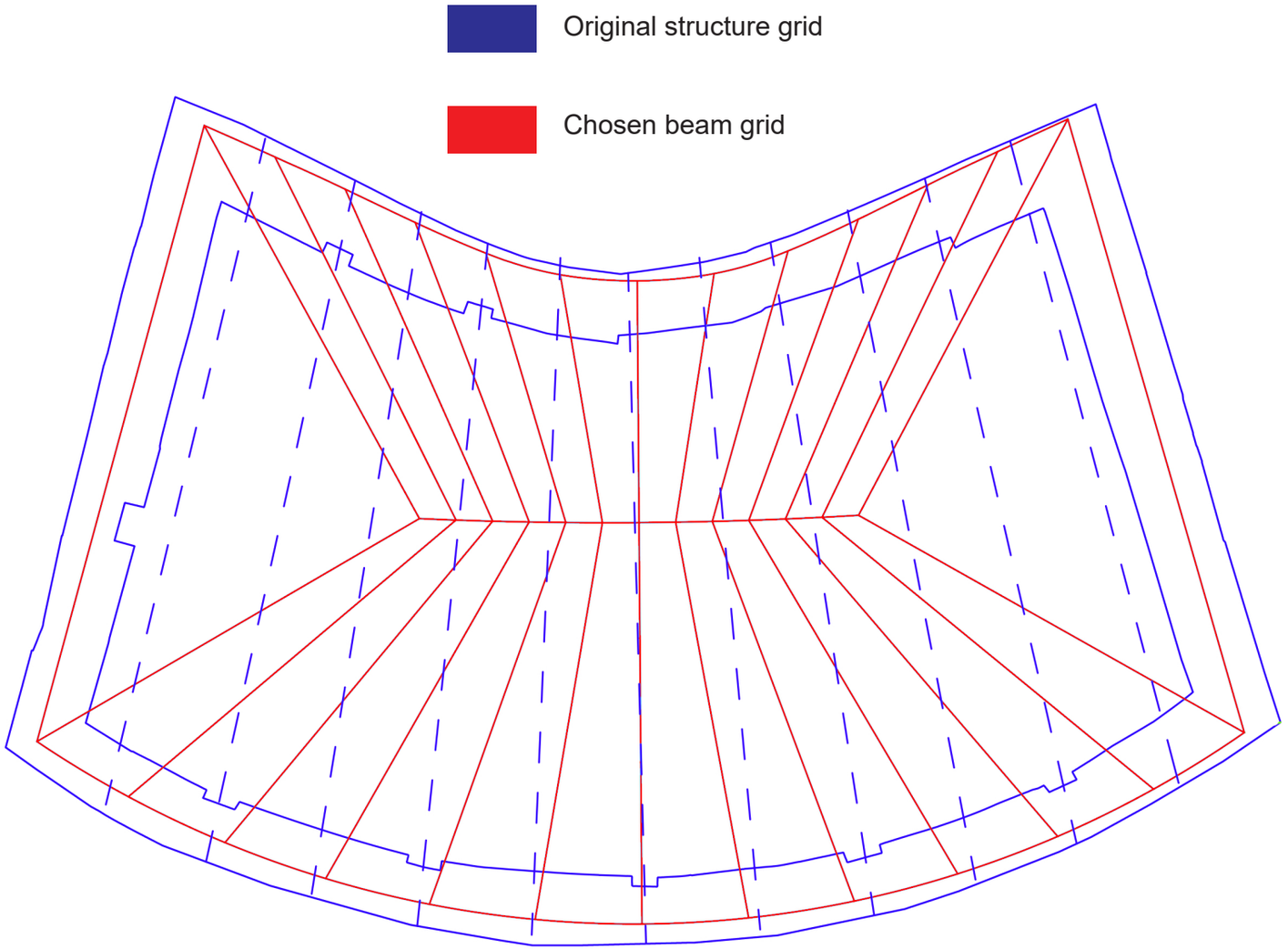
- Similar structure type as original wooden roof
- Esthetical design choice, providing a clean structure
- Identations in the walls where original roof structure was

CHOICE OF BEAM GRID

- Beams roughly 9595 - 11200 mm long

- Aligning with old beam grid
  ->
  visual integration of new with old

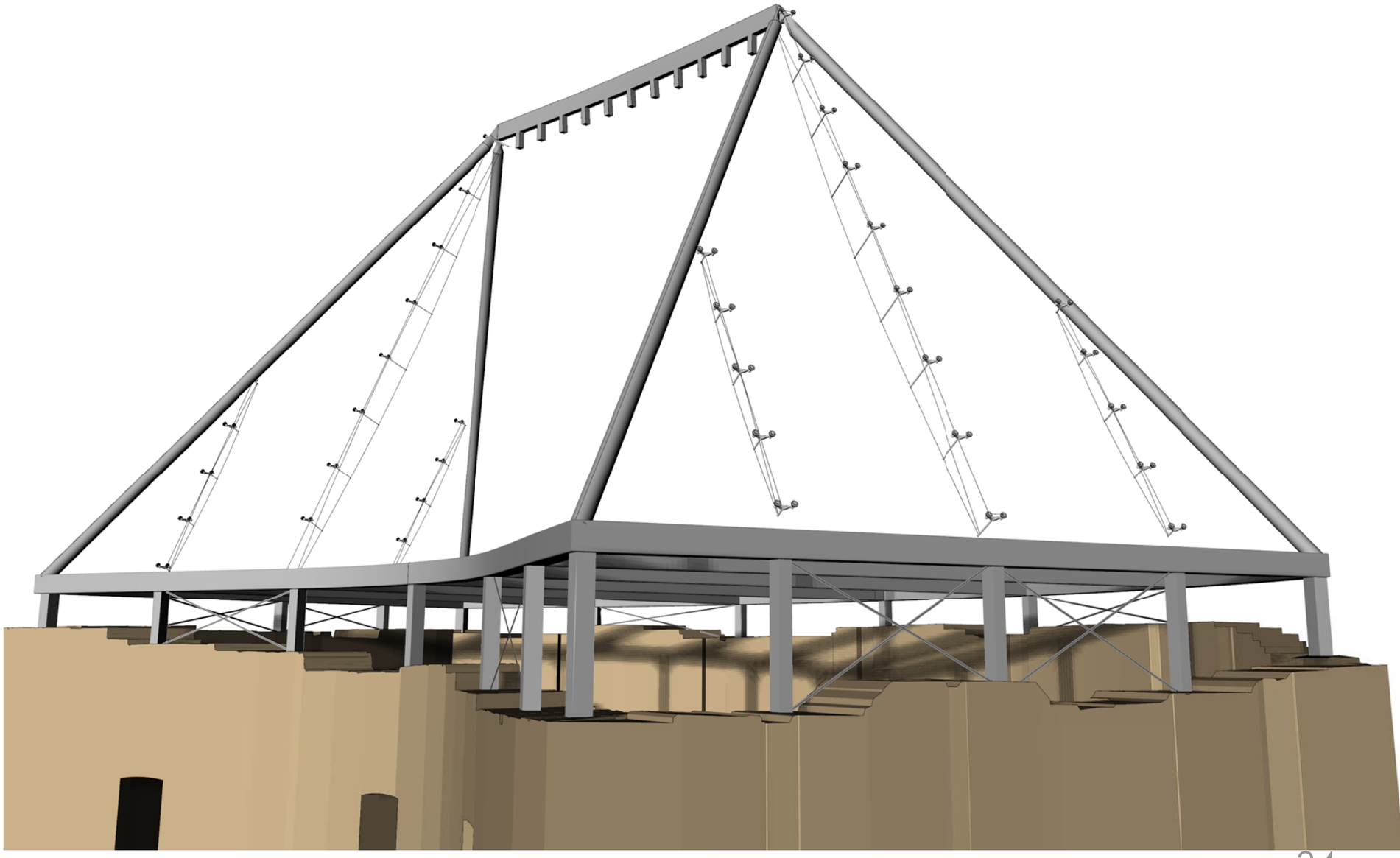
- Similar distance between panels
  ->
  lowers construction complexity



STRUCTURAL ELEMENTS
Steel cable trusses

No glass beams here because:

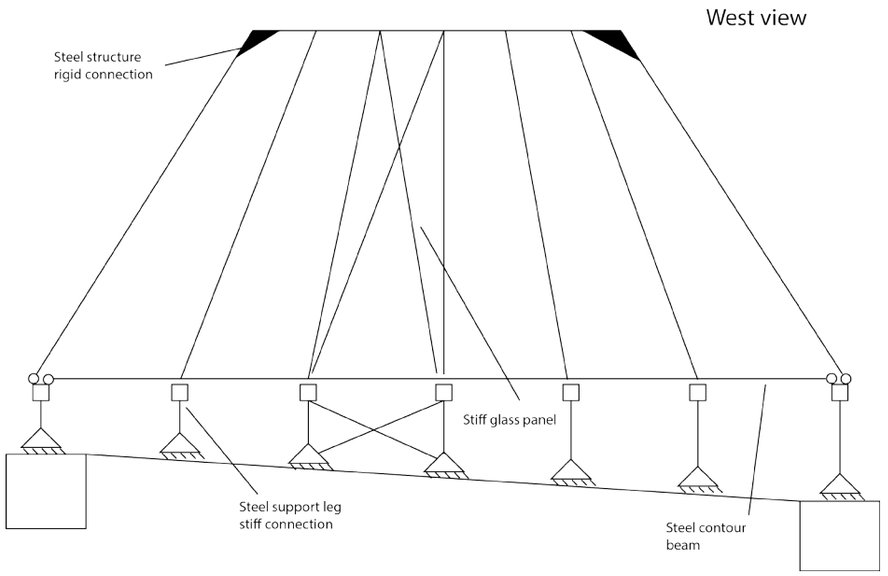
- Esthetical reasons
- Difficult connections to steel frame
- Not required since there are no identations in walls here
- Very slender structure
  ->
  Transparency
- Steel top and bottom
  ->
  easier connection

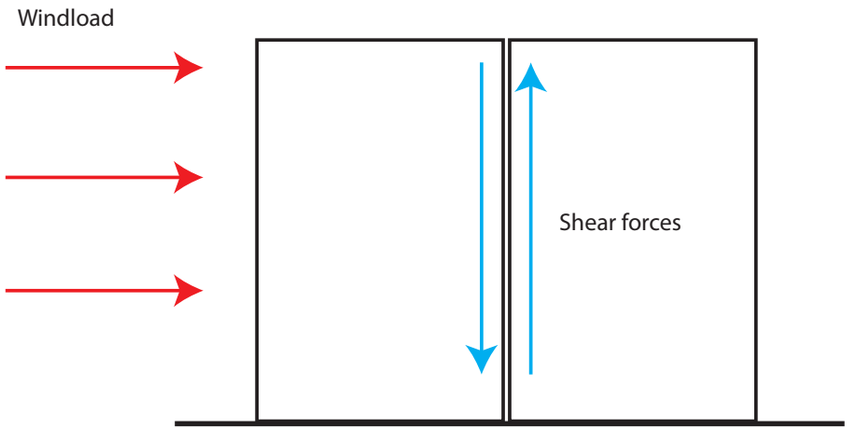


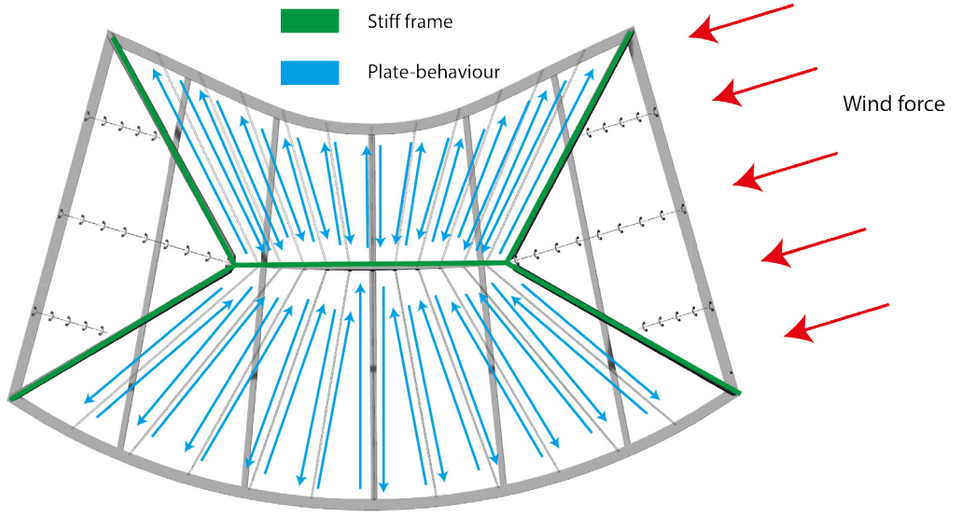
STRUCTURAL ELEMENTS

Glass panels

- Glass panels are part of structure, help to stabilize structure.
- Panels transfer windloads through shear forces in the seams
- Monolothic behaviour of structure
- Joints are crucial in this!



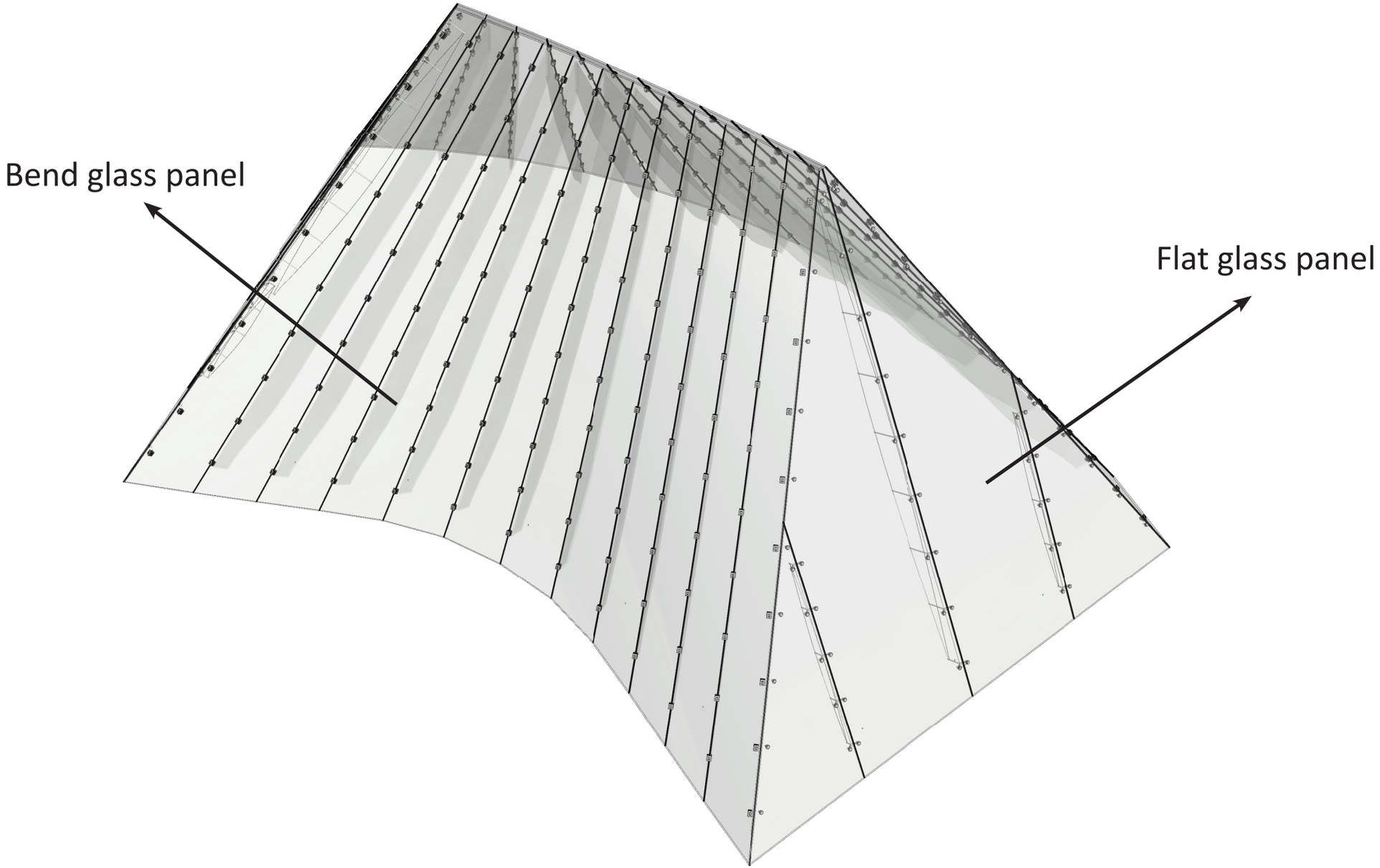




FACADE DESIGN

FACADE DESIGN

3D model

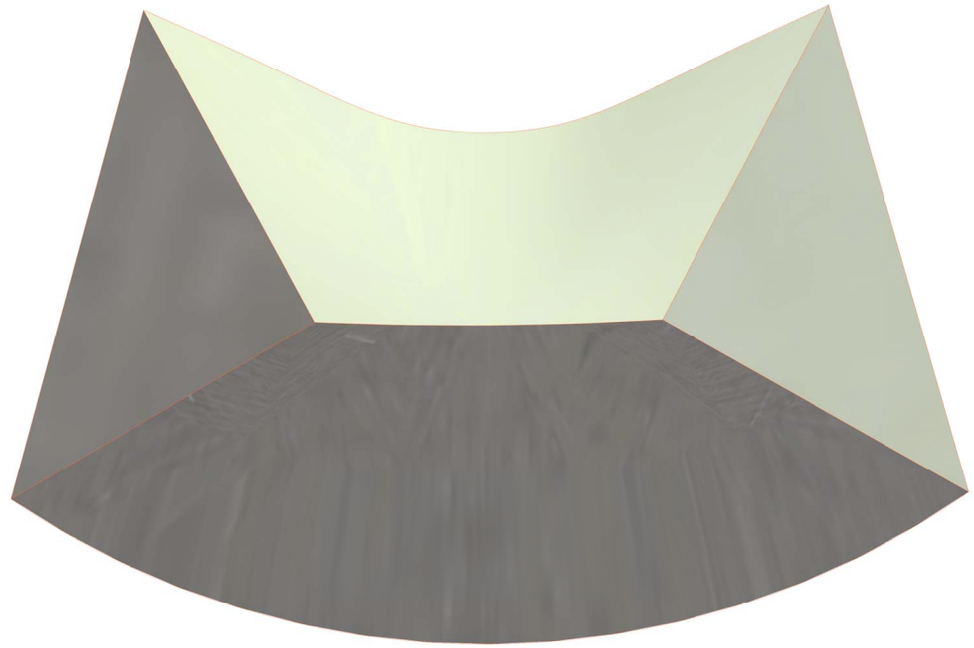


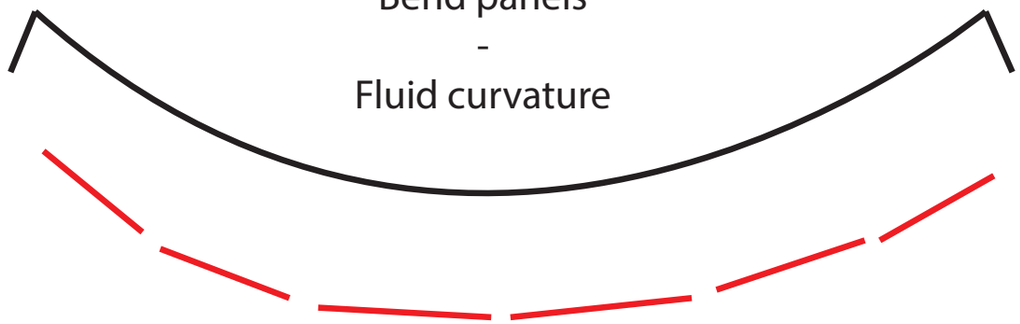
COMPLEX SHAPE

Difficult curvature on two sides of the roof

- Two options : flat or bend glass panels
- Flat panels
  =
  course curvature, distorted reflections
- Bend glass panels
  =
  fluid curvature, intact reflections

- **Choice** -> bend glass panels

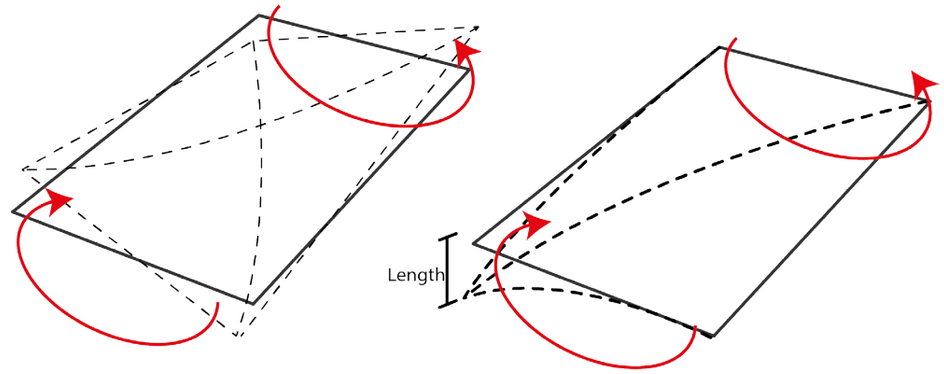




Bend panels
-
Fluid curvature

Flat panels
-
course curvature

BEND GLASS



HOT BENDING

+ Great freedom in shape
- Expensive molds needed
- Reduced optical quality

COLD BENDING

+ Cheaper, no molds needed
+ Bend on site
- Restrictions in shape and deformation

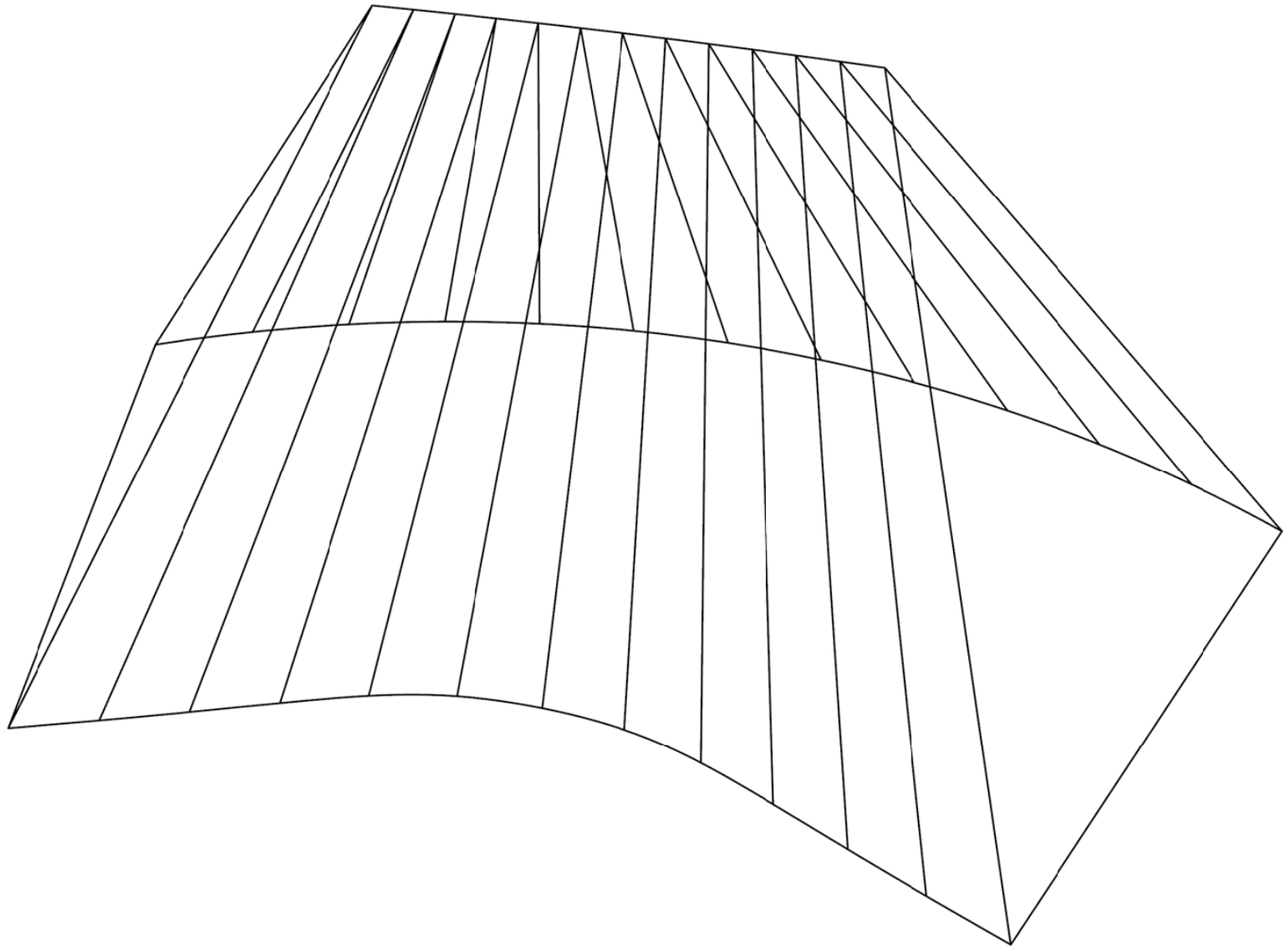
CHOSEN PANEL LAYOUT

- Panel size roughly
  1766 - 1280 mm wide,
  9595 - 11200 mm long

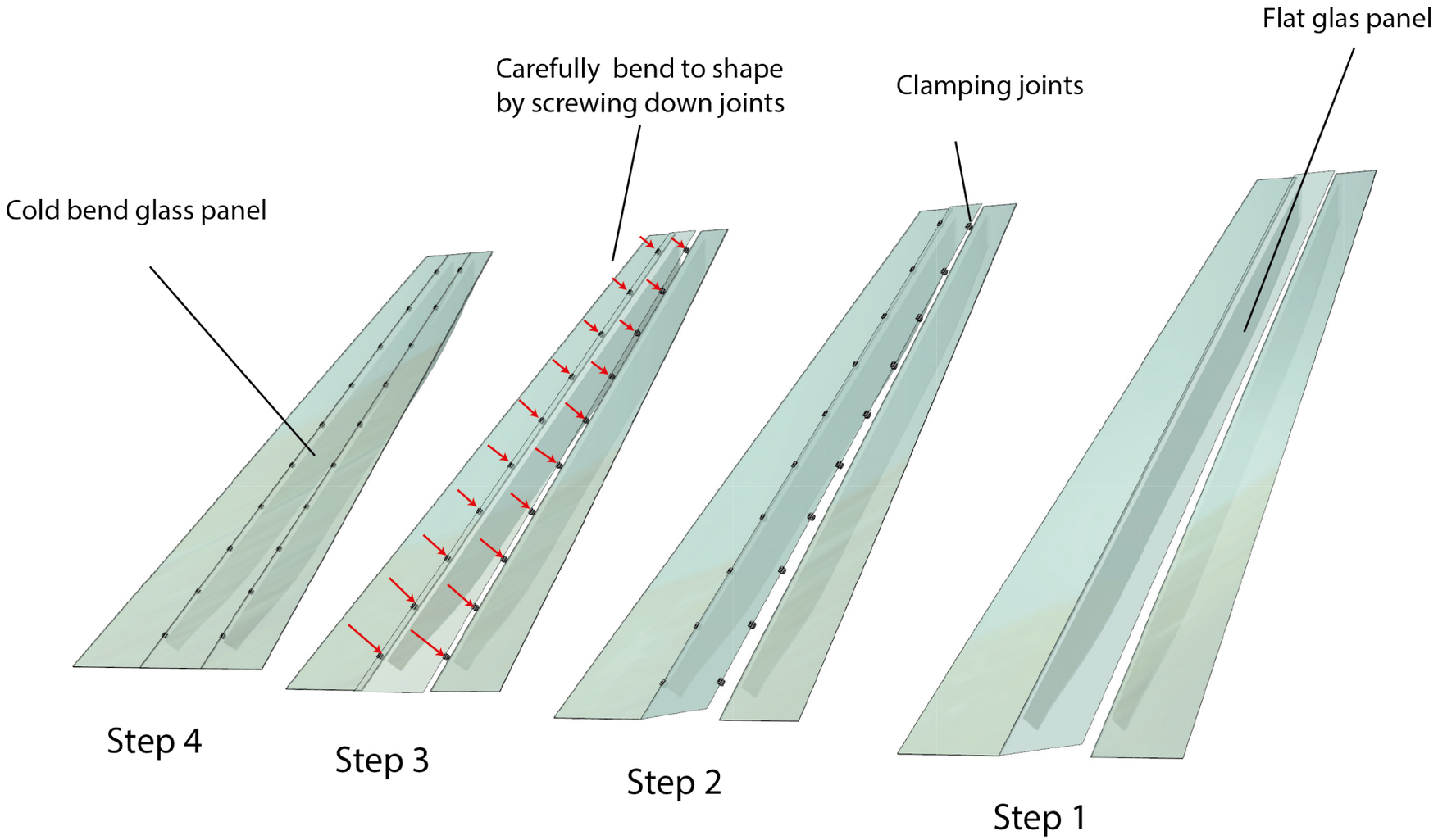
- Glass cold bent to fit curvature -> consequences for the detailling!

- Seams align with beams, less visible joints
  ->
  Transparency

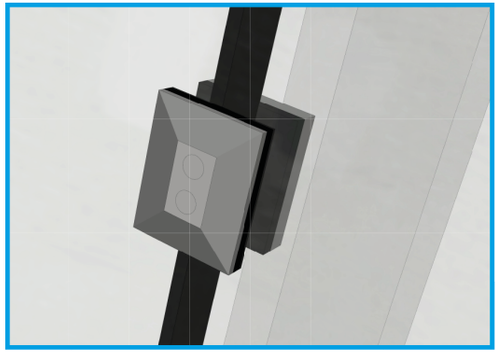
- Big panels = Less unique panels
  ->
  lower costs and construction complexity

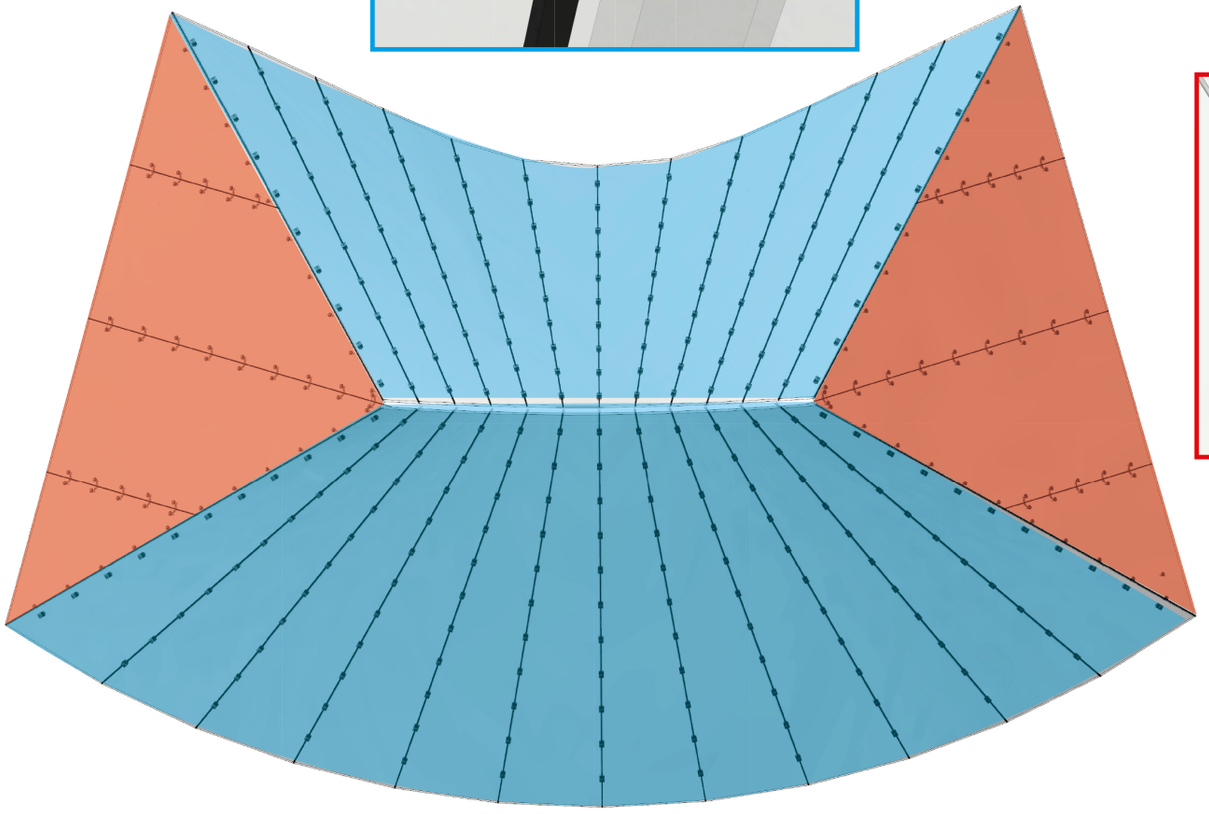


COLD BEND PANELS



GLASS JOINTS



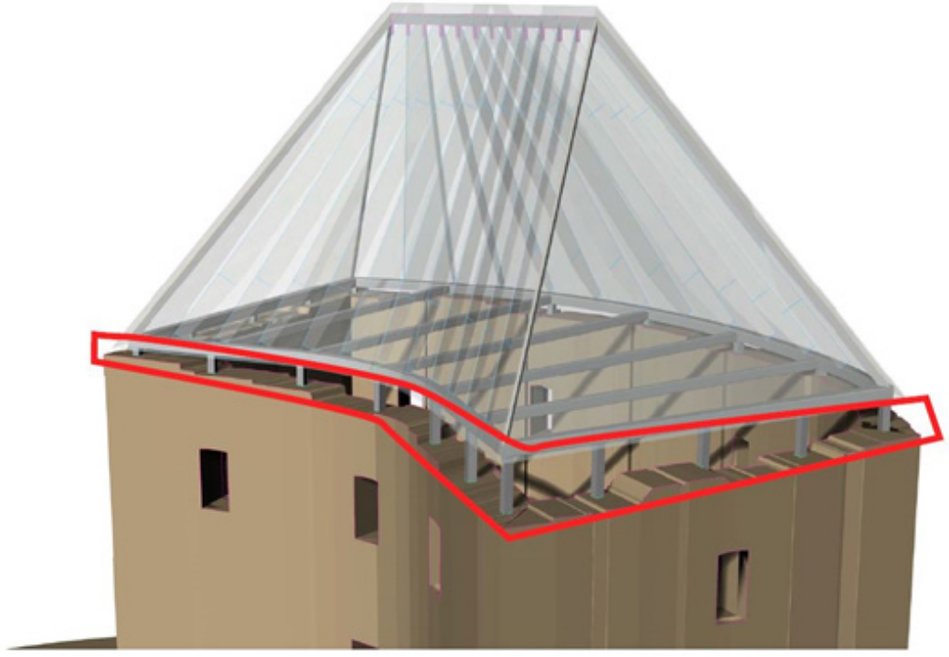


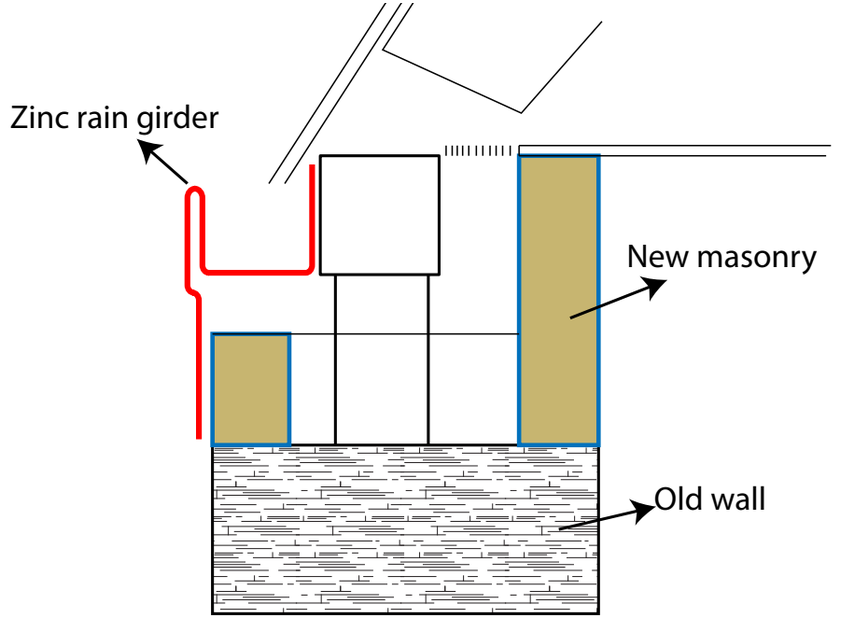
Clamp connections

Spider connections

GAP OF WALL

Architectural + Functional requirements





Clay brick + metal element

- visual integrating + yet contrasting clay brick for leveling the wall
- Zink plate material in shape of rain girder, for climatic installation integration

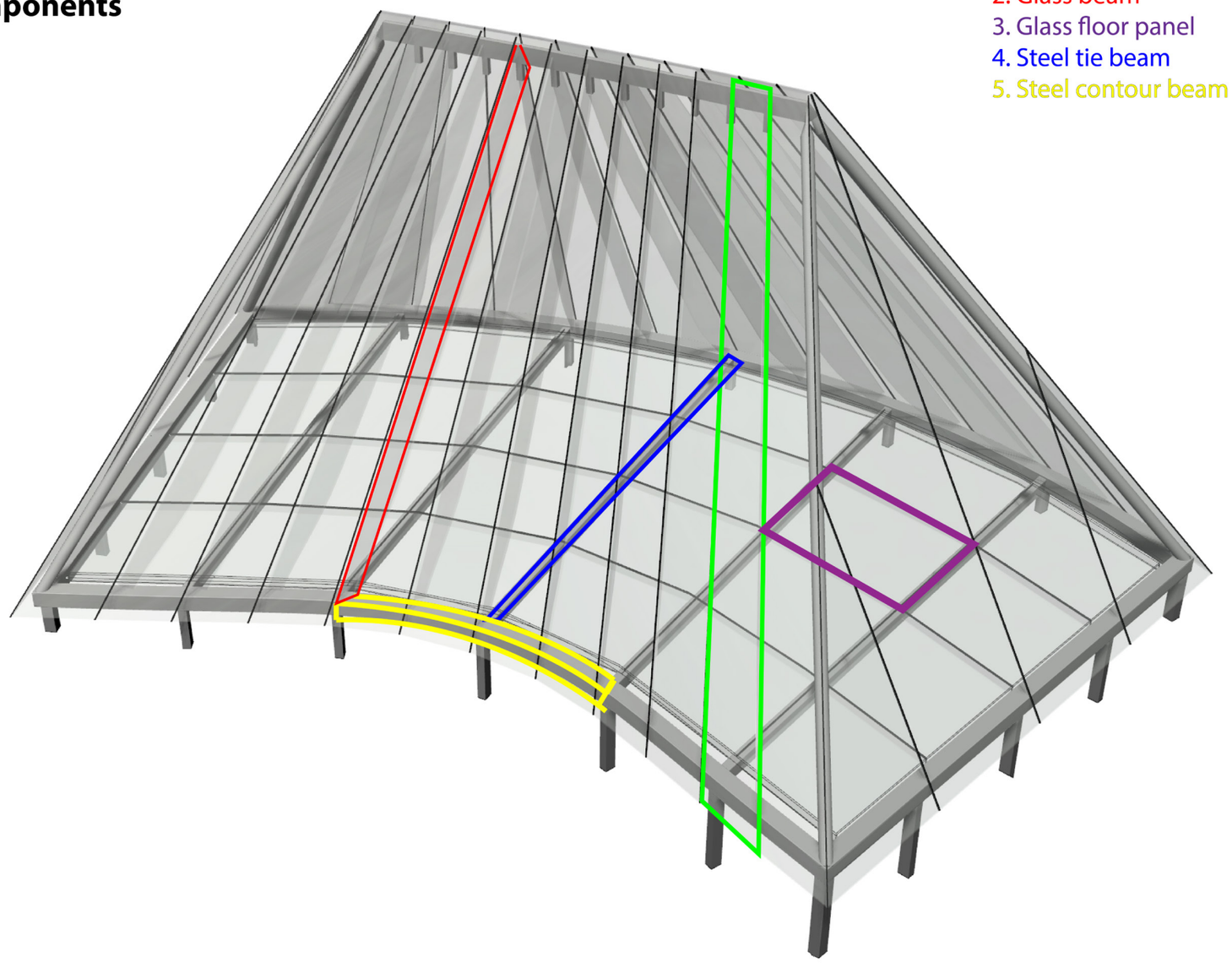
- Transition from old wall to glass with the sub layer
- Important to use the right type of brick!

STRUCTURAL CALCULATIONS

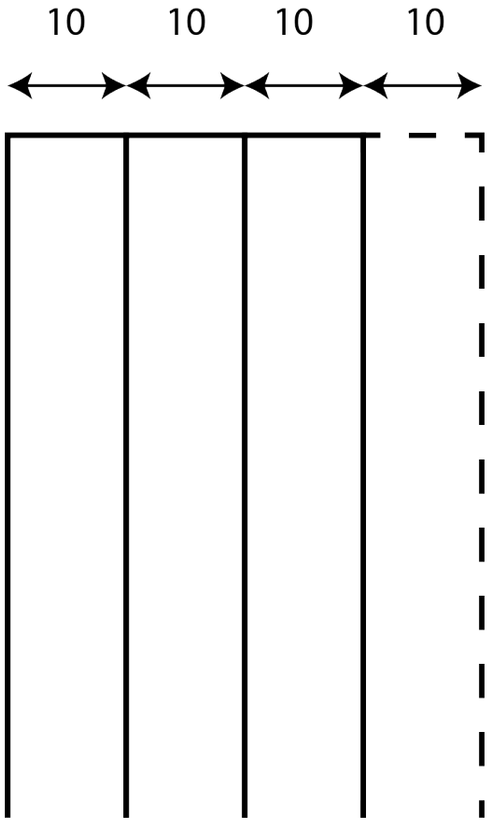
Required dimensions

HANDCALCULATIONS

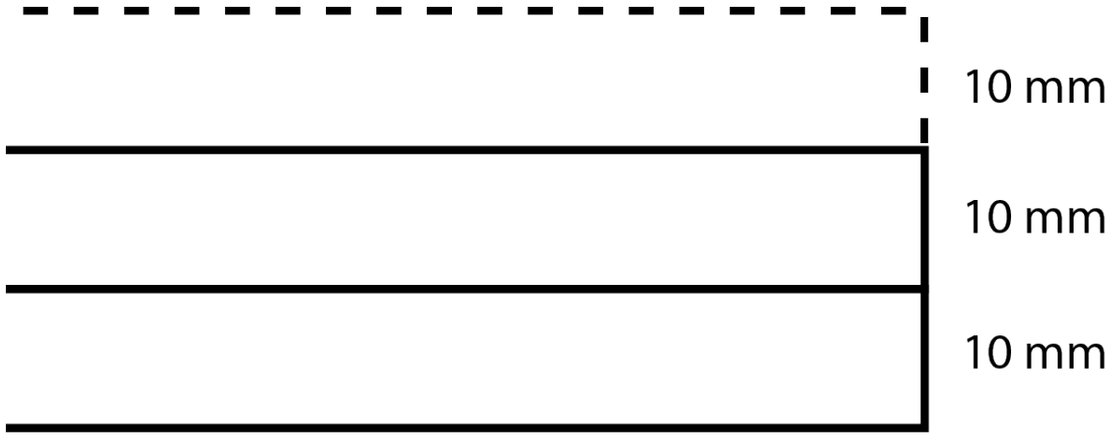
The calculated components



SAFETY ANALYSIS
Section properties



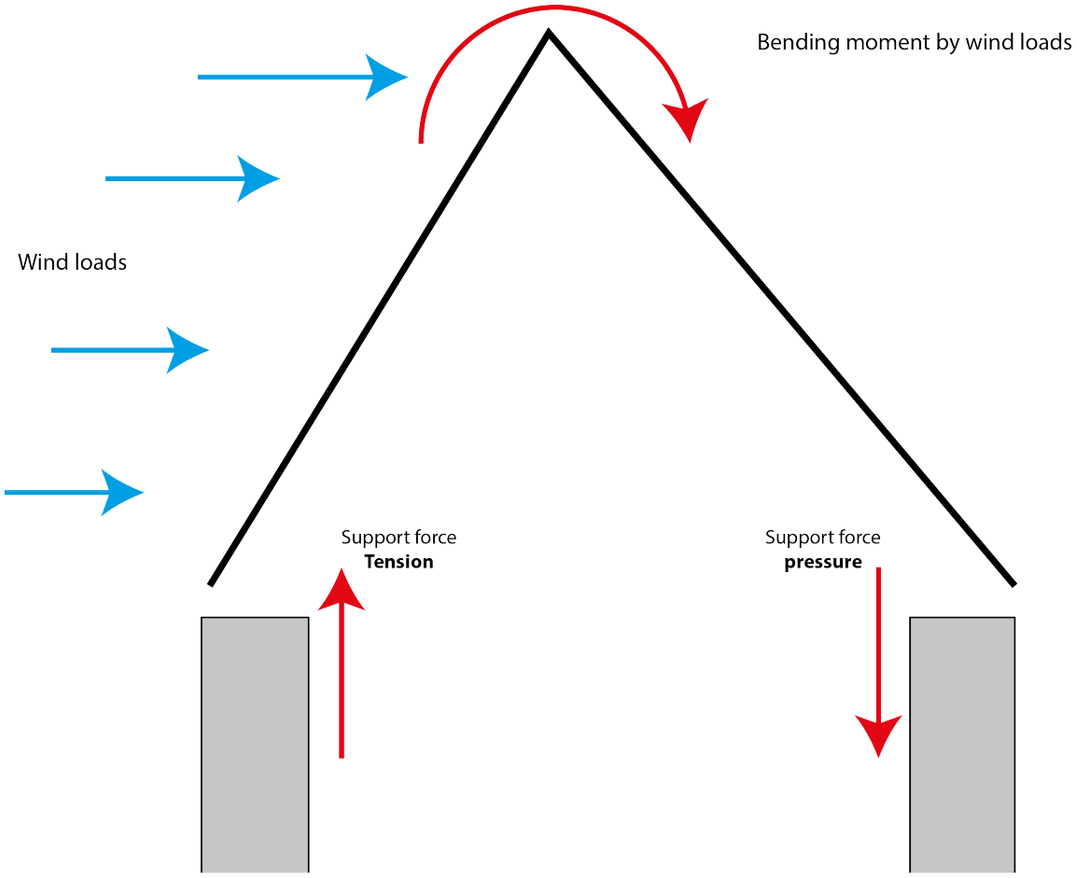
Glass beam



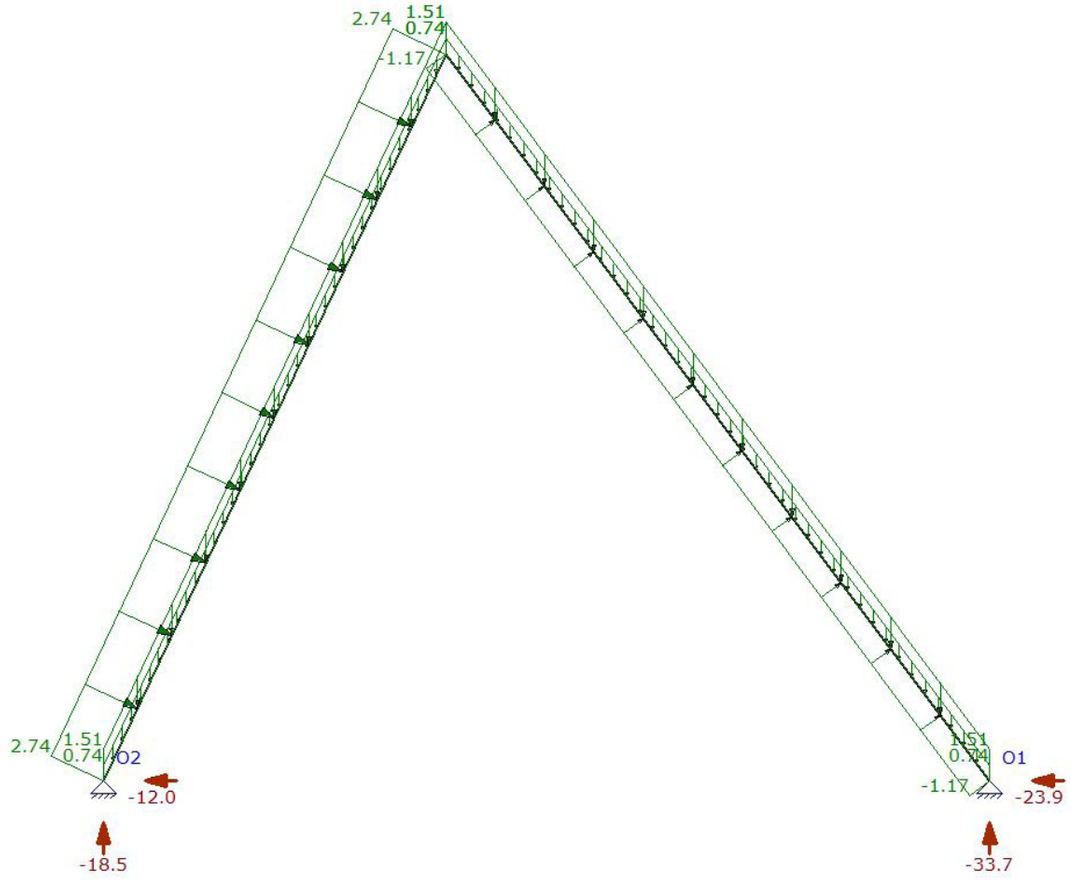
Glass panel/floor

High risk -> calculate as if one layer is always broken

MATRIXFRAME

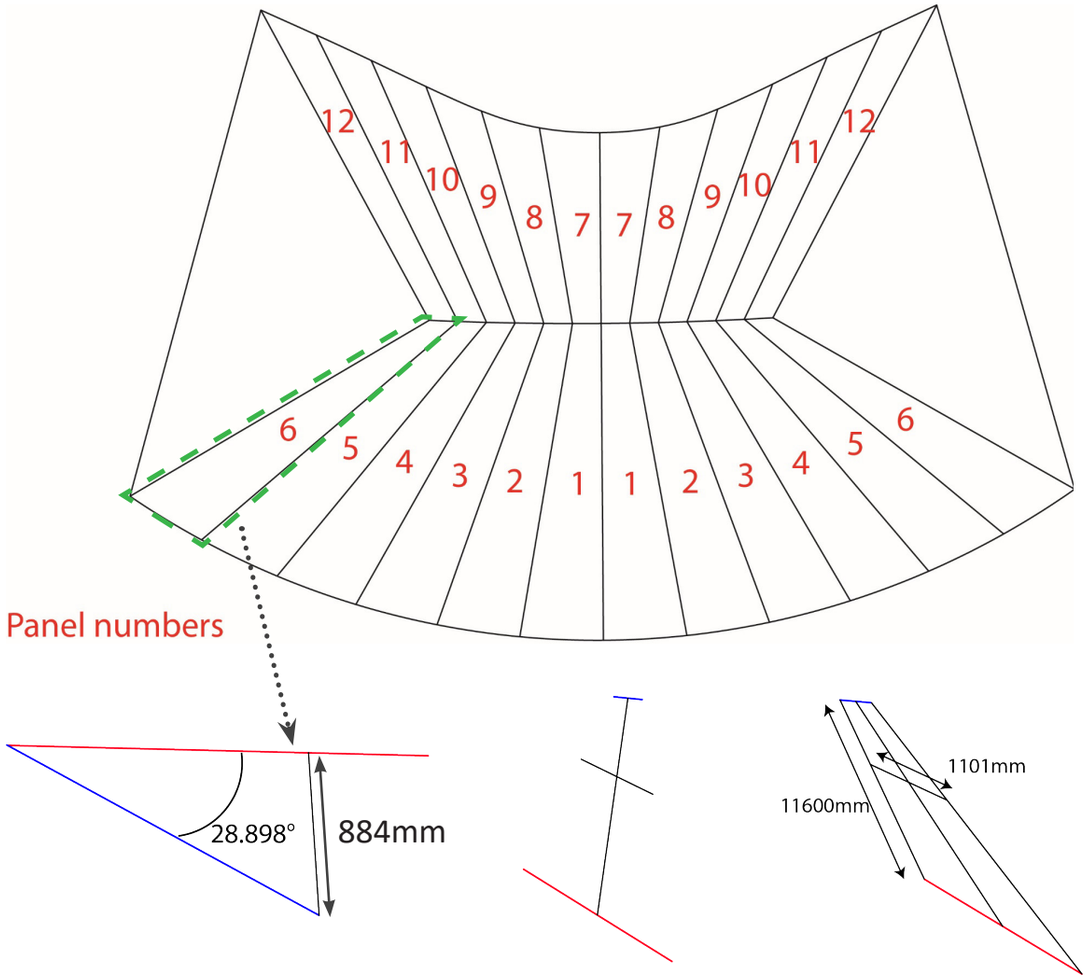


Possible tensile support reaction forces

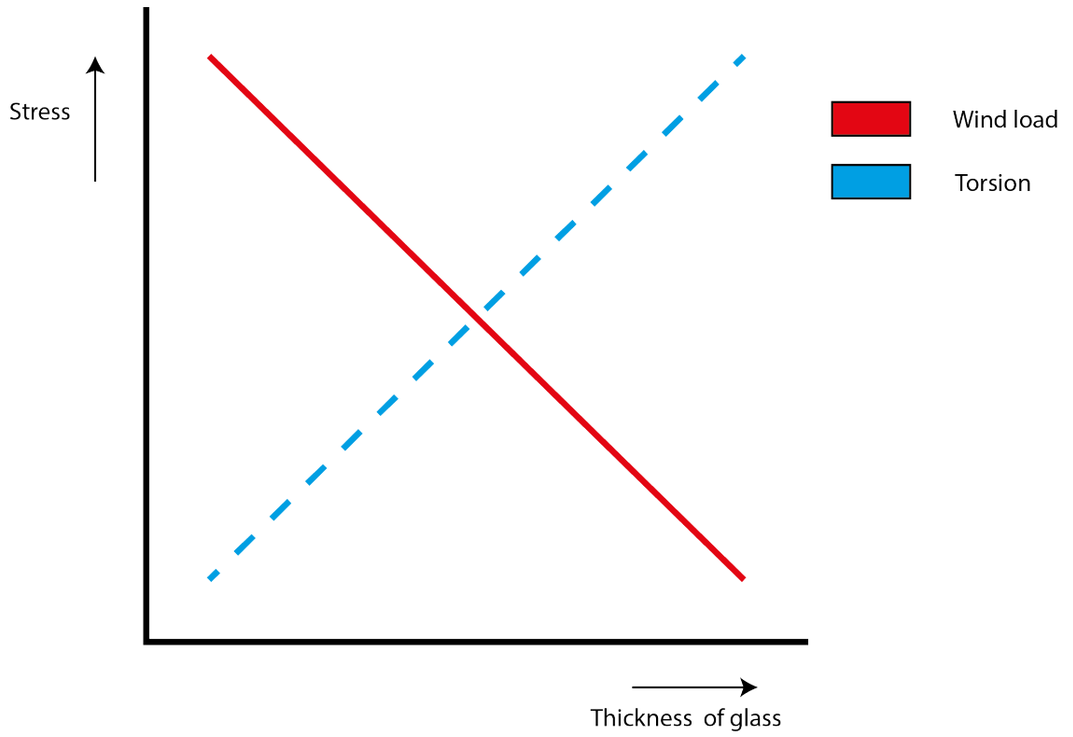


Matrixframe calculated just compressive forces

COLDBENDING GLASS



The cold bending means inducing shear stresses by torsion



Interesting contradiction

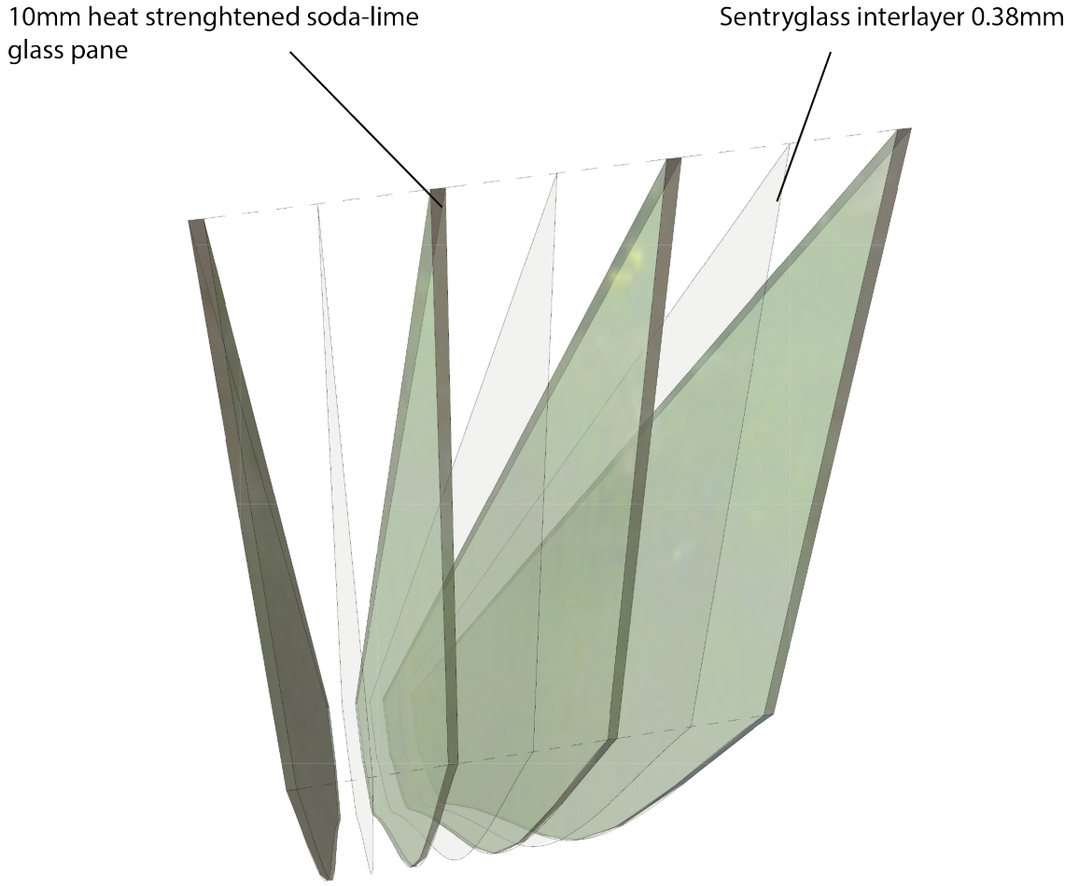
RESULTS - DIMENSIONS

Summary of Results						
Component	**Height**	**Width**	**Thickness**	**Type of glass**	**Max stress**	**Max allow. stress**
Glass panel		30mm	3 x 10 mm	HS - FT -HS	44,74 Mpa	40 Mpa
Glass beam	480 - 560 mm	40 mm	4 x 10mm	HS	39,41 Mpa	40 Mpa
Glass floor panel		30mm	3 x 10mm	HS	33,53 Mpa	40 Mpa
Steel tie beam	260mm	180mm	16mm	S235	174,89 Mpa	235 Mpa
Steel contour beam	300mm	300mm	10mm	S235	20,86 Mpa	235 Mpa

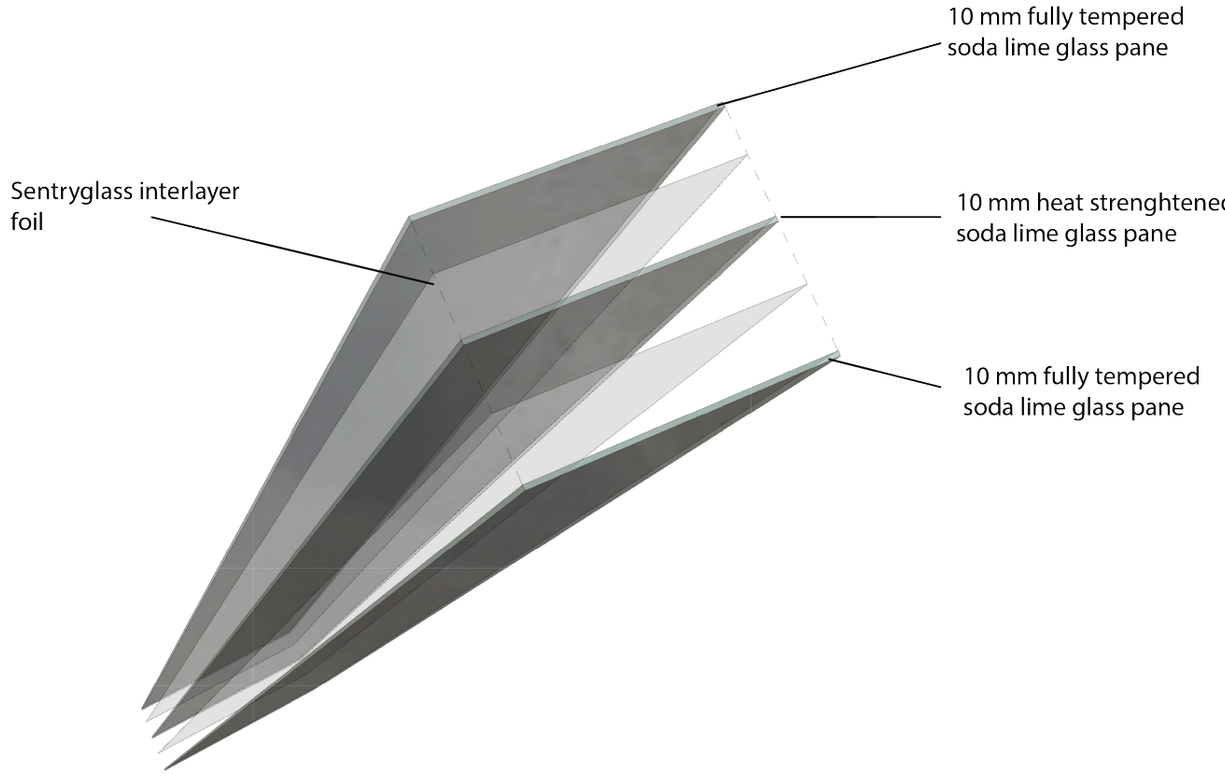
- Dimensions of element derived
- Cold bending of panels requires further research!

SAFETY AND STRENGTH

In the structural elements



Safety = Heat strenghtened laminated SGP glass beams

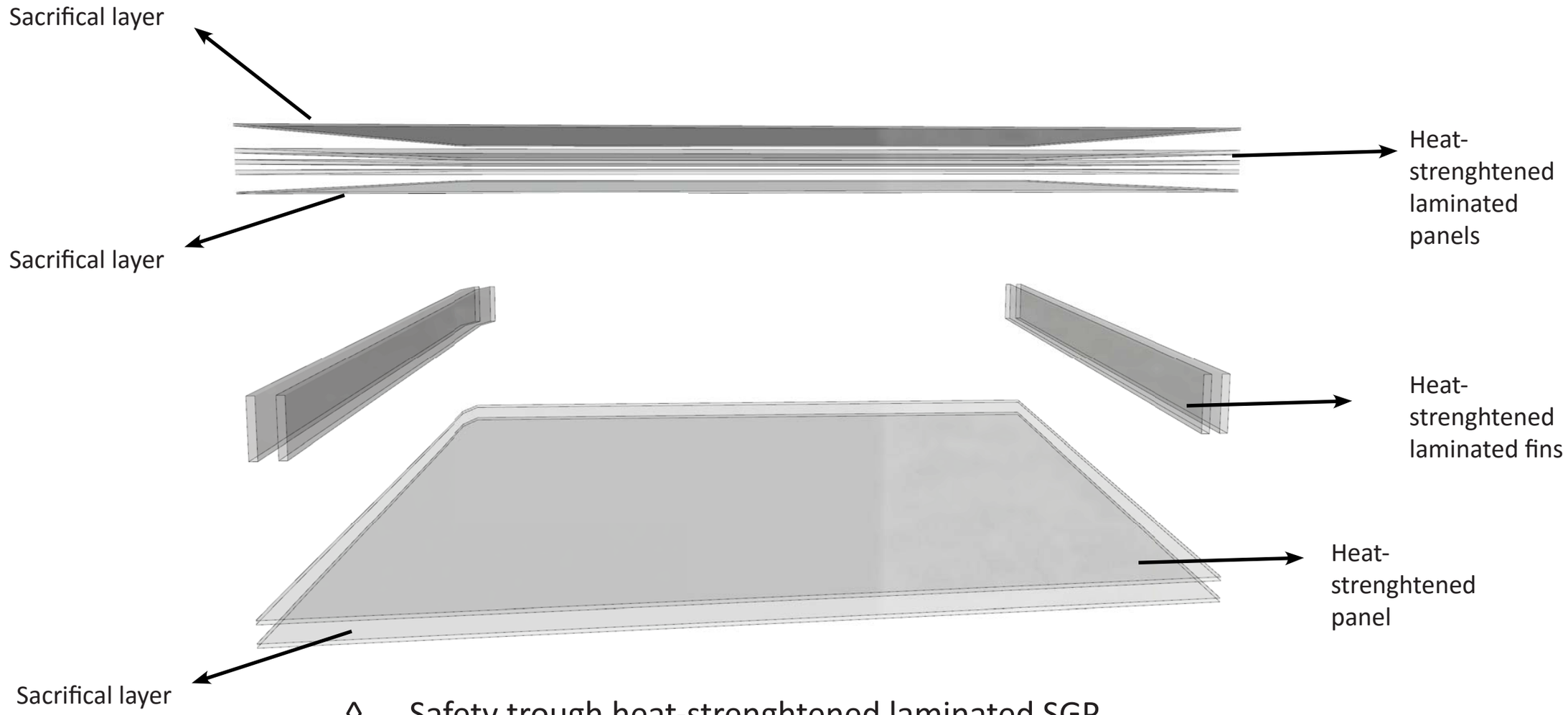


Safety trough heat-treated laminated SGP glass panel

Combination of glass types for optimal performance

SAFETY AND STRENGTH

In the structural elements



- Safety trough heat-strenghtened laminated SGP glass panel
- Sacrifial layers

CLIMATE DESIGN

CLIMATIC PERFORMANCE
Without measures

In case of no ventilation

$$T_i(t) = T_e + \frac{W}{H}\left(1 - e^{-\frac{H}{M}t}\right)$$

With

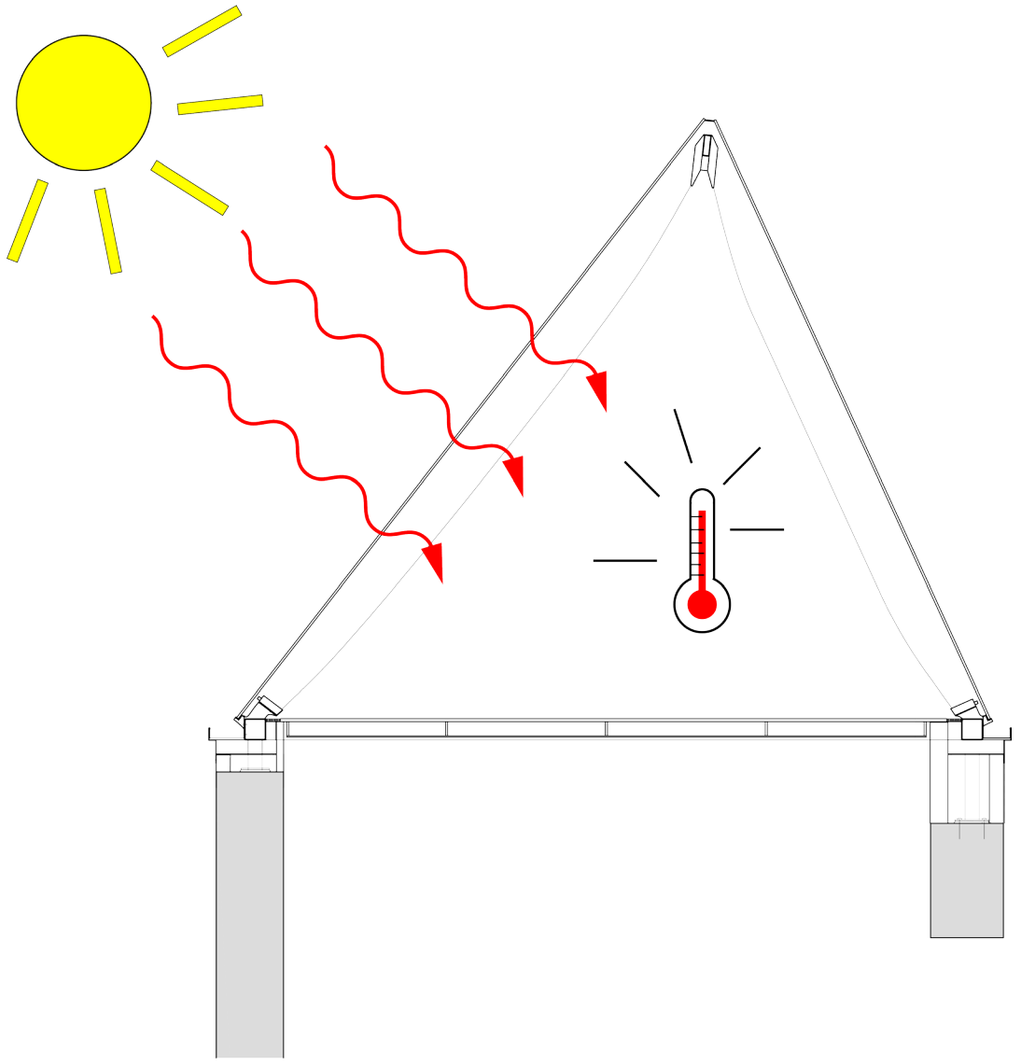
$$W = 0{,}4 * 370 * 600\ W/m^2 = 88800\ W$$
$$H = U * A = 1{,}5 * 370 = 555$$
$$M = 27238474$$
$$t = 5 * 3600\ s$$

Resulting in

$$T_i(5 * 3600) = 15 + \frac{88800}{555}\left(1 - e^{-\frac{555}{27238474} * (5 * 3600)}\right)$$

$$T_i(5 * 3600) = 15 + 160(1 - 0{,}69)$$

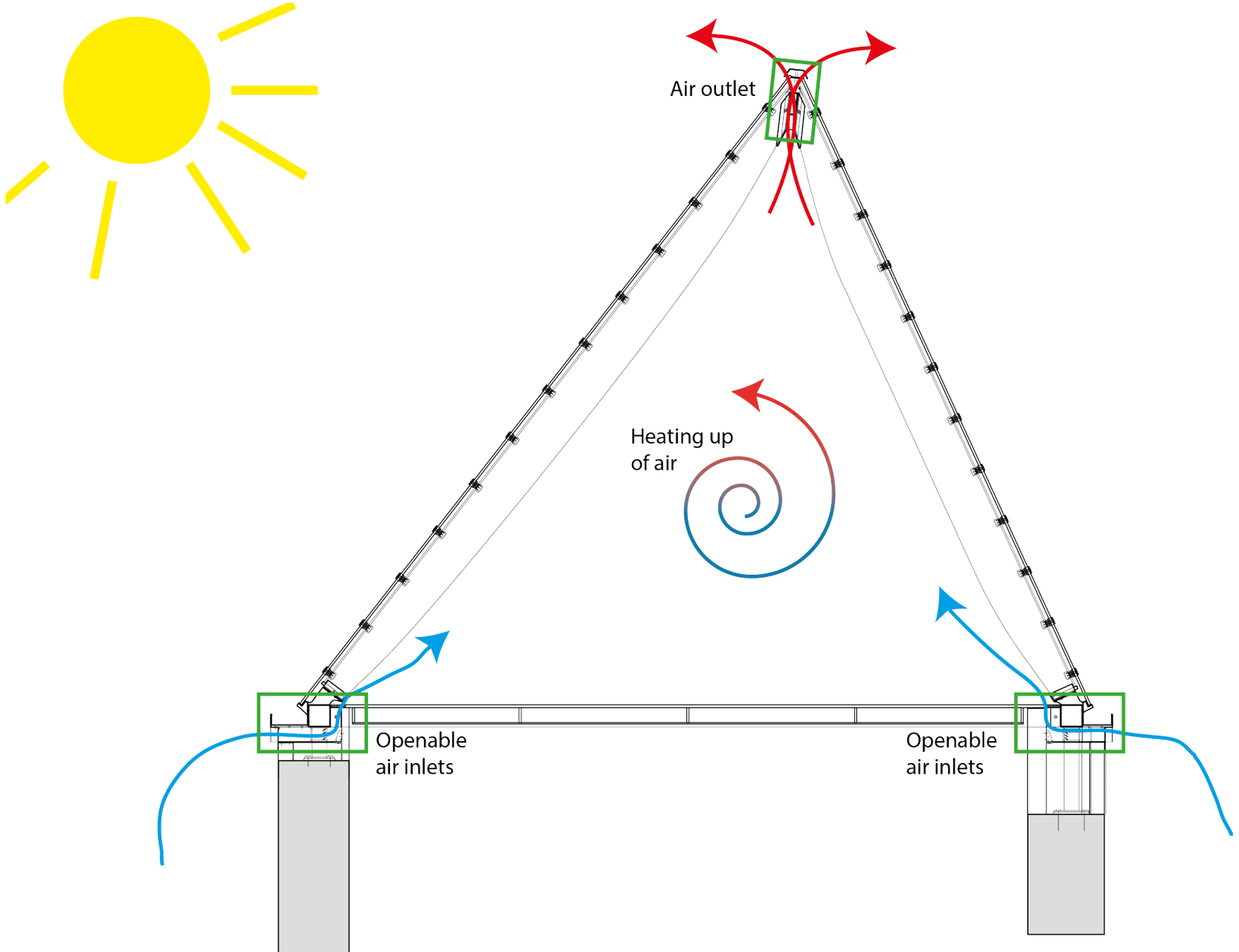
$$T_i = 64\ °C$$



- Serious risk of over heating
- Measures required to prevent that

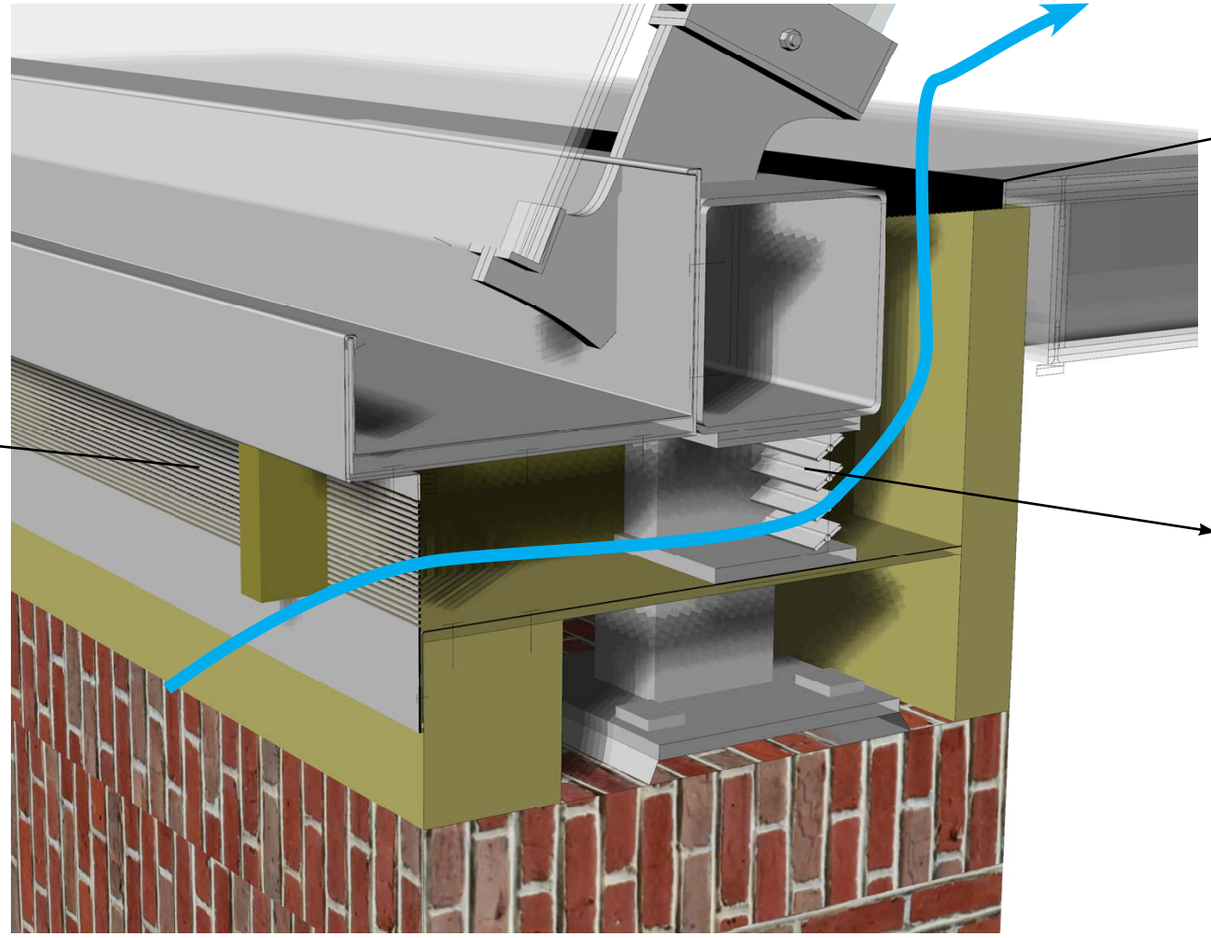
- Climate installations are big and ugly
- Therefore: **Passive climate measures**!

CLIMATIC SCHEMES
Natural ventilation



CLIMATIC SCHEMES

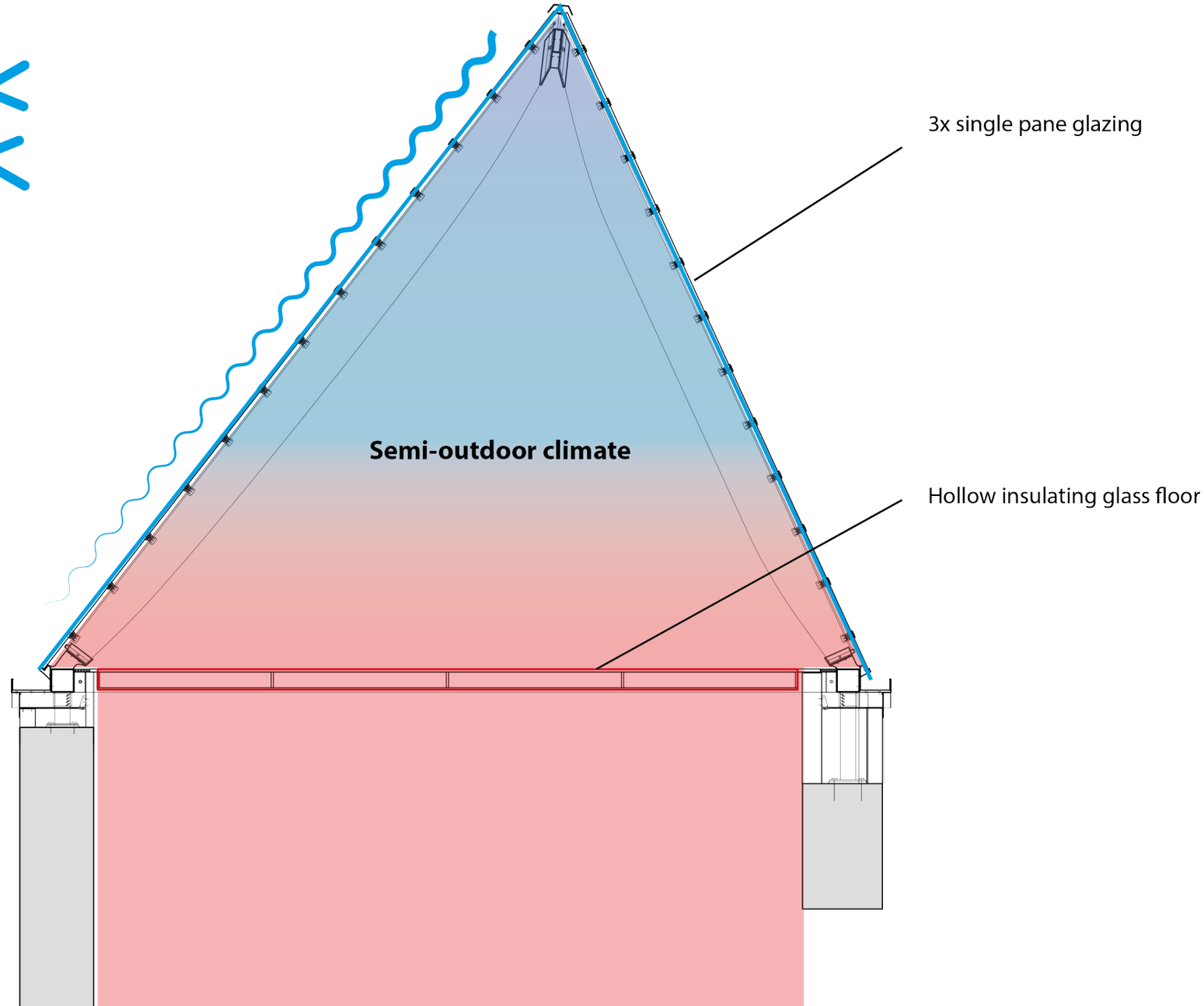
Natural ventilation



◊ Integrated natural ventilation system in raingirder

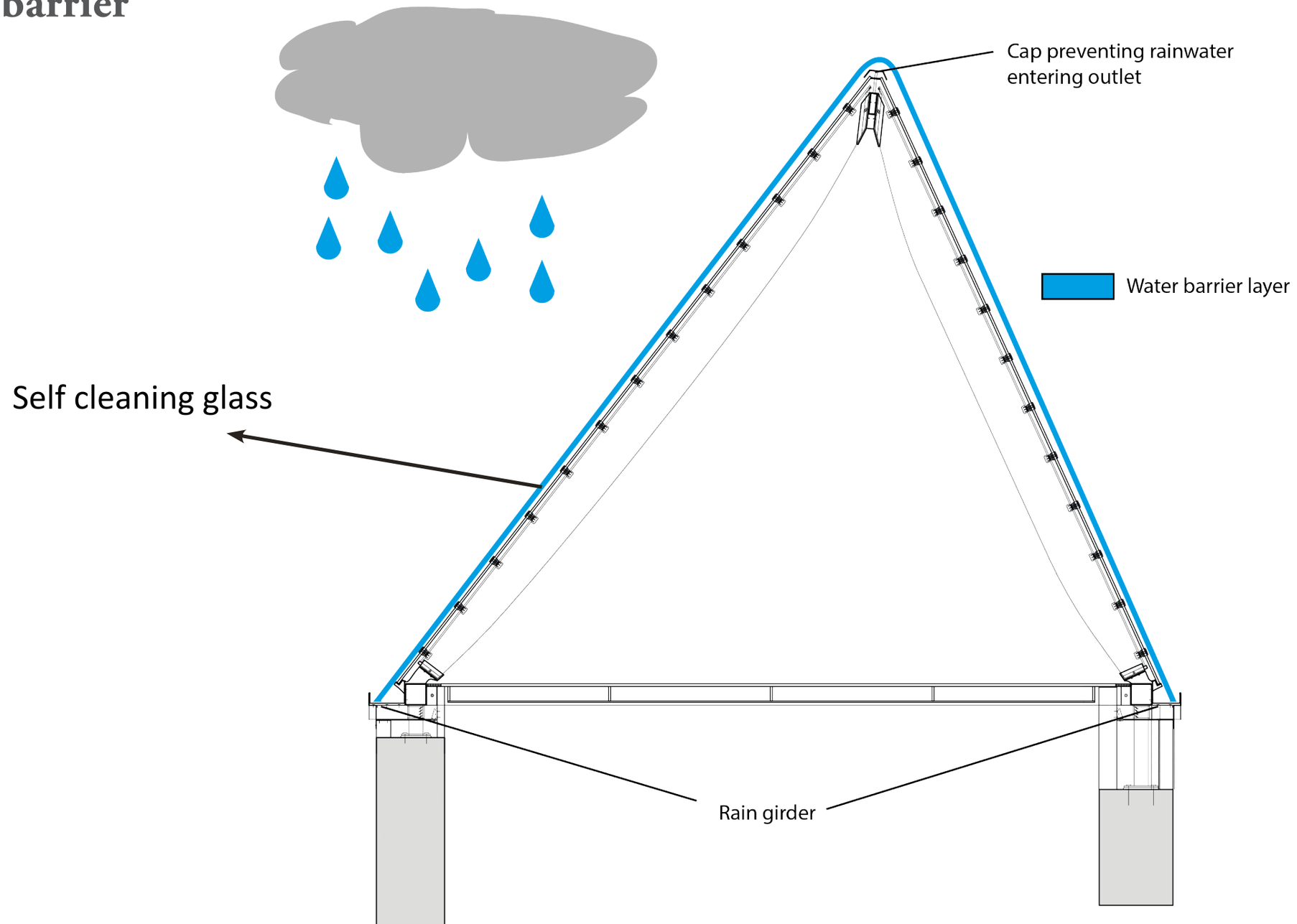
CLIMATIC SCHEMES

Insulation

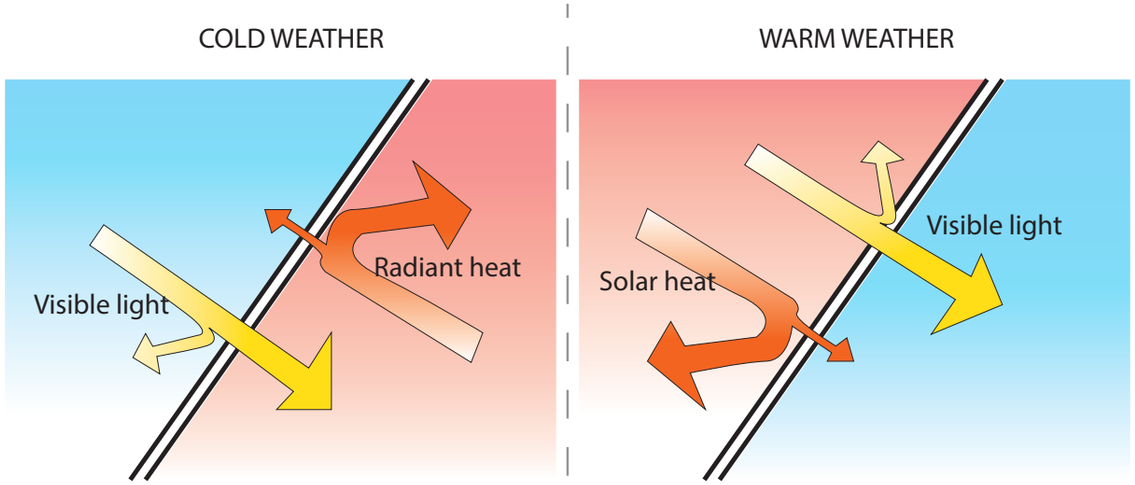


CLIMATIC SCHEMES

Water barrier

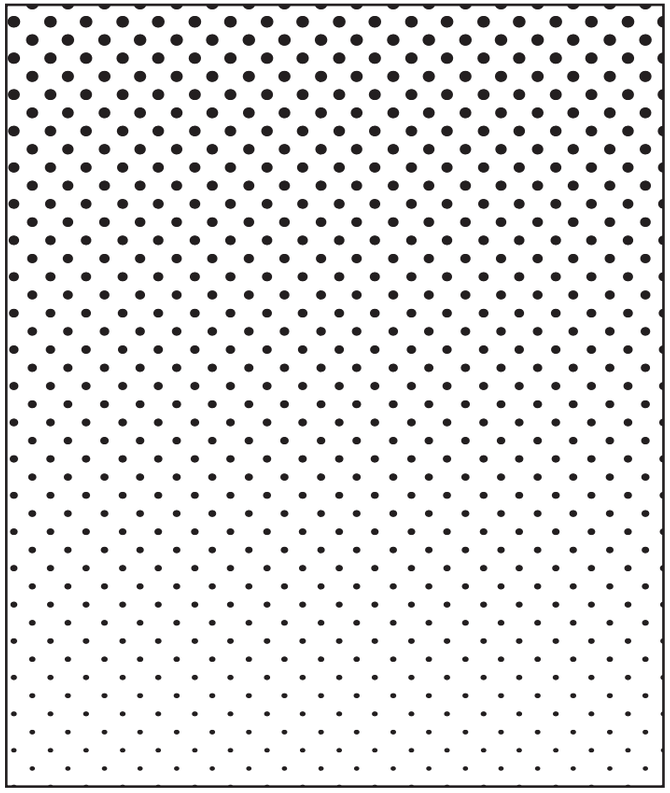


CLIMATIC MEASURES



Low-E glass

Reduces solar heat load, and radiant heat loss



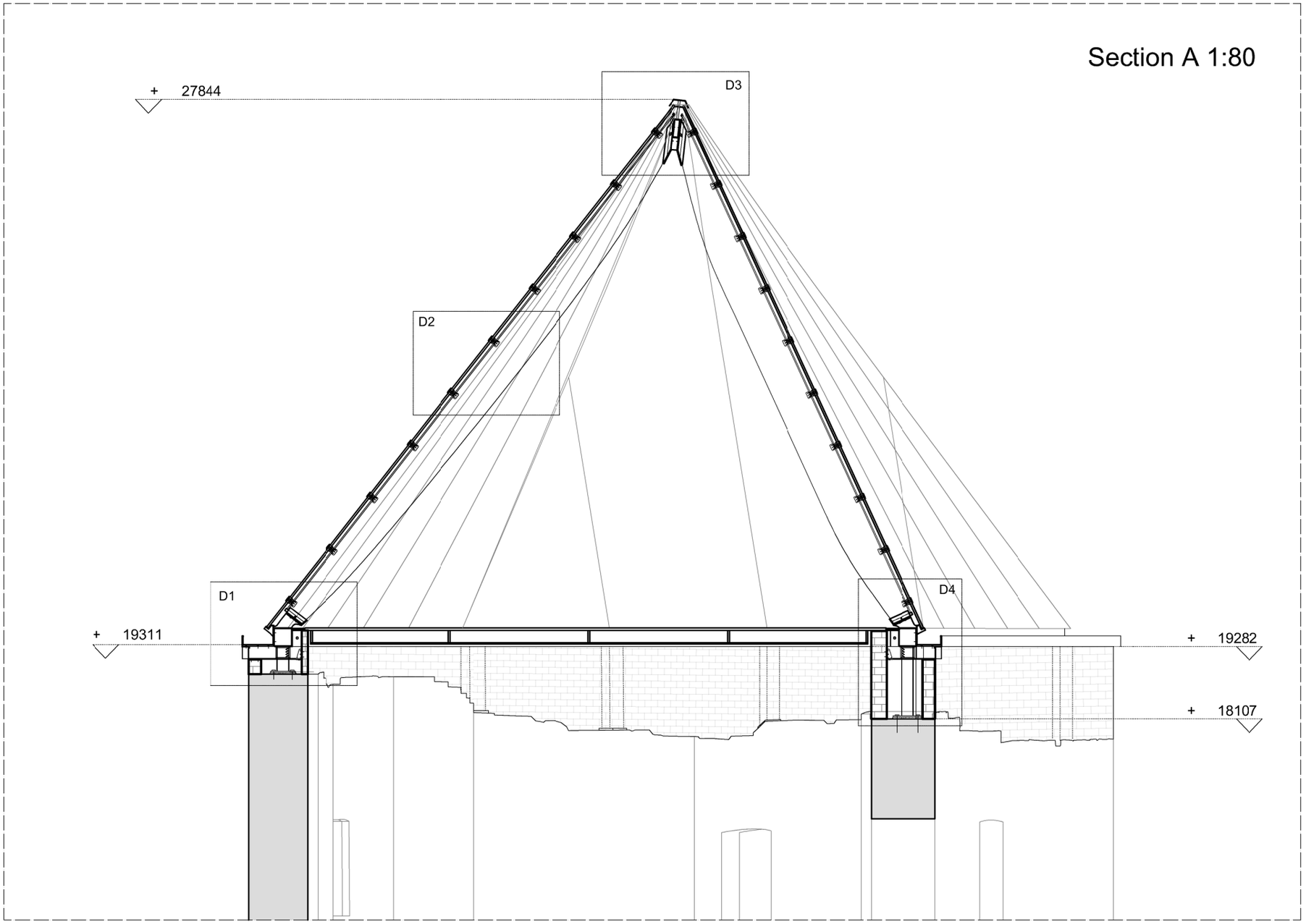
Fritting on the glass

Reduces solar heat load

DETAILLING

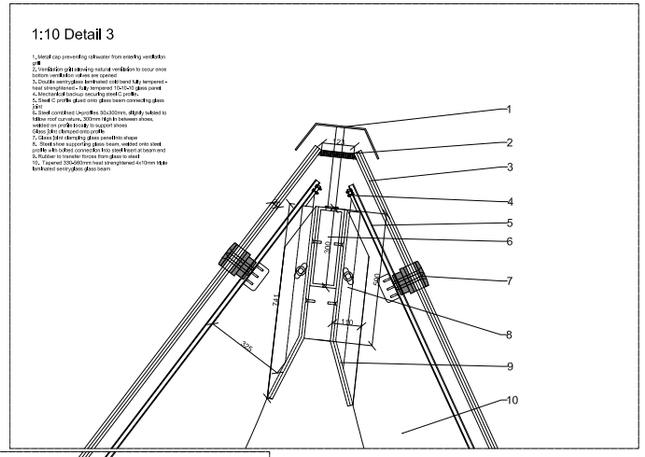
TECHNICAL DRAWINGS

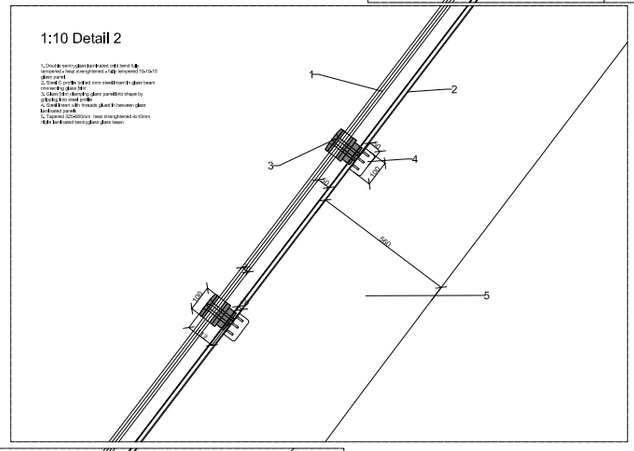
Section

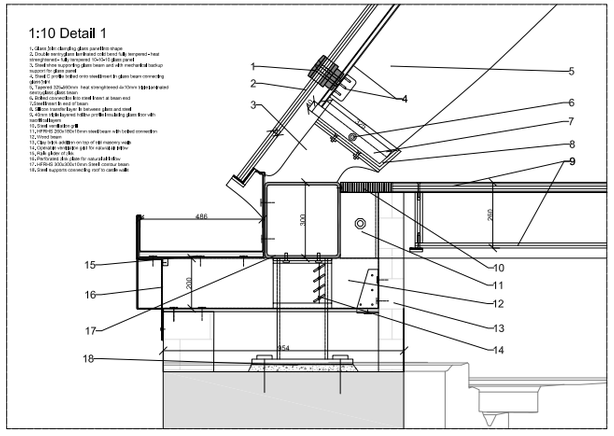


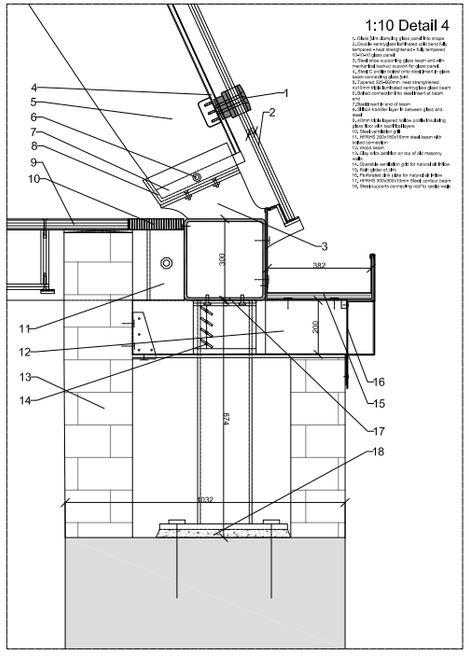
TECHNICAL DRAWINGS
Detailling

Key details are worked out
at 10 locations in the structure





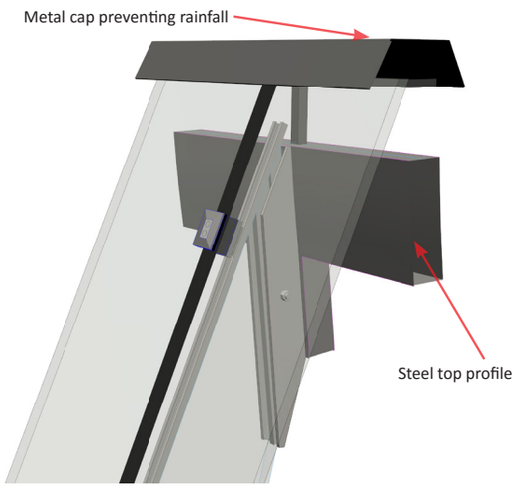


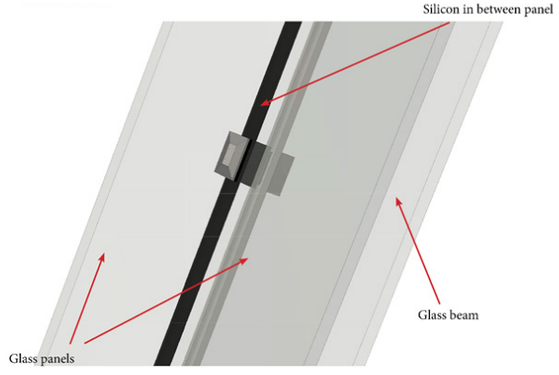


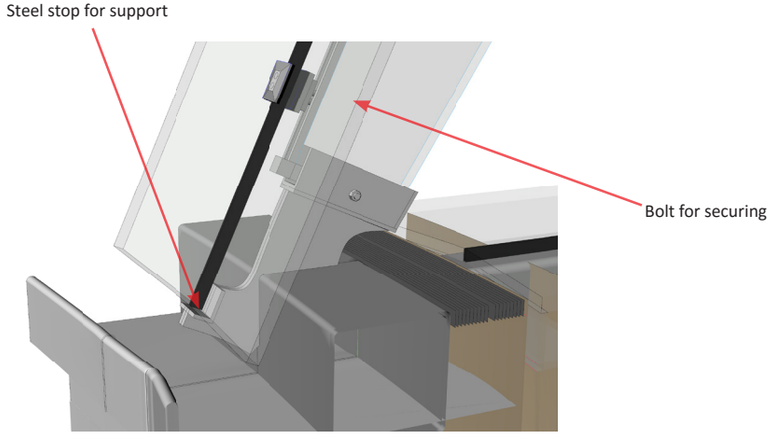
TECHNICAL DRAWINGS

3D of details

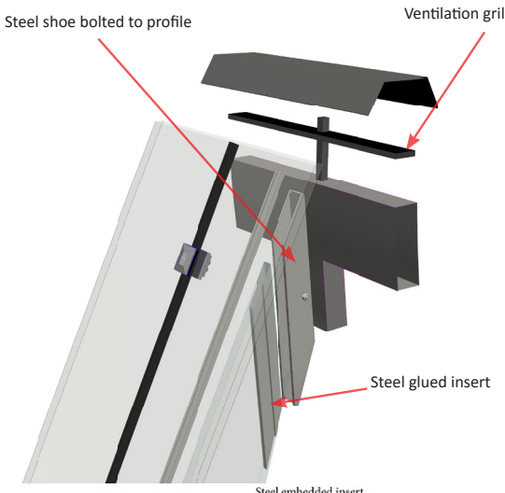
Assembled connection

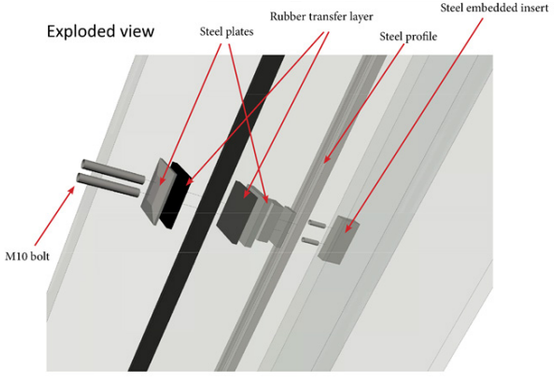


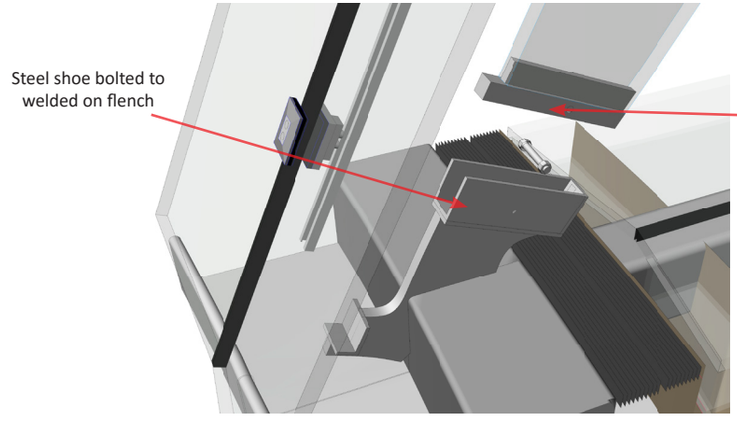




Exploded view



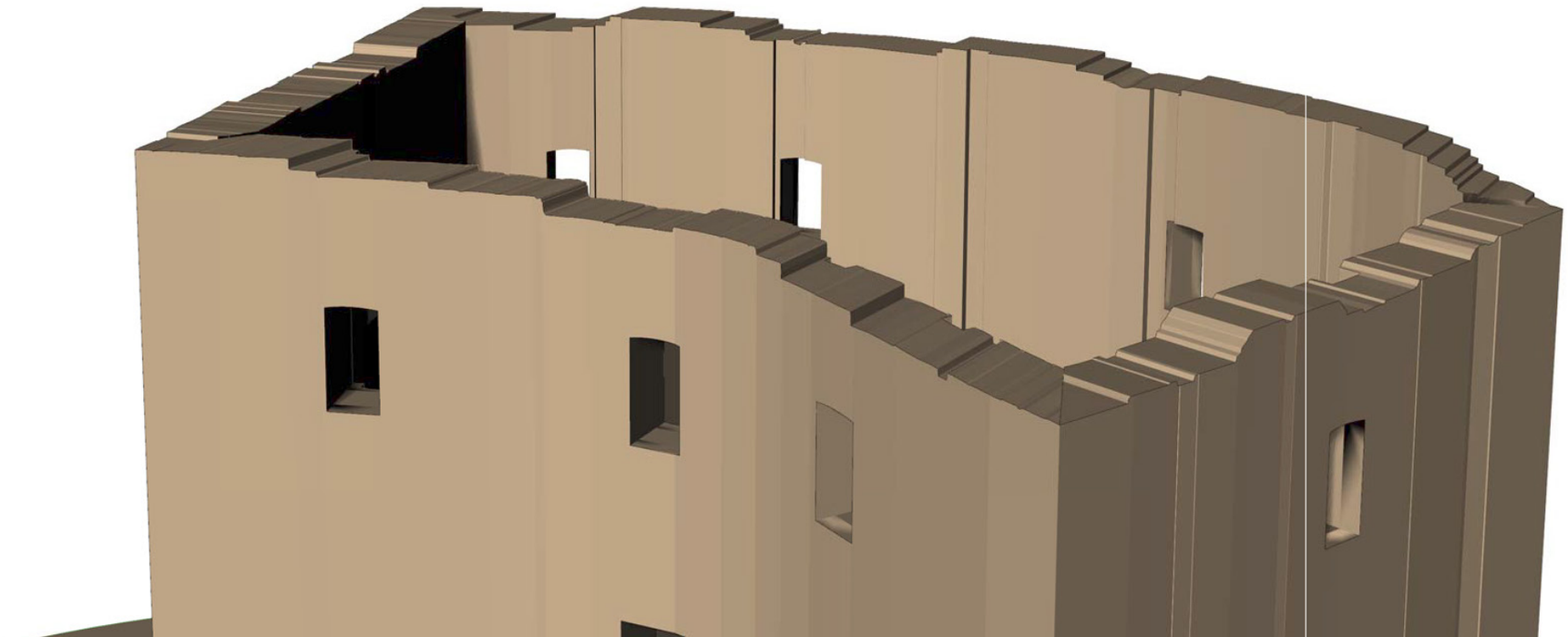




ASSEMBLY OF STRUCTURE

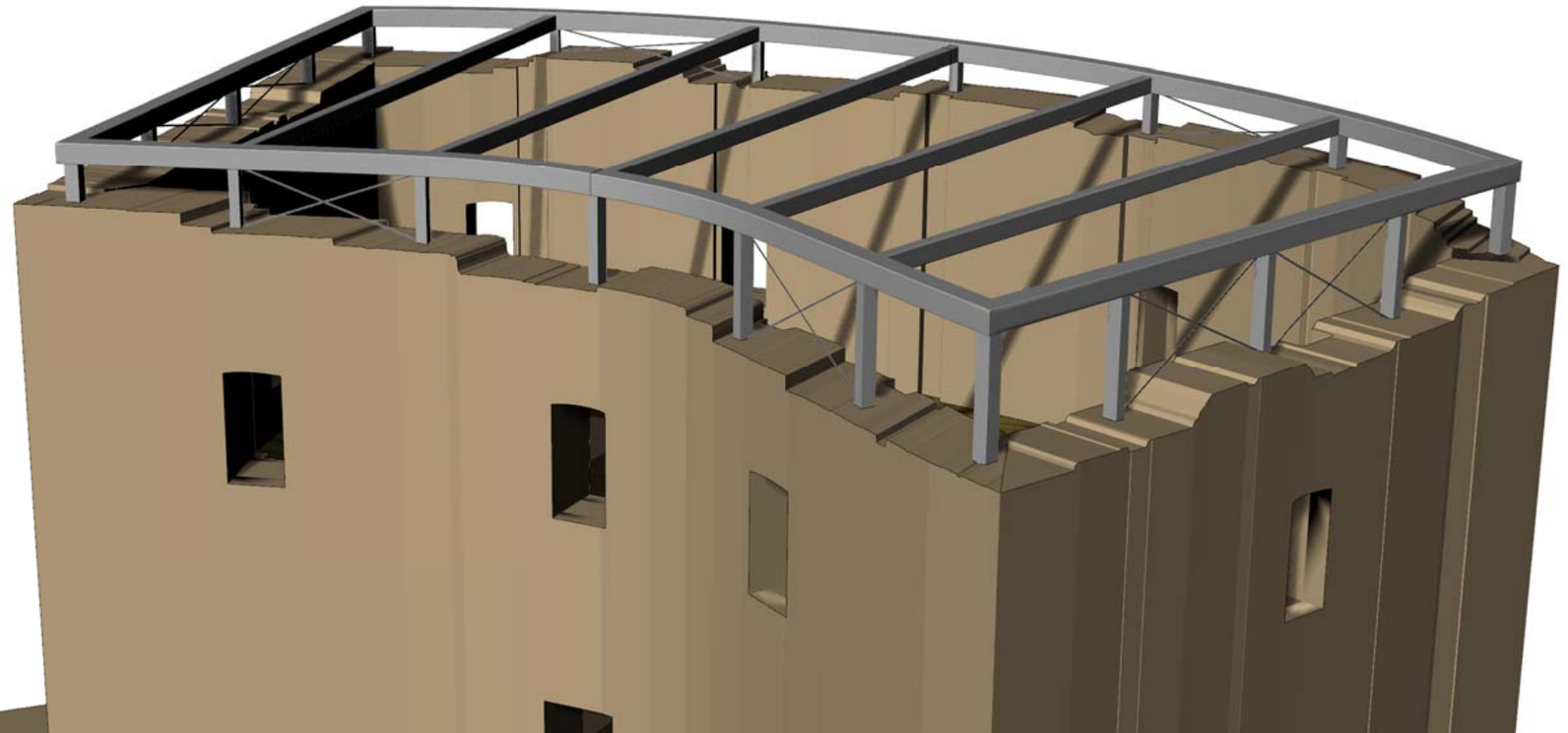
ASSEMBLY ORDER

Step 0 - uneven masonry donjon walls



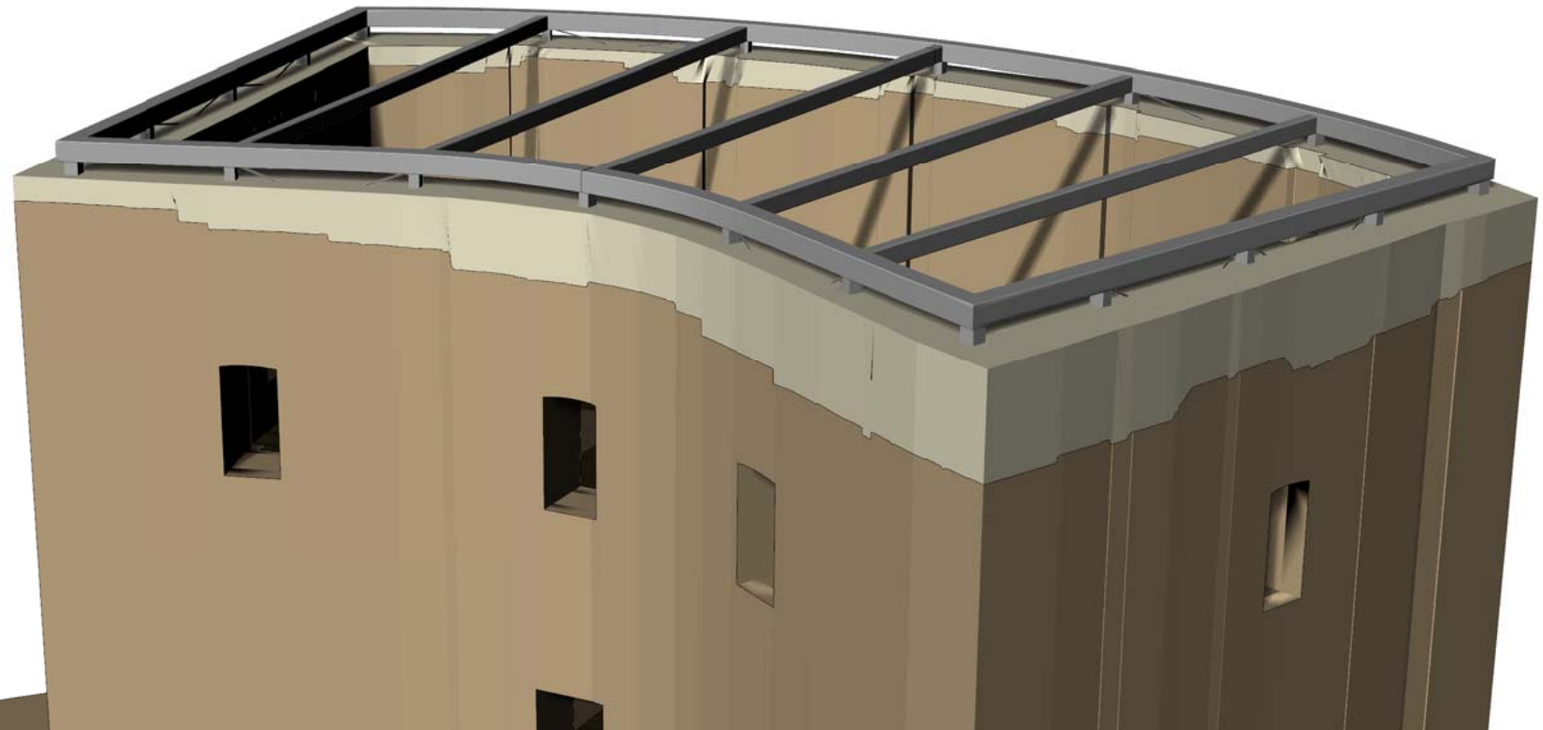
ASSEMBLY ORDER

Step 1 - Steel contour frame



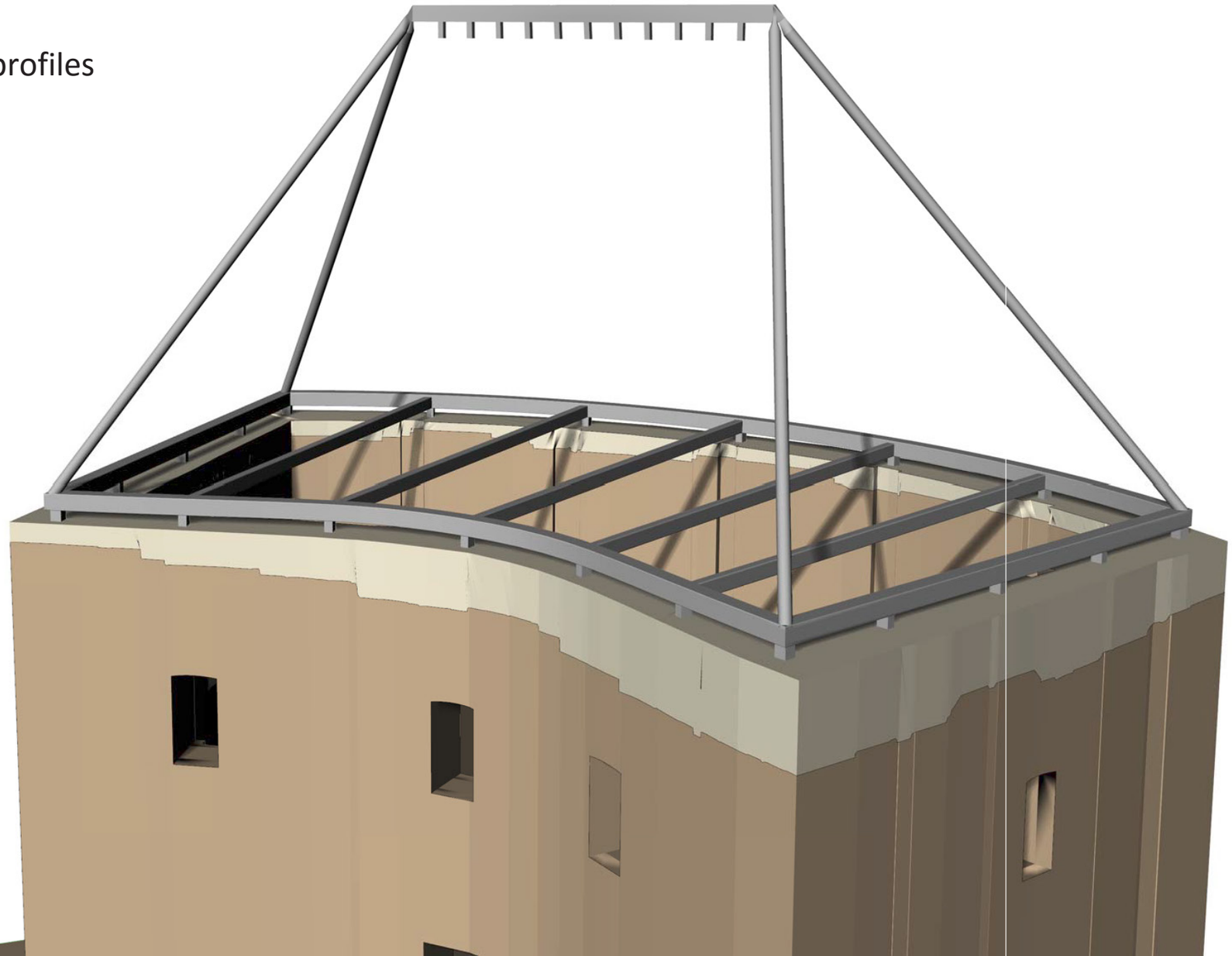
ASSEMBLY ORDER

Step 2 - New masonry



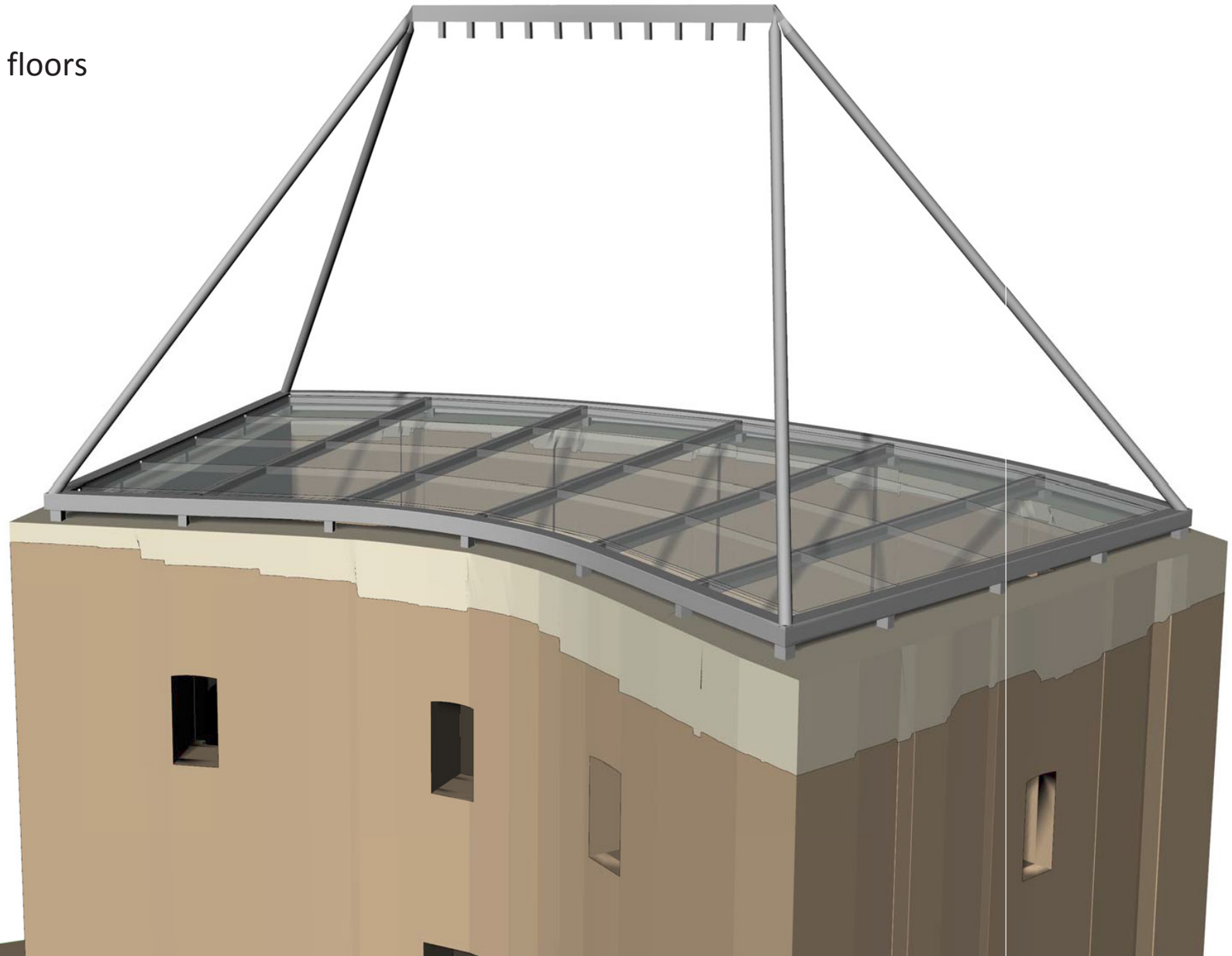
ASSEMBLY ORDER

Step 3 - Steel side and top profiles



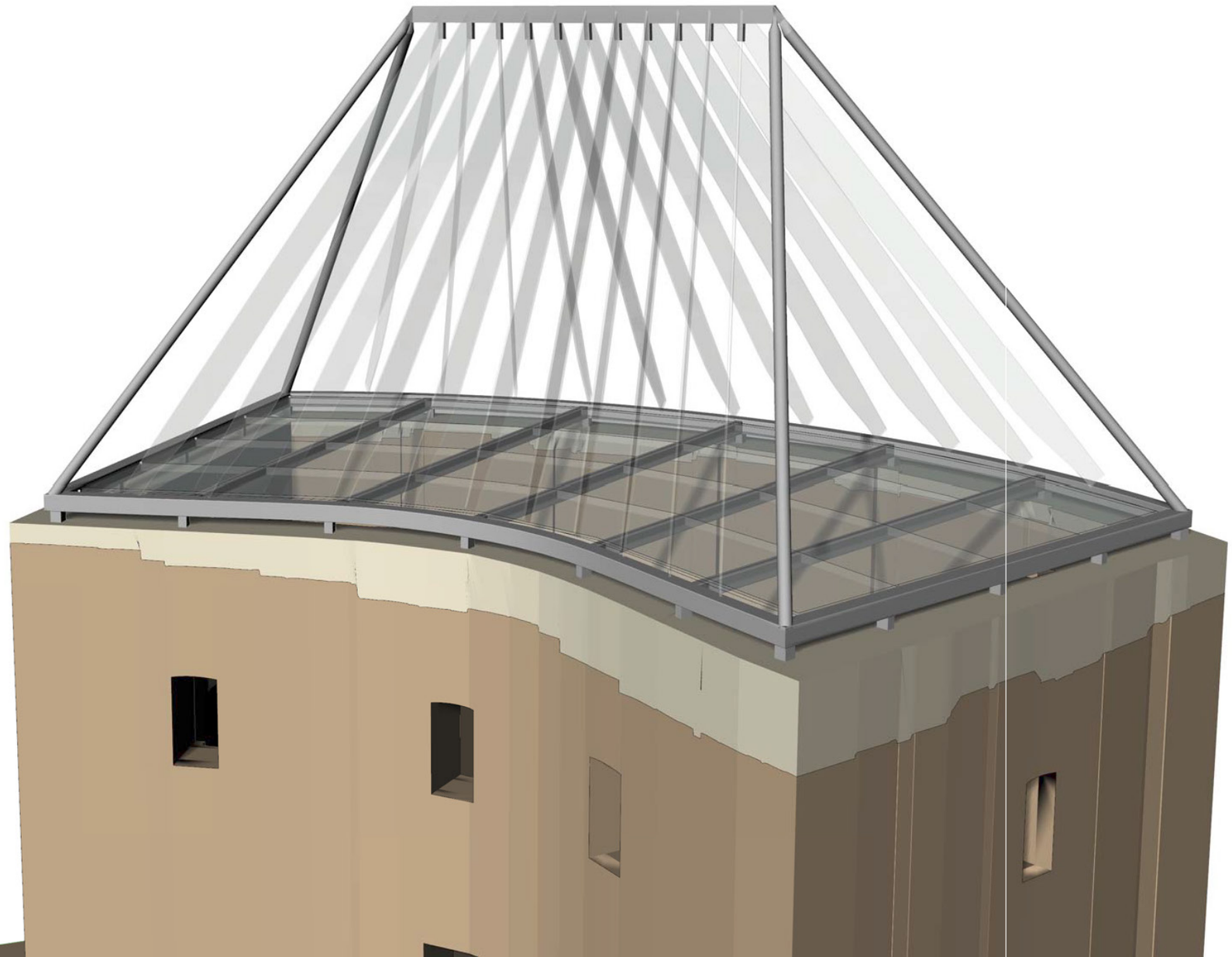
ASSEMBLY ORDER

Step 4 - Installation of glass floors



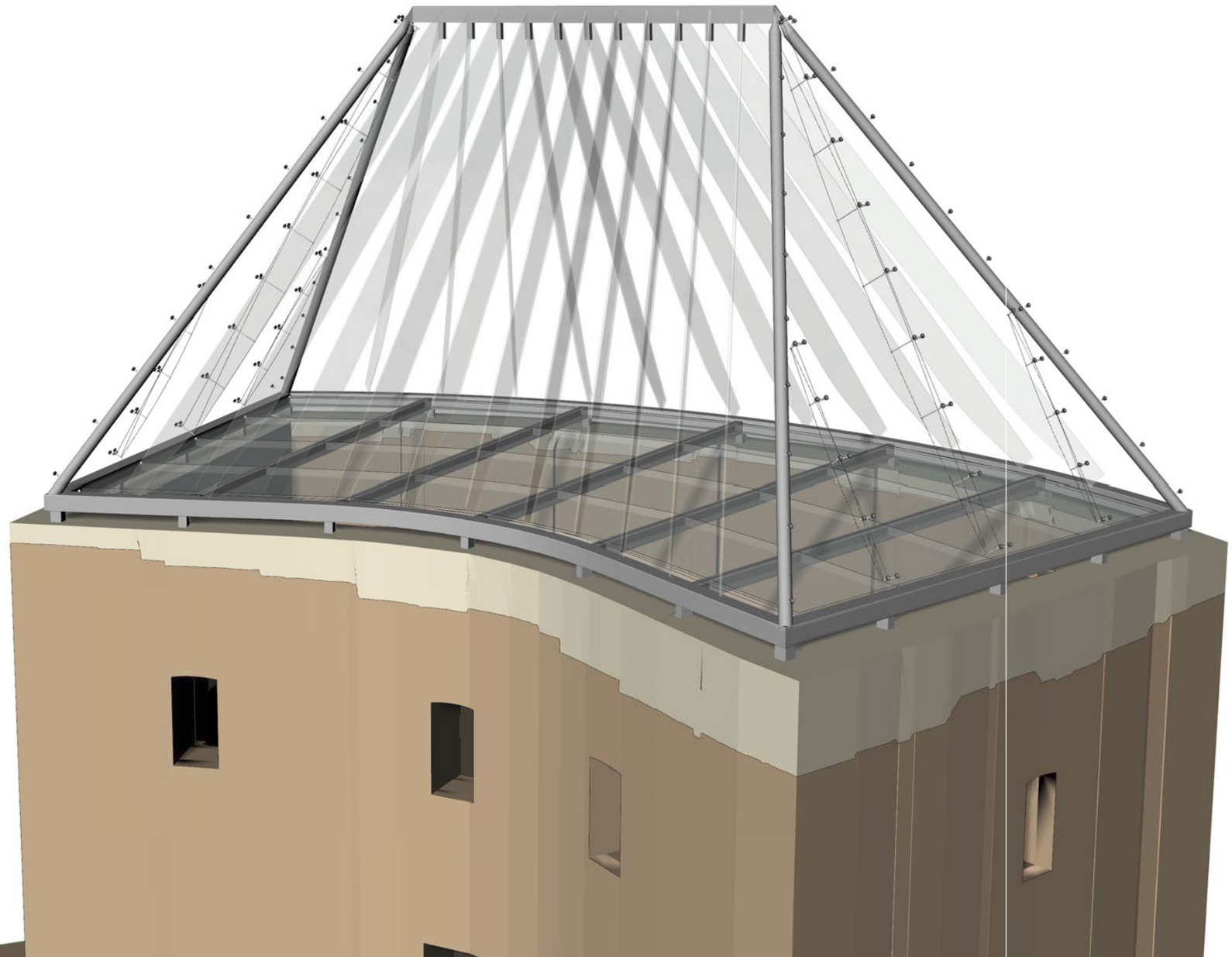
ASSEMBLY ORDER

Step 5 - glass beams



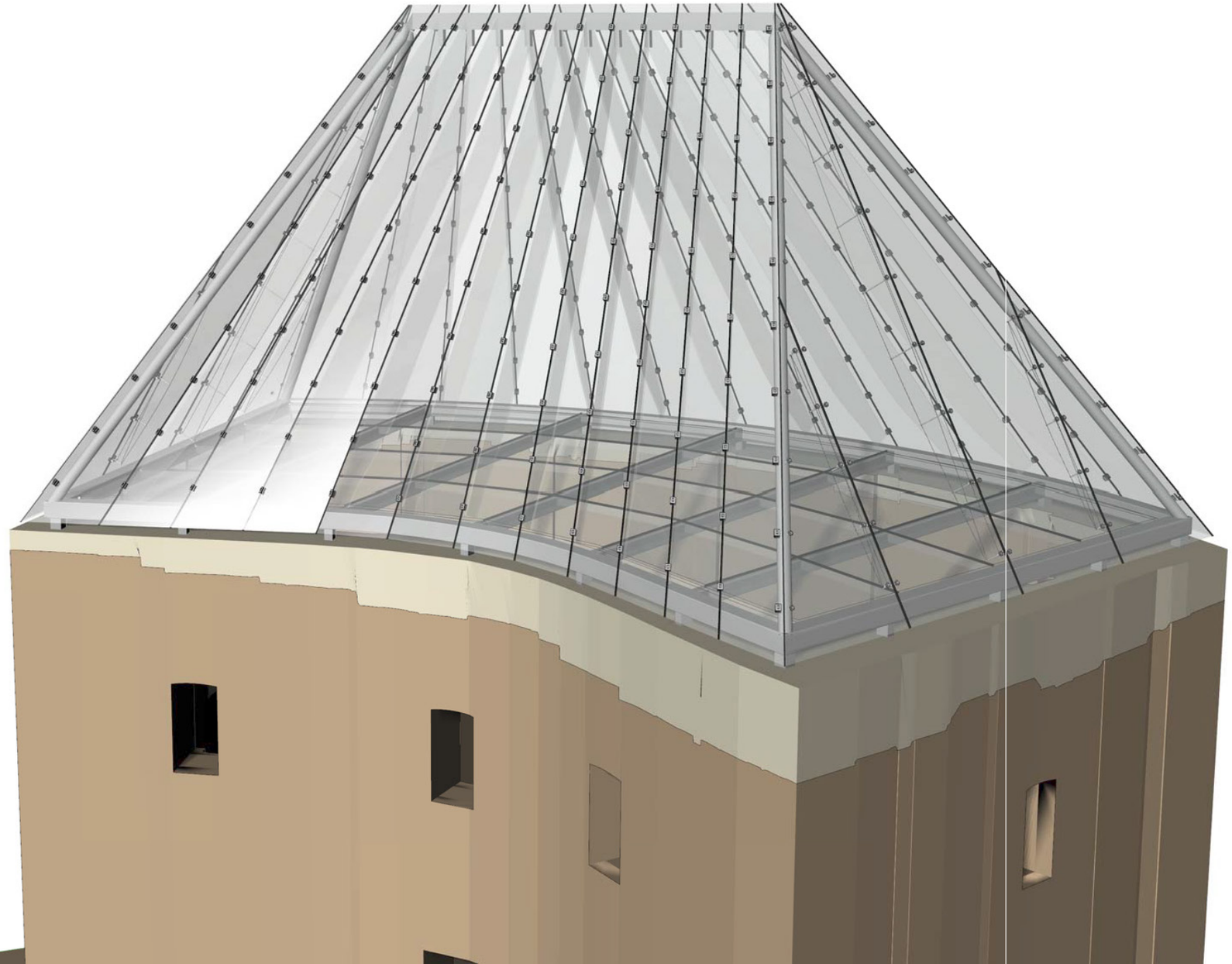
ASSEMBLY ORDER

Step 6 - Steel cable trusses



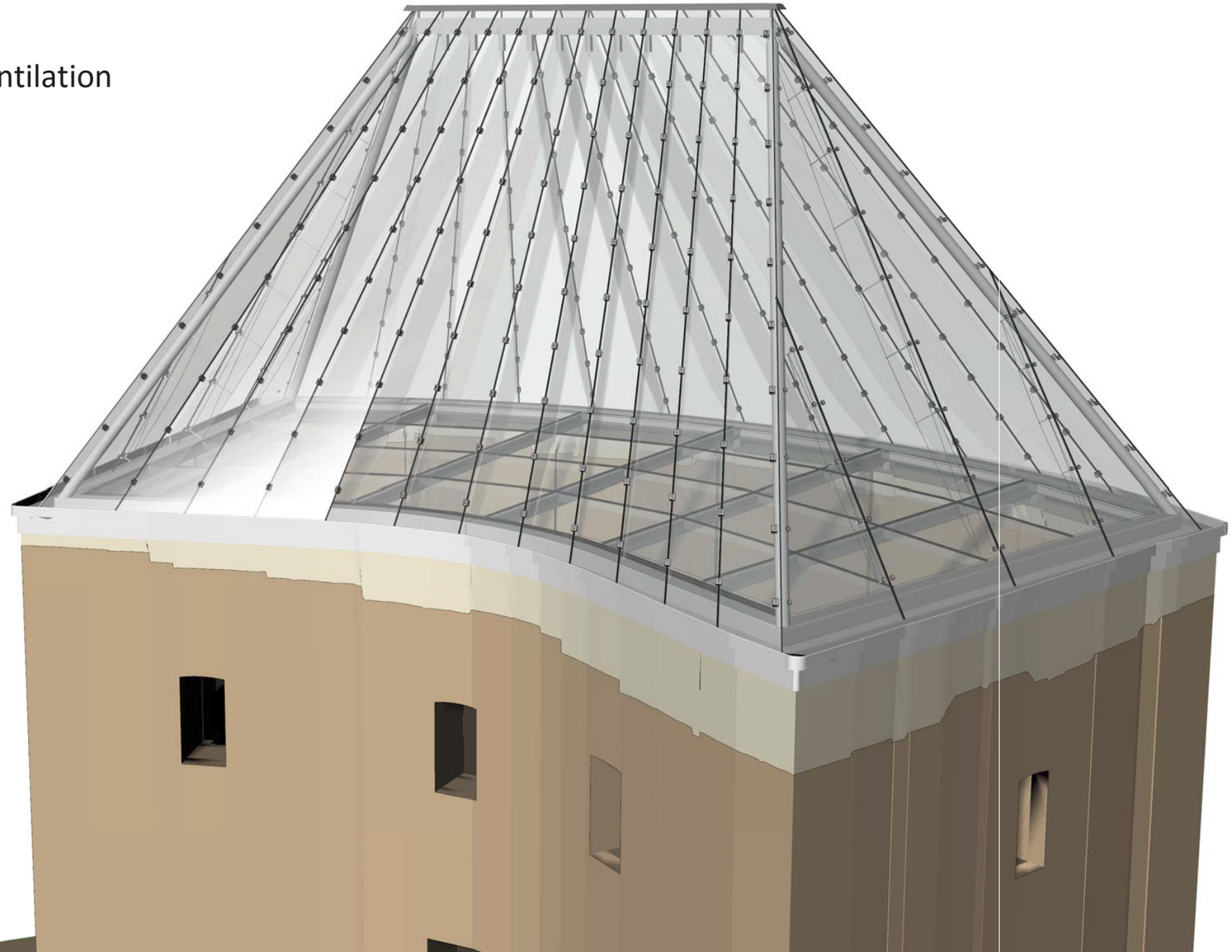
ASSEMBLY ORDER

Step 7 - Glass panels



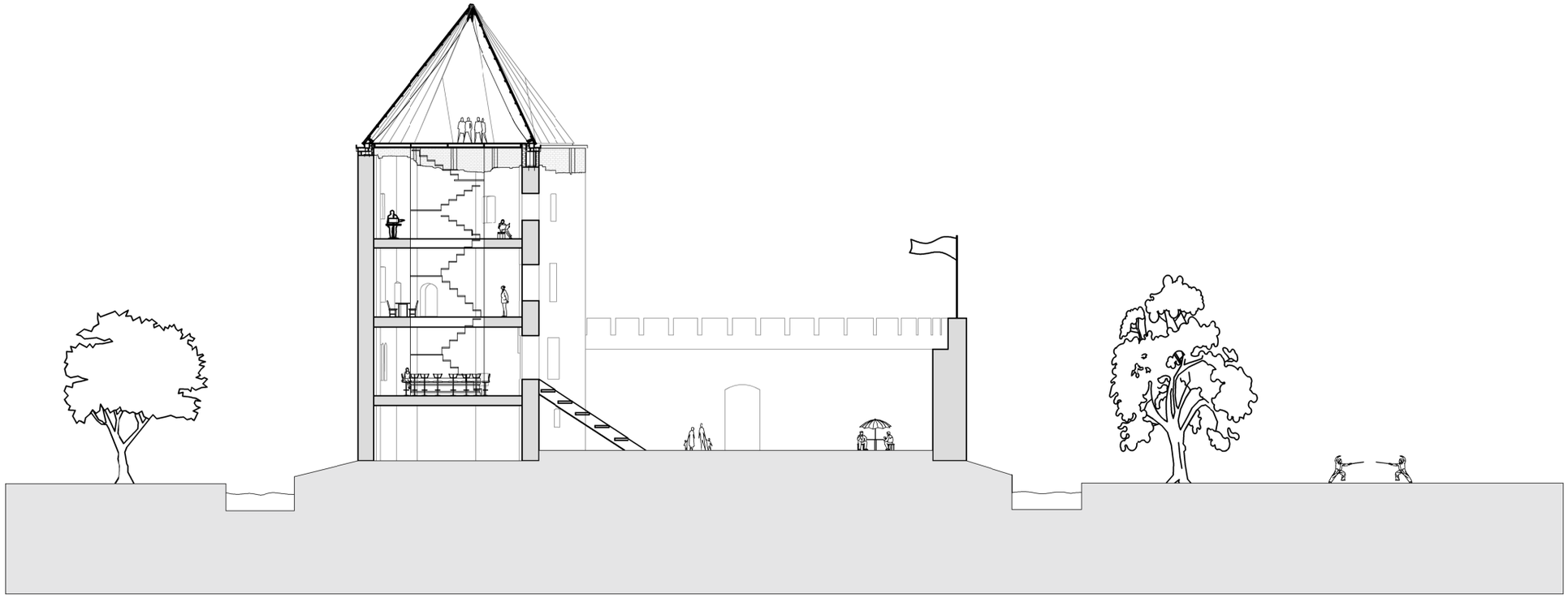
ASSEMBLY ORDER

Step 8 - Rain girder and ventilation



CONCLUSIONS

NEW FUNCTIONALITY FOR SLOT TEYLINGEN



Roof required to fullfill two demands for facilitating a new function:
1. Technical requirements + 2. Attractiveness

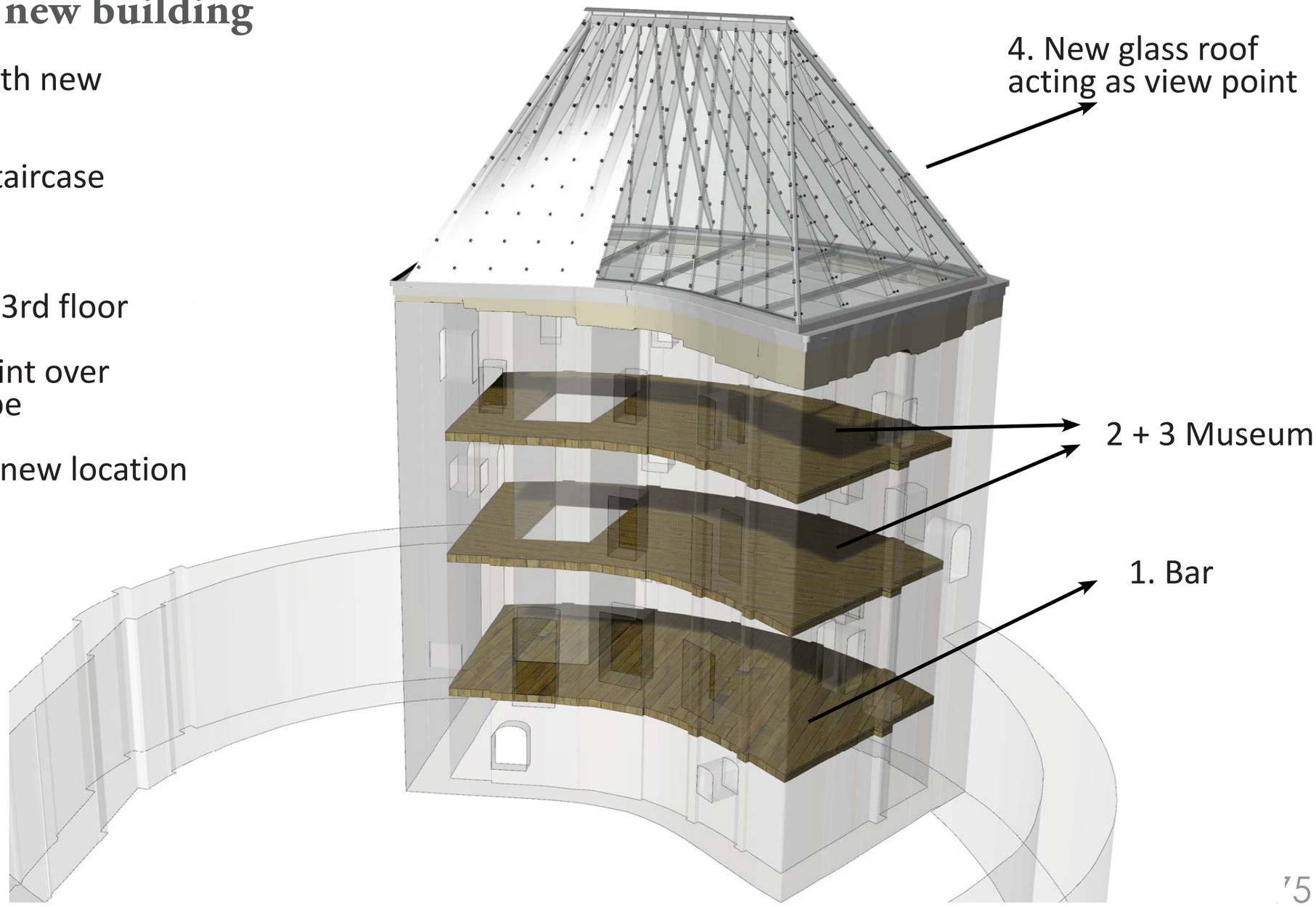
1. Roof fulfills technical requirements
- Enclosing and protecting the castle
- Providing a safe and strong structure
- Creating a comfortable indoor climate

2. Roof creates an attractive usable location
- Roof revives the atmosphere
- Bar and museum fit nicely in the restored building
- Combining the past with the present

NEW FUNCTIONS

Function scheme of new building

- Refurbished castle with new floors
- Connected by glass staircase
- Bar on 1st floor
- Museum on 2nd and 3rd floor
- Glass roof as view point over surrounding landscape
- Creates an attractive new location

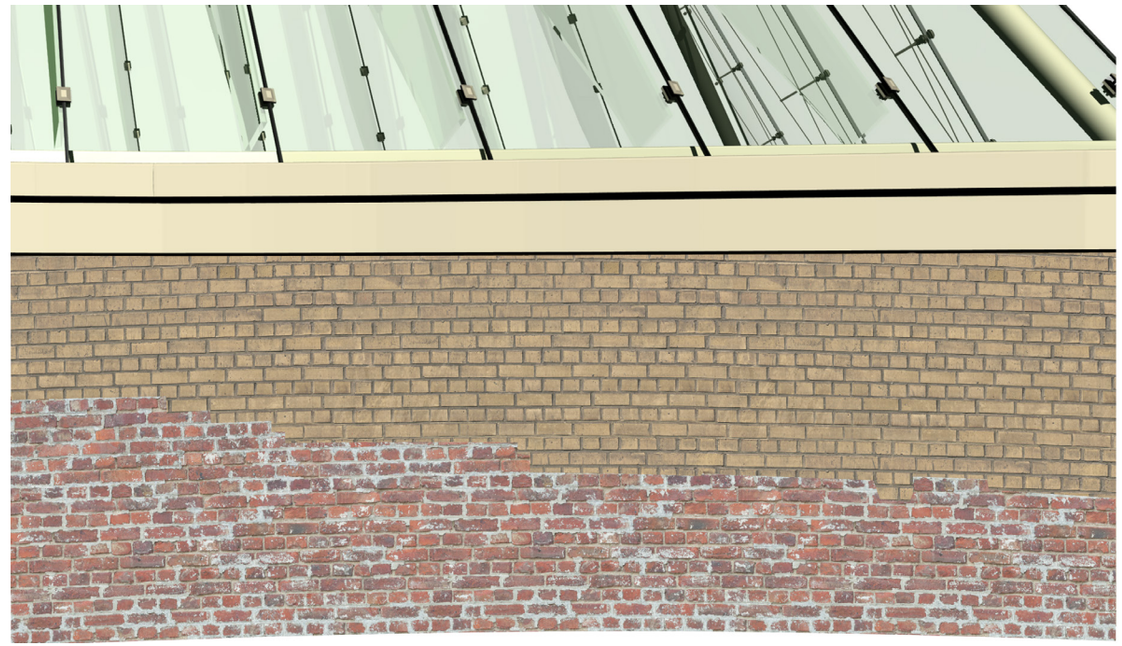


IMPACT ON ORIGINAL BUILDING

- During every design phase, historical context has been taken into account
  - Visual language of the Glass Roof engages with its environment
  - Shape, size, grid layout and rain girders reflect the original roof

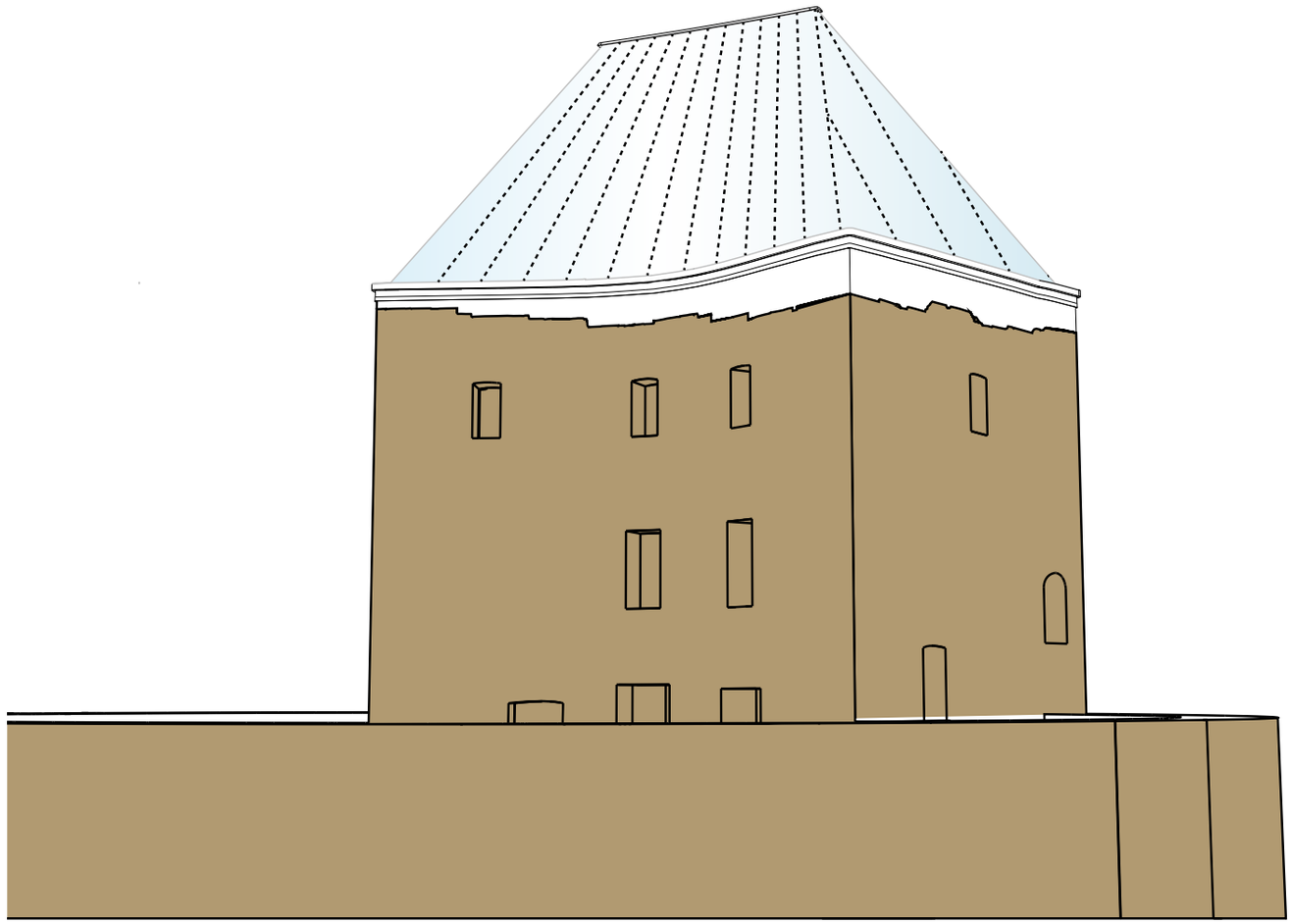
However

- Addition of new material is inevitable in restoration: always discussion if the intervention is appropriate
- Proper argumentation required to justify any addition to an historical building



TRANSPARENCY

- How transparent has the roof become?
- *Maximized* transparency?
- A glass structure is never completely transparent -> redirection of light
- Transparency also achieved by geometry
- *Optimized* transparency!



CONCLUSIONS

Architecture

Integrating yet distinguisable addition

Roof in the shape, size and grid as the original roof

Functional elements as rain girder refer to past

Structural design

A slender structure has been designed

Facade is part of the structure

Structural details are crucial for proper functioning

Steel elements are needed for proper force distribution

Facade Design

To create the complex shape, cold bend glass can be used

Facade detailling is crucial

Climate design

Passive measures can be used to create a comfortable indoor climate

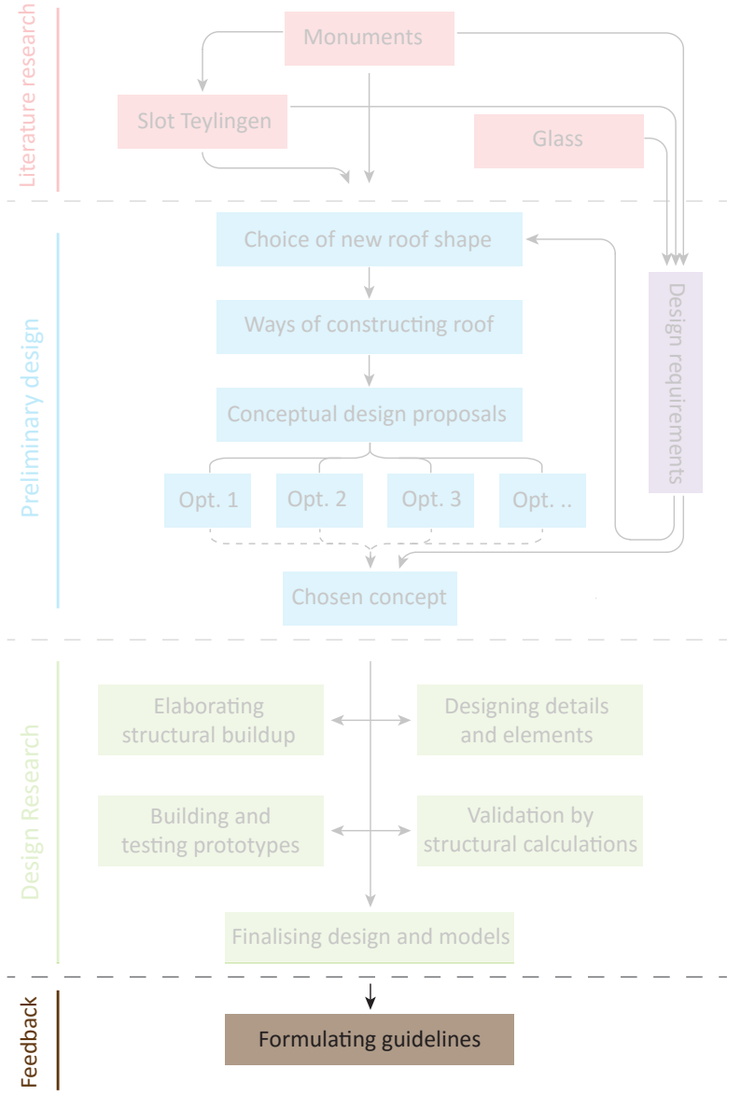
Integration of services to minimize distortion

If designed and engineered properly, glass structures can be appropriate solutions for the restoration of monumental buildings!

FORMULATED DESIGN GUIDELINES

For future transparent restorations

- A proper case study research
- Clear appropriate design requirements based on the study of authentic documents, and the Venice Charters
- A slender well considered design should be made.
- Good detailing in glass structures is crucial
- Measures to minimize the probability of failure of the glass
- Measures to minimize the consequences of failure of the glass.
- The force introduction of the new structure on the old structure should be done very carefully and well-considered.
- The design should have integrated technical solutions, to become a slender and transparent whole.



FURTHER RECOMMENDATIONS

- More research should be done in high level of cold bending of laminated glass panels.
- More calculations should be done in the climate aspects of the glass roof
- Research into a reversible masonry joint of old and new.
- Further FEM calculations should be done to check the total deformation and stiffness of the overall structure.
- The support forces of the entire structure on the old wall should be checked by calculations.

Thank you for your attention!