Glass Performance Days 2025

10 – 12 JUNE 2025 | NOKIA ARENA - TAMPERE, FINLAND

GLASS PERFORMANCE DAYS 2025

# Structural optimisation of glass plates

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# Motivation

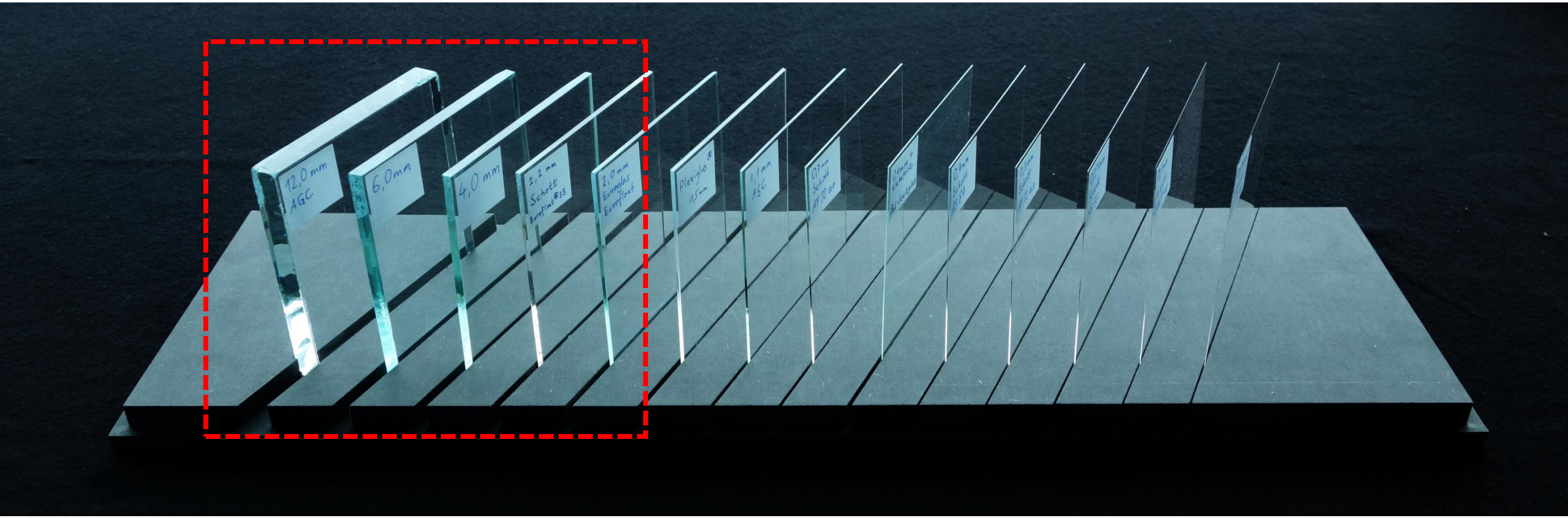
## Architectural Glass

Music hall (Musis Sacrum Arnhem)

Vakko Headquarter (Source: Knaack, 2010)

# Motivation

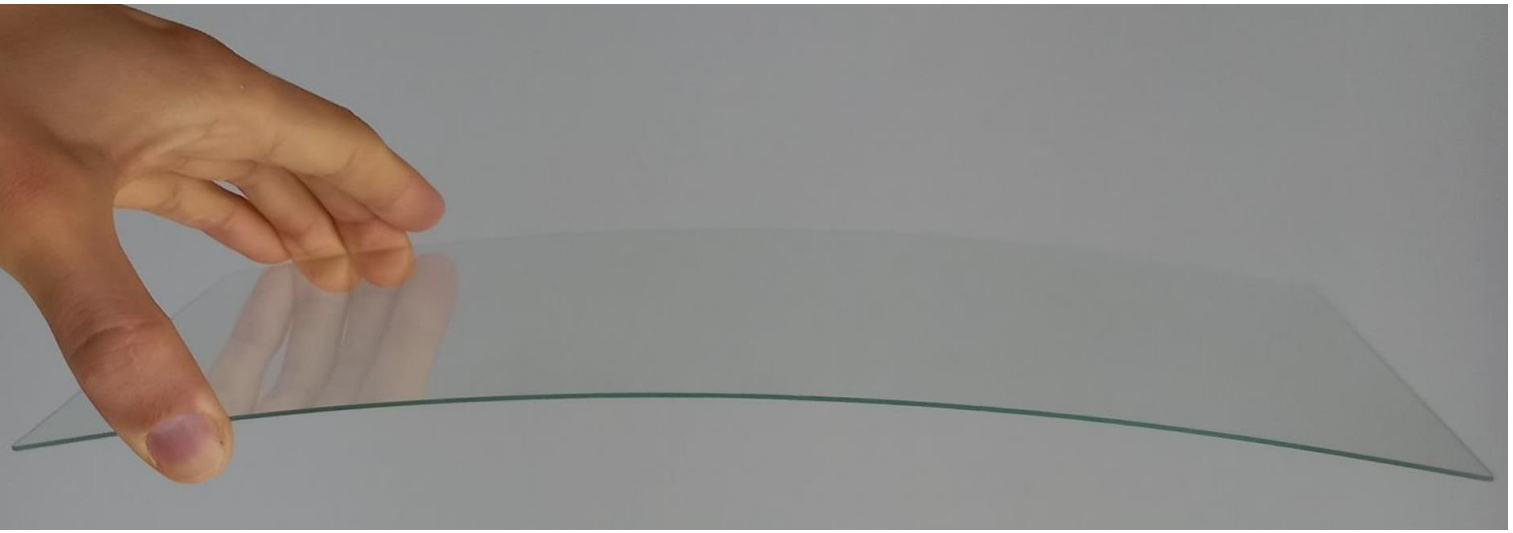
## Architectural Glass – Flat glass (EN 572-2 thickness range 2…25 mm)




Source: Peters 2024, *Dünnglas - Prüfverfahren für Architekturanwendungen*, PhD-Thesis, GCC, DOI 10.26083/tuprints-00026974

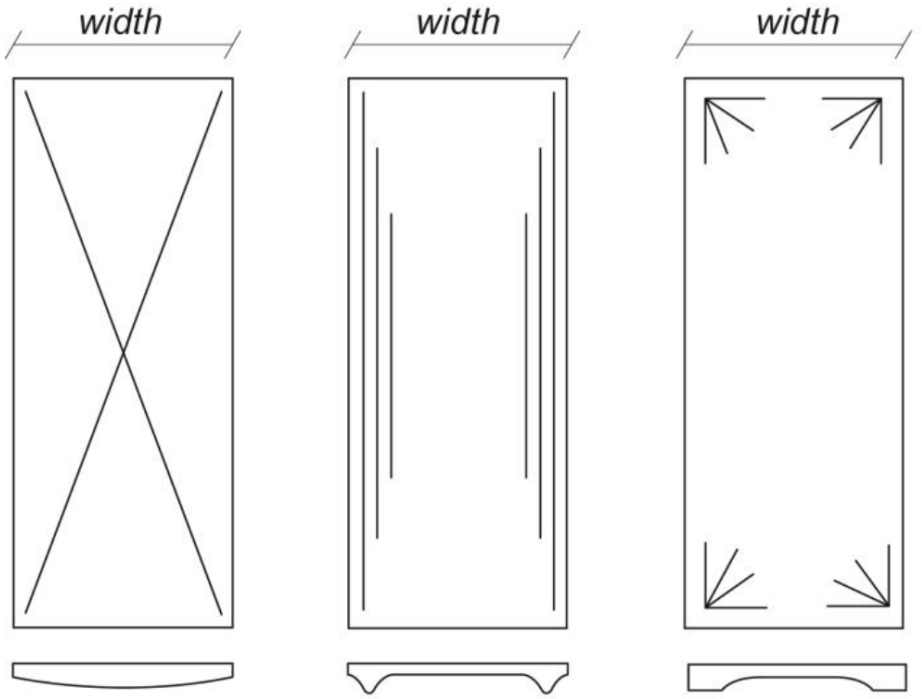
# Motivation

## Architectural Glass



**SLS is the limiting factor (L/100)**

**1 kg flat glass ≈ 1 kg $CO_2$ equ. (GWP)**




Source: Seel et al 2018 *Fused glass deposition modelling for applications in the built environment.* https://doi.org/10.1002/mawe.201800075

# Structural optimisation – Types

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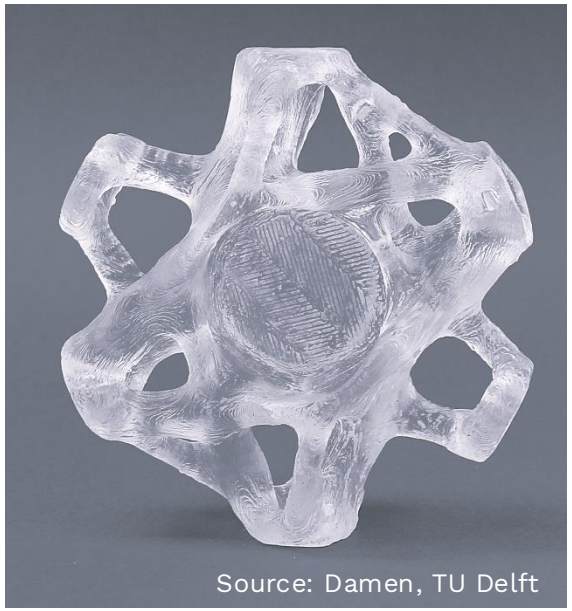
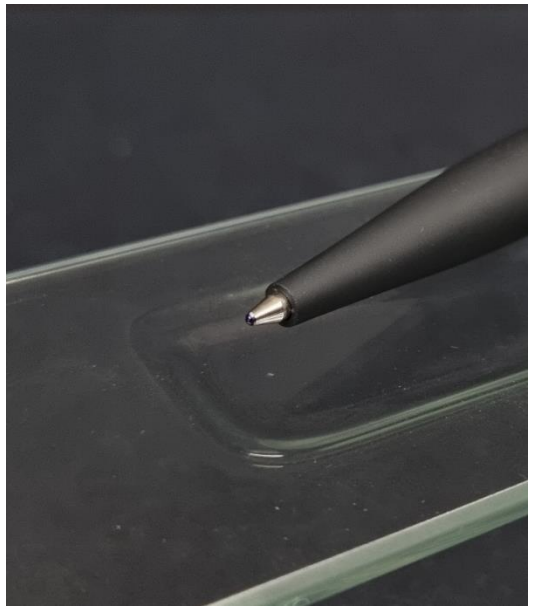
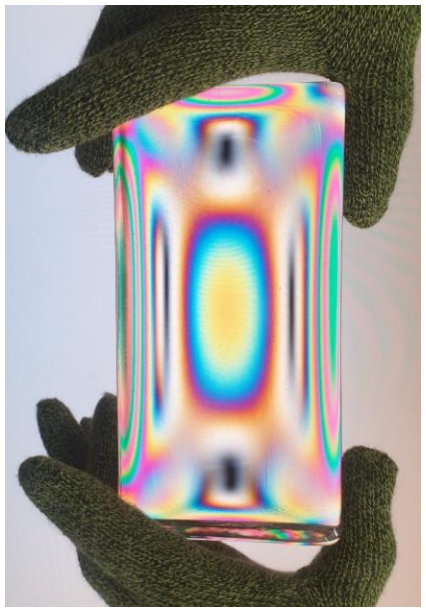
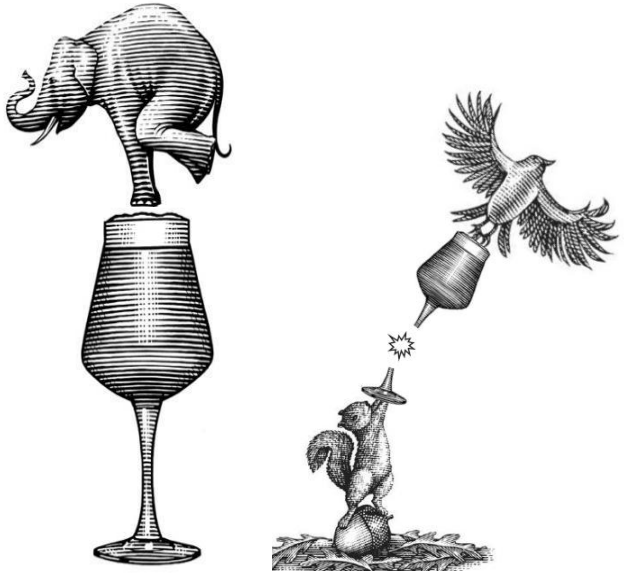
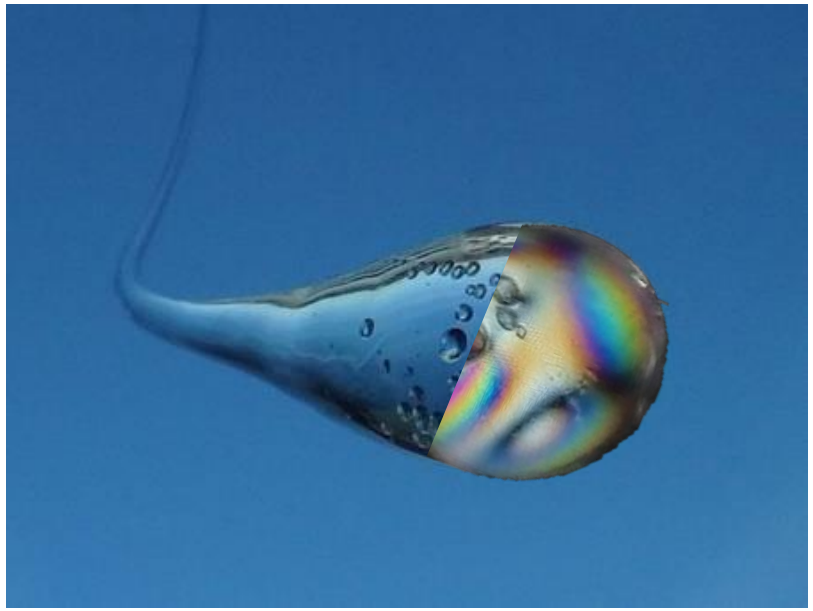
| | Topology optimisation | Shape optimisation | Topography optimisation | Material optimisation |
|---|---|---|---|---|
| Visualisation |  Source: Damen, TU Delft |  Source: Akerboom, GCC |  |  |
| Target values | ***Stiffness*** **(max)**<br>**Mass (min)** | $\sigma$ **(min)**<br>$d\sigma'/dx_i$ **(min)** | $I_y$ **(max)**<br>**Mass (min)** | $f_k$ **(max)**<br>$E_{\parallel}; E_{\perp}$ |

# Structural optimisation – Constrains



Source: Images from Steven Noble



Source: https://eu.metrowestdailynews.com

# Structural optimisation – Manufacturing

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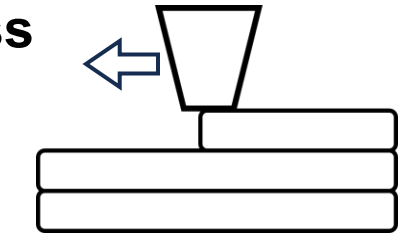
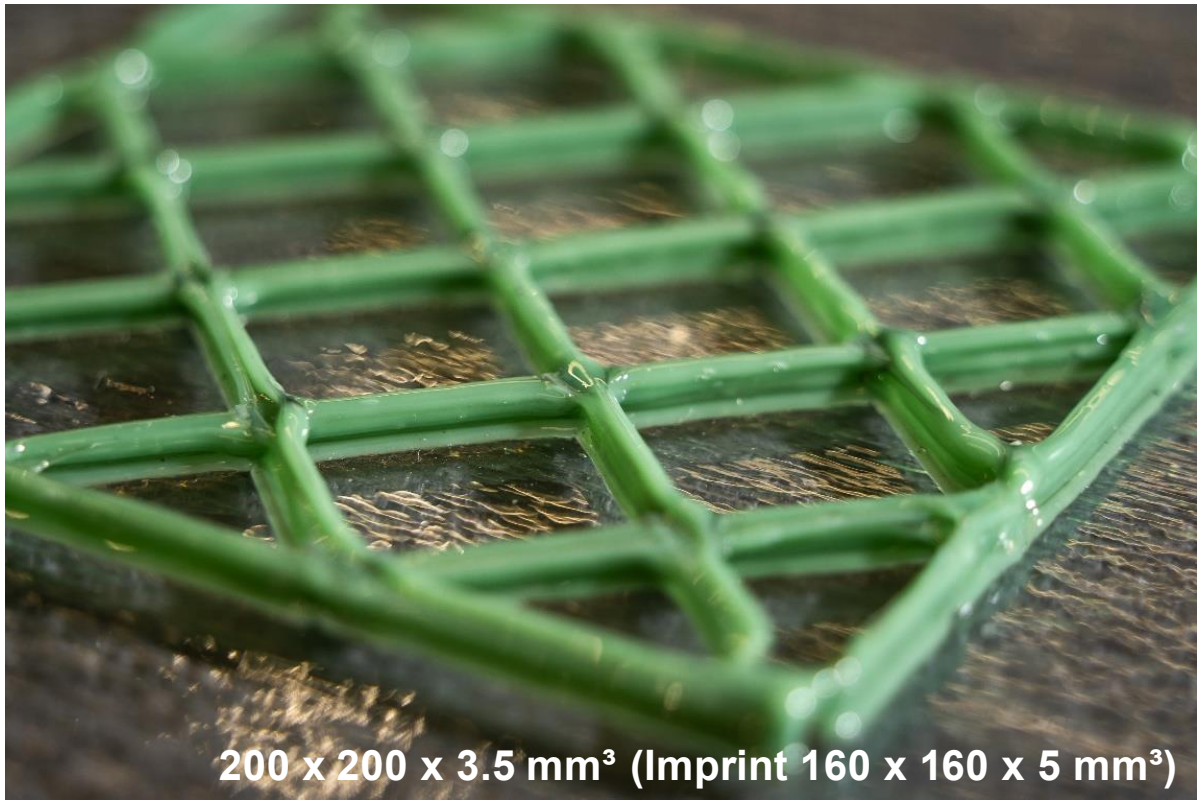
## Additive Manufacturing of Glass






Source: MapleGlass + GCC

## Glass shaping for lowering areas

Source: GLAPE/IWM + GCC

# Structural optimisation – Topology

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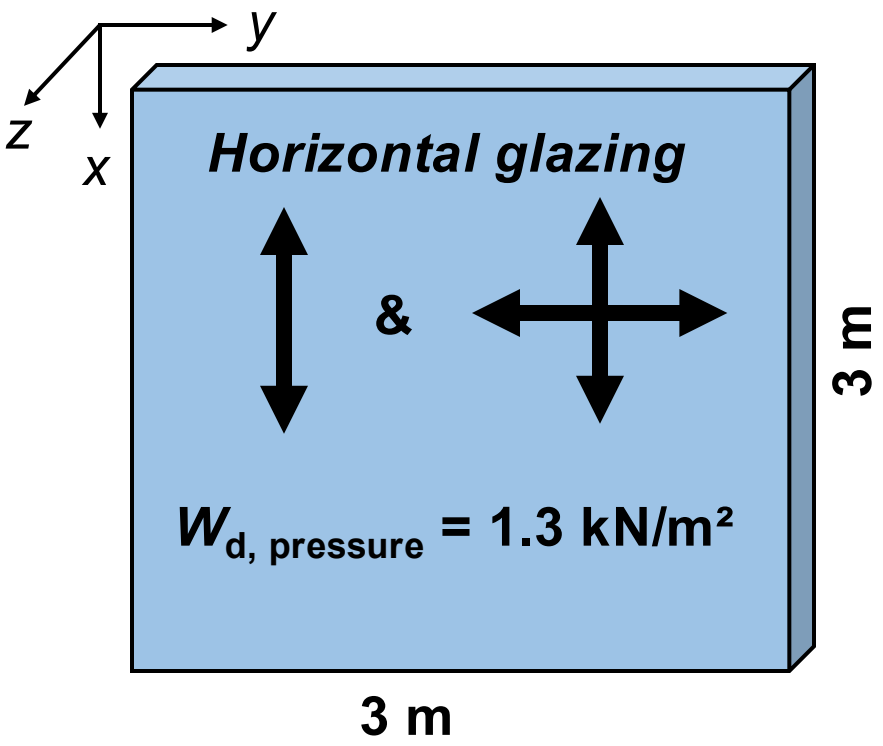
## Task



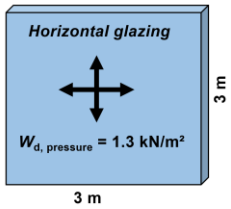

## Model assumptions and boundary conditions

- Min./max. construction height of 10 / 200 mm (glass cross-section)
- Min. glass thickness of flat glass 4 mm,
- Design wind load $w_d$ amounts 1.3 kN/m² (pressure),
- 2-sided or 4-sided linear (Navier) support
- Stiffening geometry without overhang (angle = 0°),
- Minimisation of contact surface between base plate and the imprint for optical reasons
- Calculation of optimisation with geometrically linear method

## Design limit value according DIN 18008 (Constrains)

- **$C_d$ = $L$/100 = 30 mm (SLS – criteria)**
- **$f_{y,d}$ = 17 MPa (ULS – criteria, annealed glass)**

# Structural optimisation – Topology

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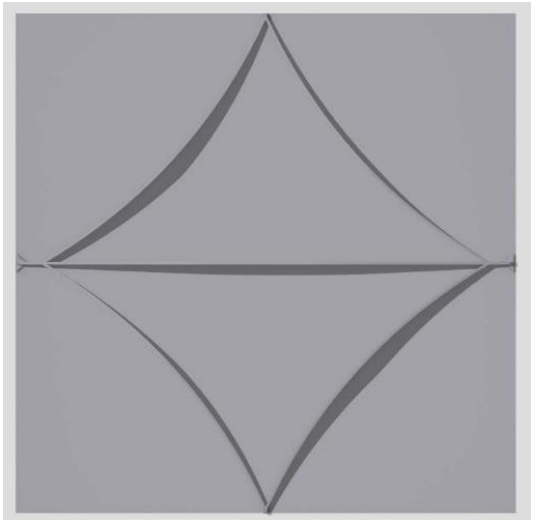
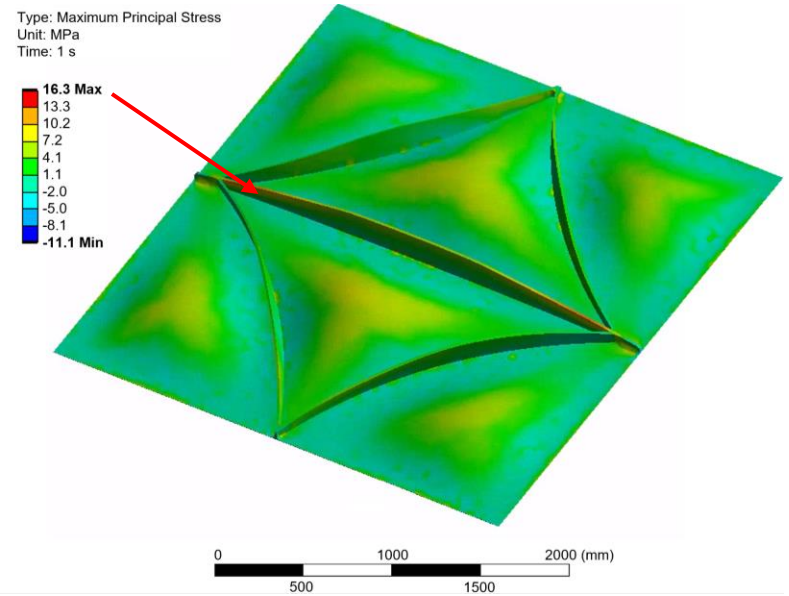
## Results – 4 sided-support (4-ops1 )

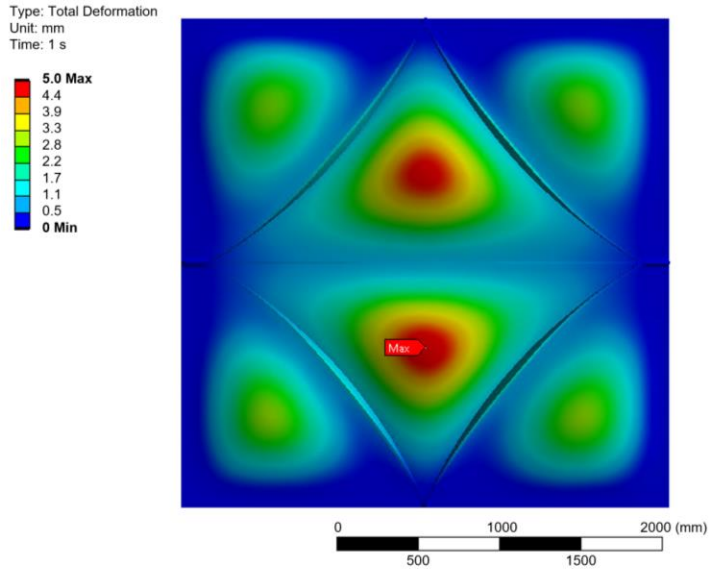
Topology optimisation



Stress analysis




Deformation analysis




4 mm flat glass + imprint
196 mm
**Mass 140 kg**

Max. stress 16 MPa

Max. deformation 5 mm

**59% less mass than reference plate (thickness 15 mm)**

# Structural optimisation – Topology

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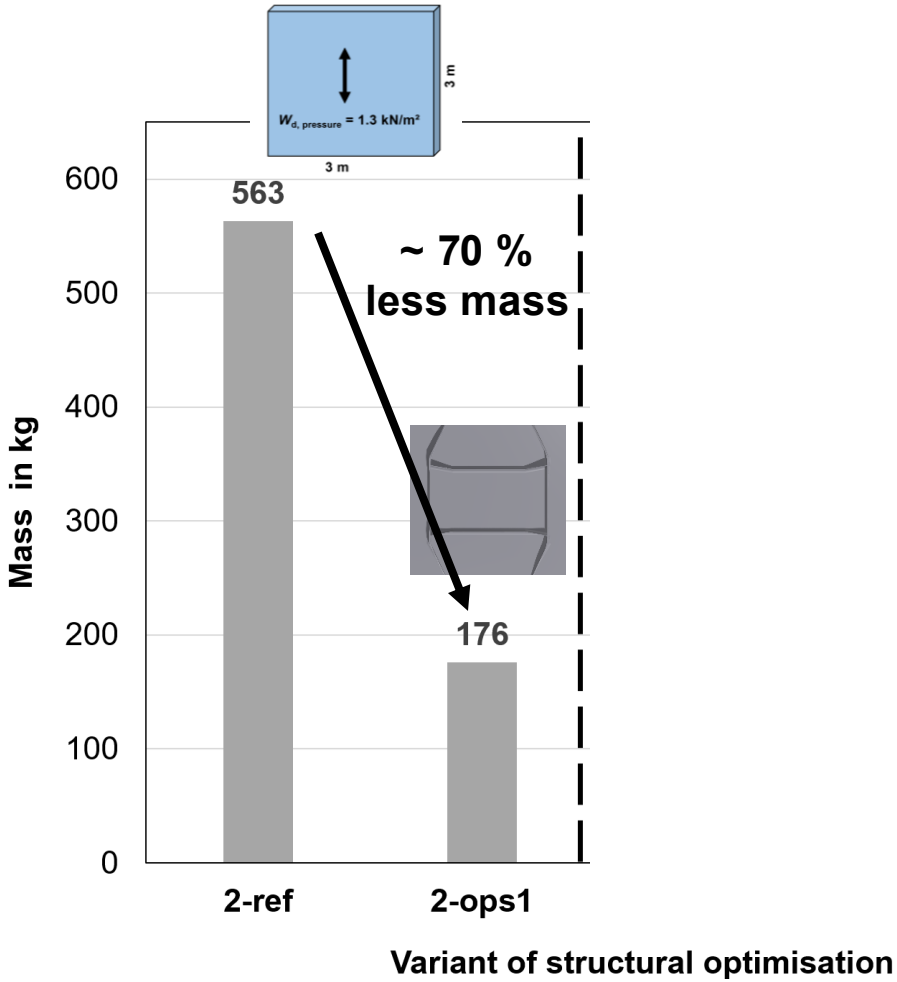
## Results – overview



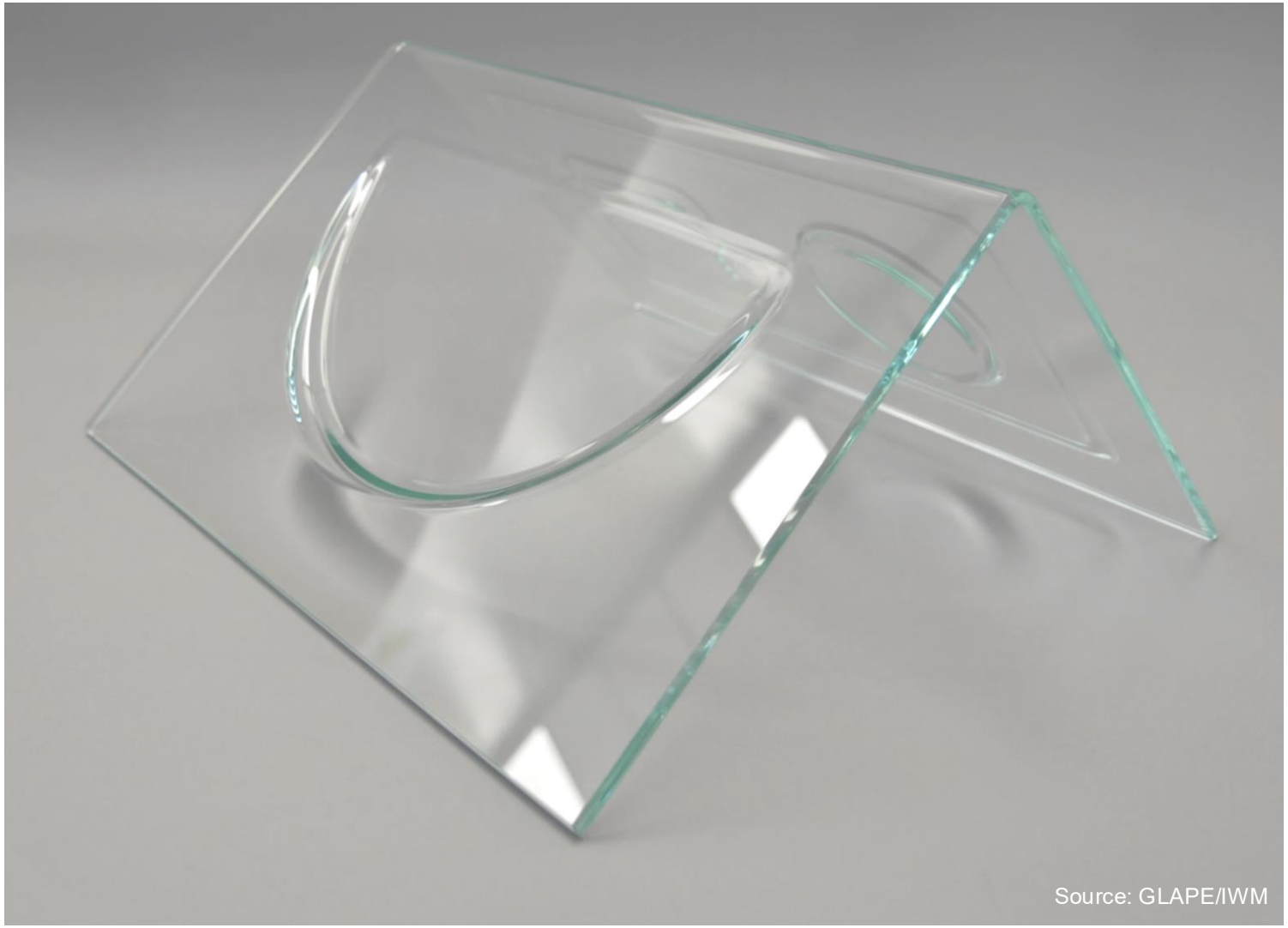

| Criteria / Variants | 2-ref | 2-ops1 |
|---|---|---|
| Type of support | 2-sided | 2-sided |
| Glass built up | 25 mm glass plate | 4 mm glass plate +196 mm imprint |

**SLS is not relevant →**
**ULS is limiting factor + (stability)**

| | | |
|---|---|---|
| Max. deflection [mm] | 25.9 | 7.3 |
| Mass [kg] | 563 | 176 (= 90 + 86) |
| Mass reduction (base ref.) [%] | - | 69 |
| Limitation criteria | ULS/SLS | ULS |

**Notes:** * ... Result based on geometrically non-linear calculation
** ... Comparison with result of geometrically non-linear calculation of reference (4-sided)

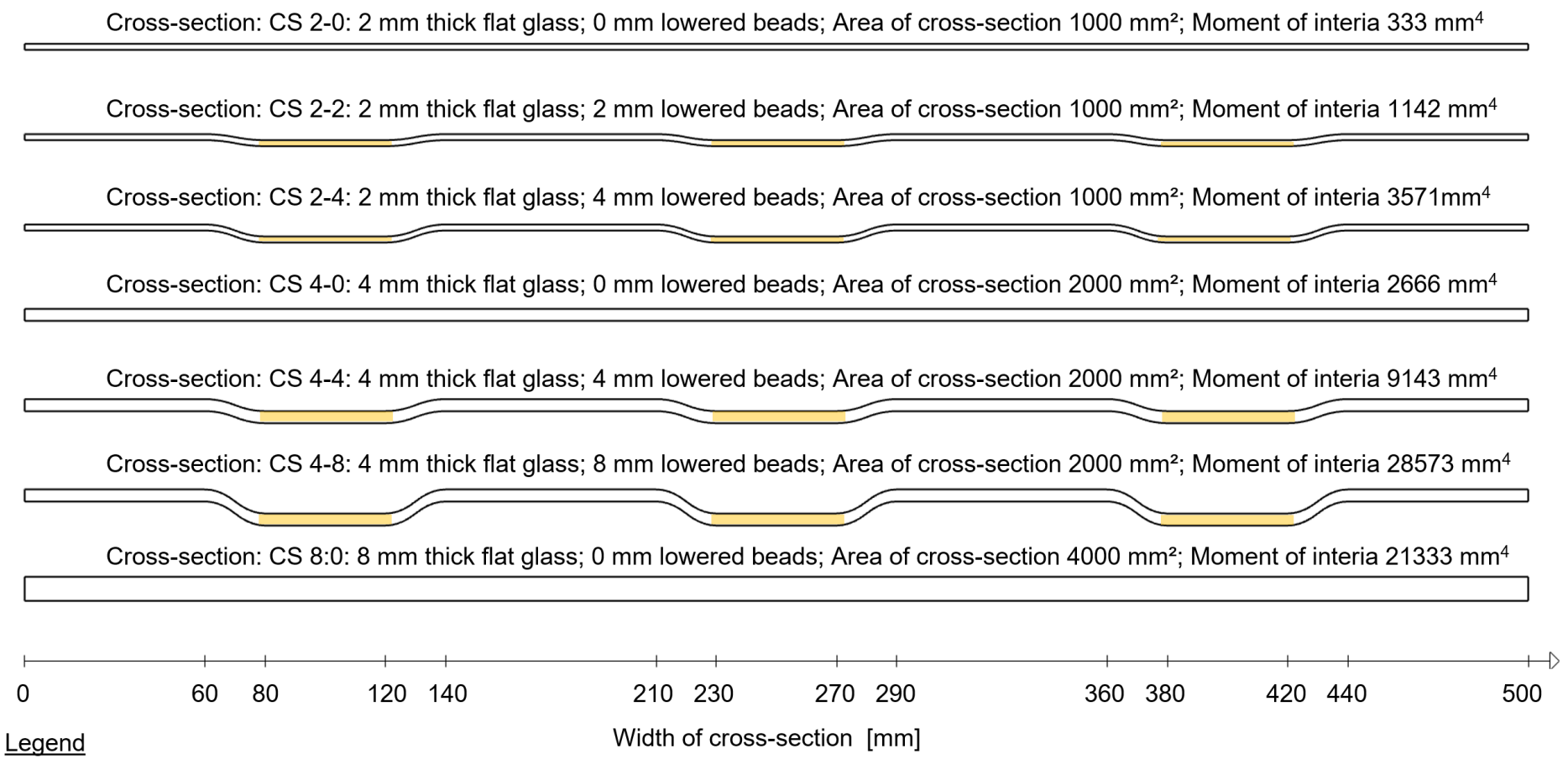
# Structural optimisation – Topography



# Structural optimisation – Topography

## 3 lowering areas/beads each 40 mm width over 500 mm (B)

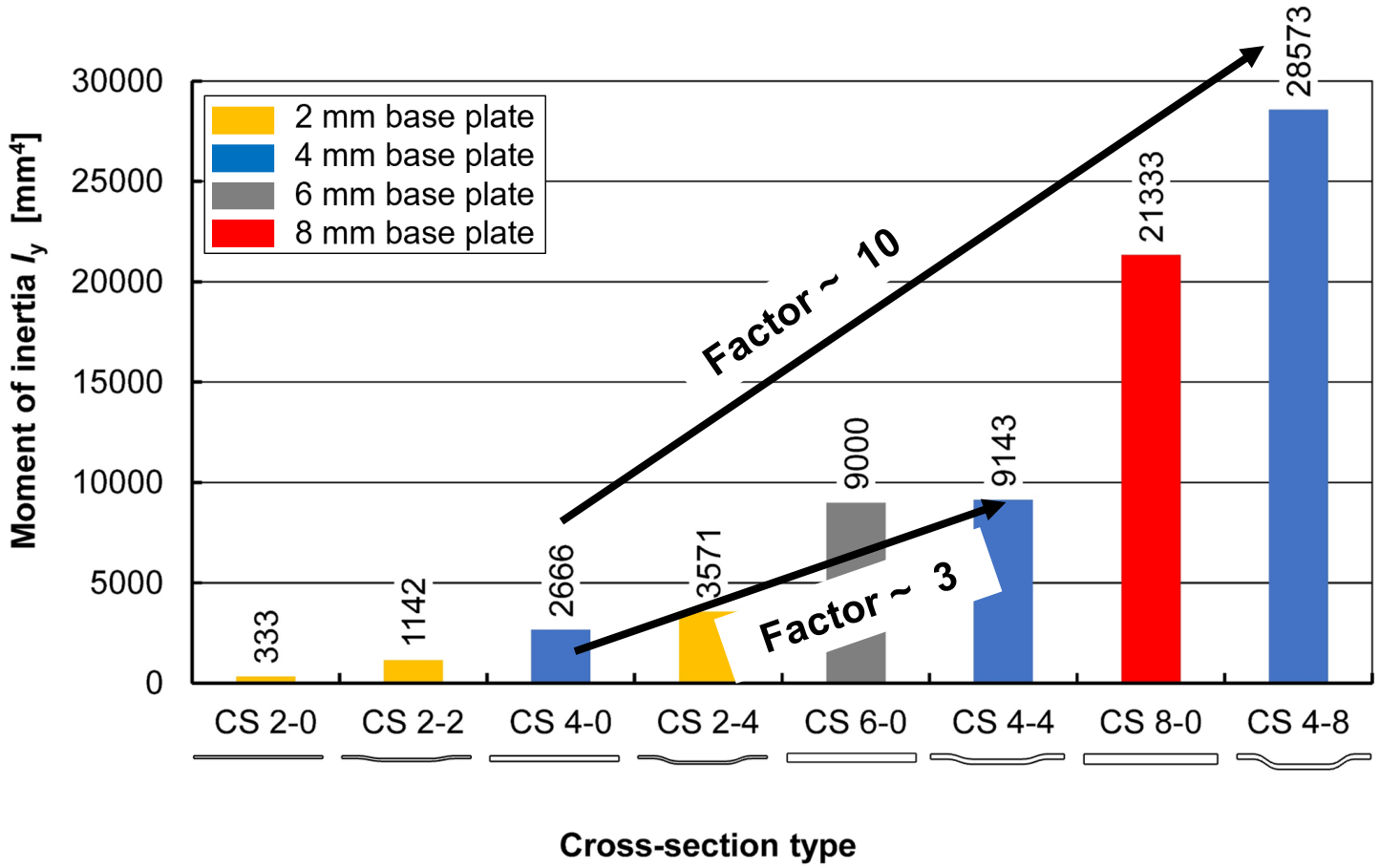
Cross-section (Dimensions in mm)

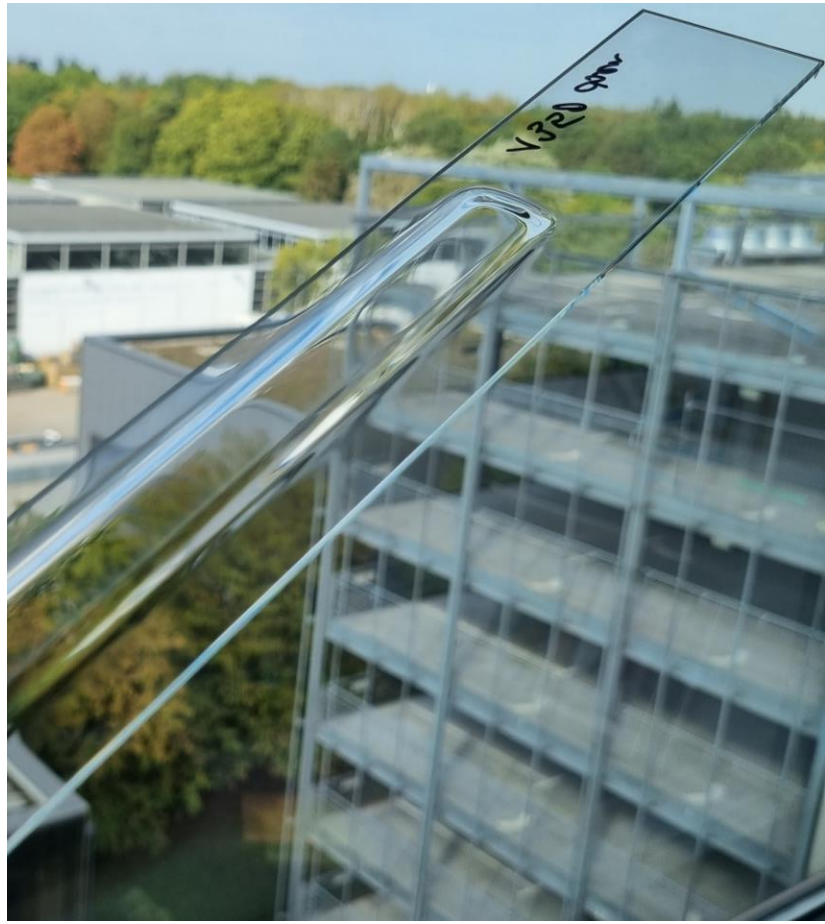



# Structural optimisation – Topography

## 3 lowering areas/beads each 40 mm width over 500 mm (B) – results

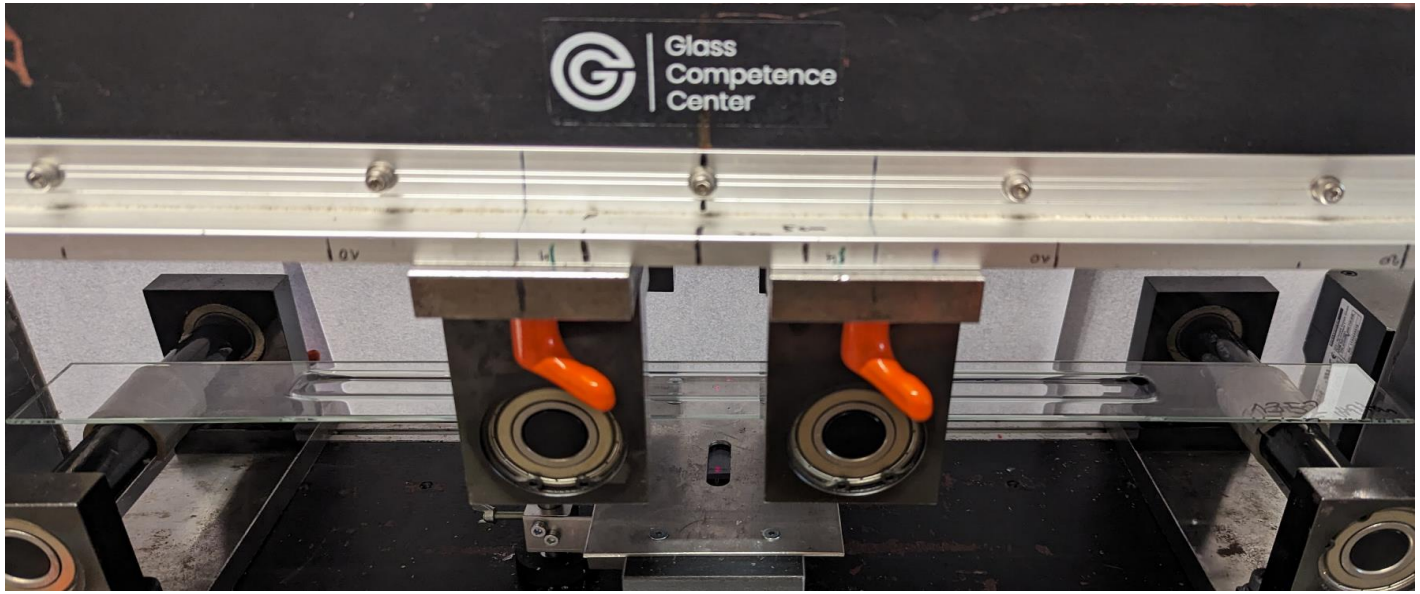
Cross-section (Dimensions in mm)

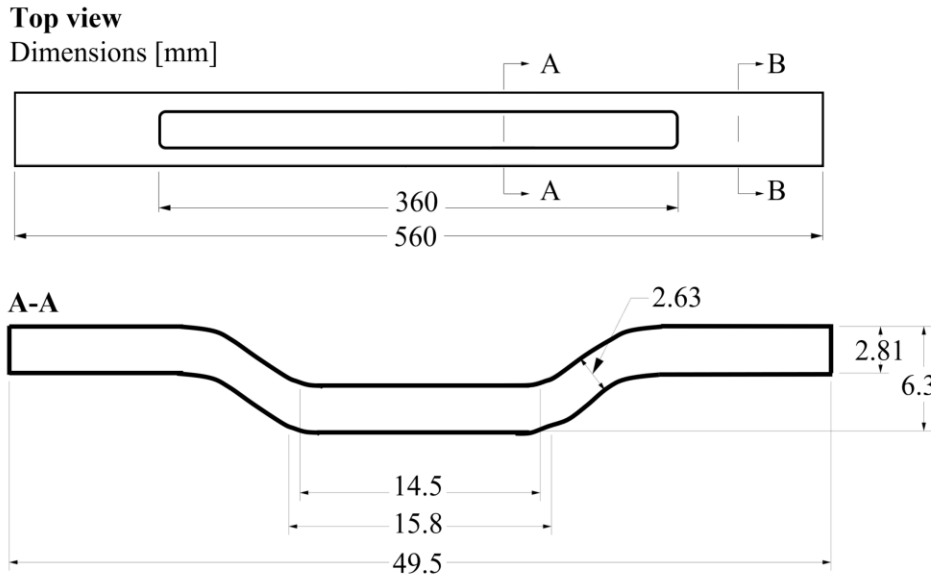


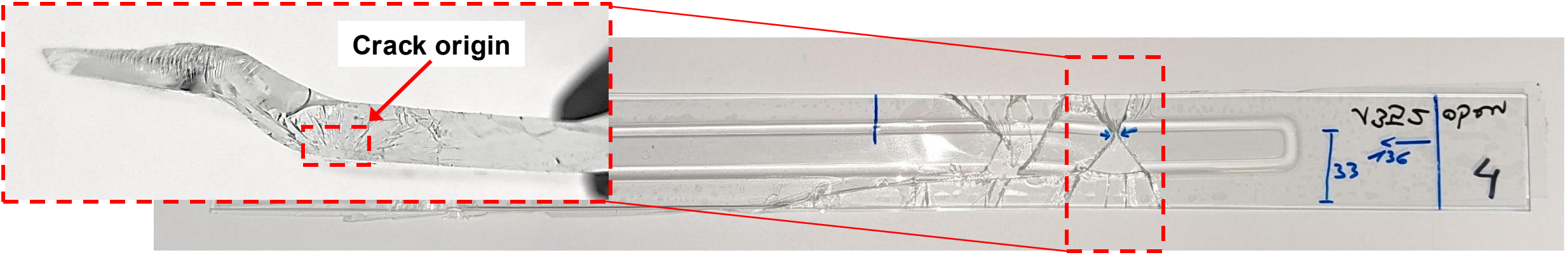



# Structural optimisation – Topography

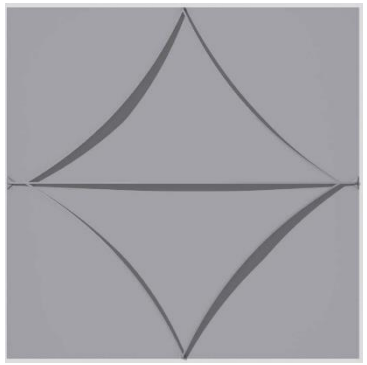
## Experimental results (3 x 50 x 560 mm³)

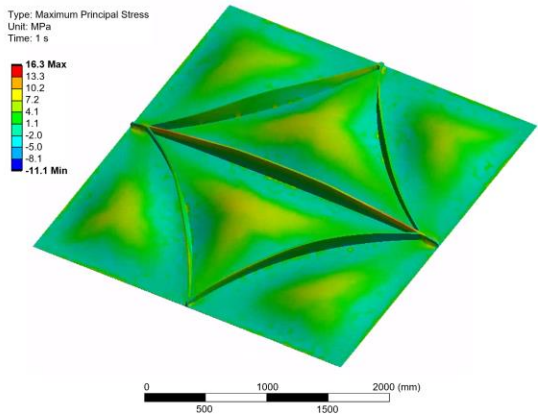


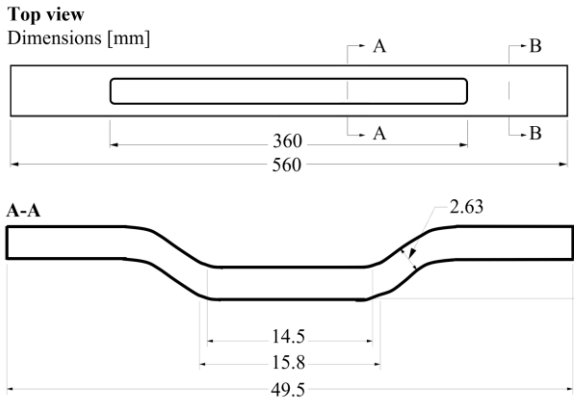



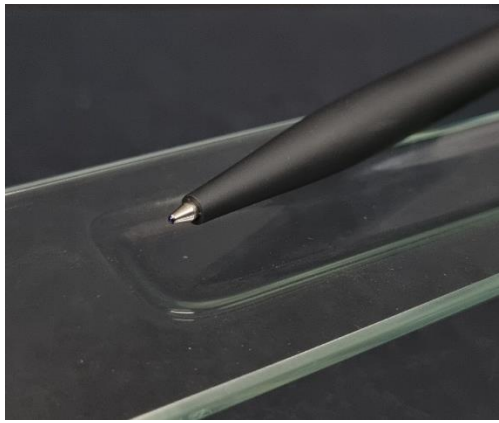



# Conclusion





Structural optimisation for 3D, but not for 2.1 D ("no software")

Manufacturing techniques "3D glass printing" / "local forming" is state of the scientific research

**Structural optimisation**
**→ Lightweight @ glass structures**
**→ Significant weight reduction**

**→ Architectural benefits**

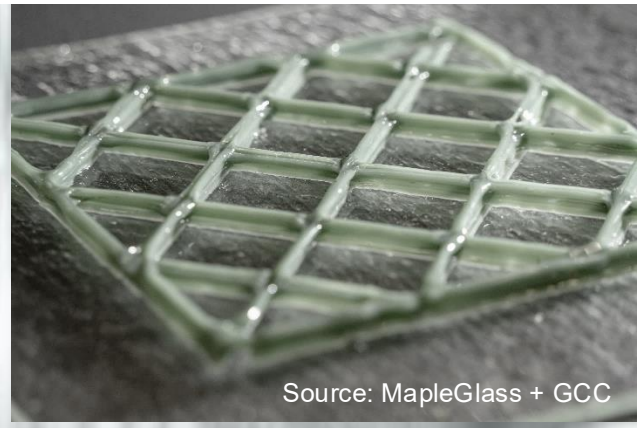
UpScaling to facade size is essential

Safety aspects (laminations & pre-stressing?)

SLS is not relevant →
ULS is limiting factor + (stability)

# Outlook

## Vision of stiffened glass structures in architecture

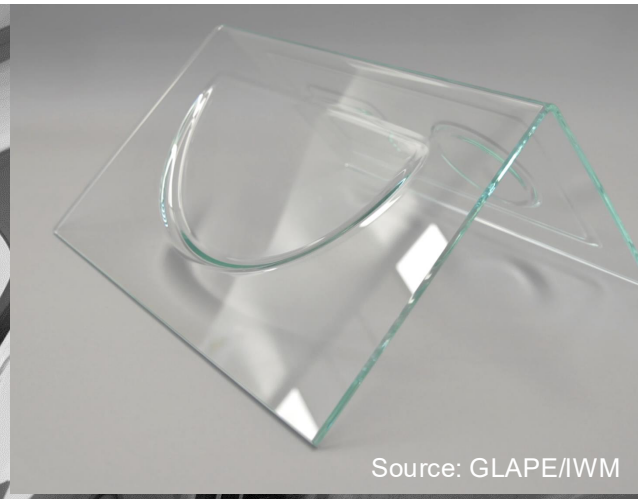


Source: MapleGlass + GCC

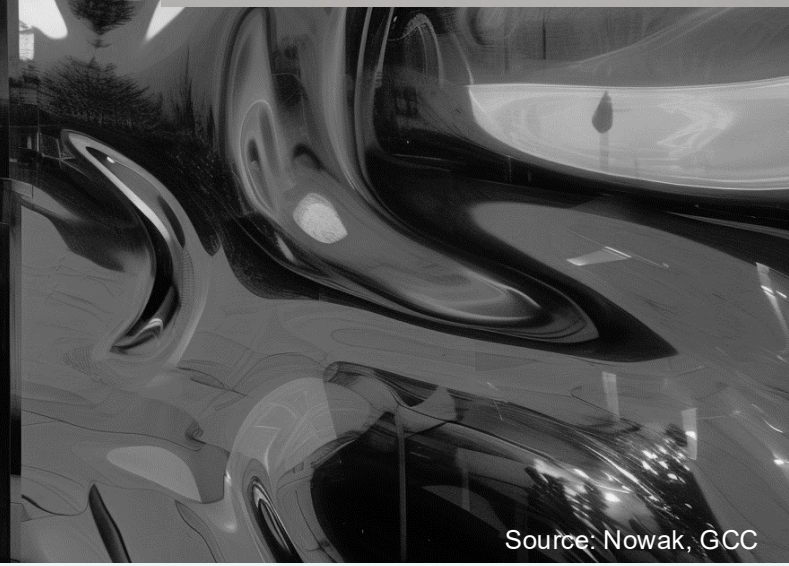
Source: Nowak, GCC

# Outlook

## Vision of non-flat glass in architecture



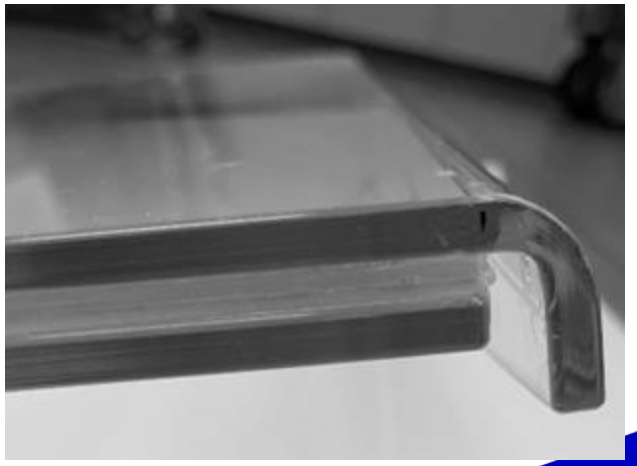
Source: GLAPE/IWM

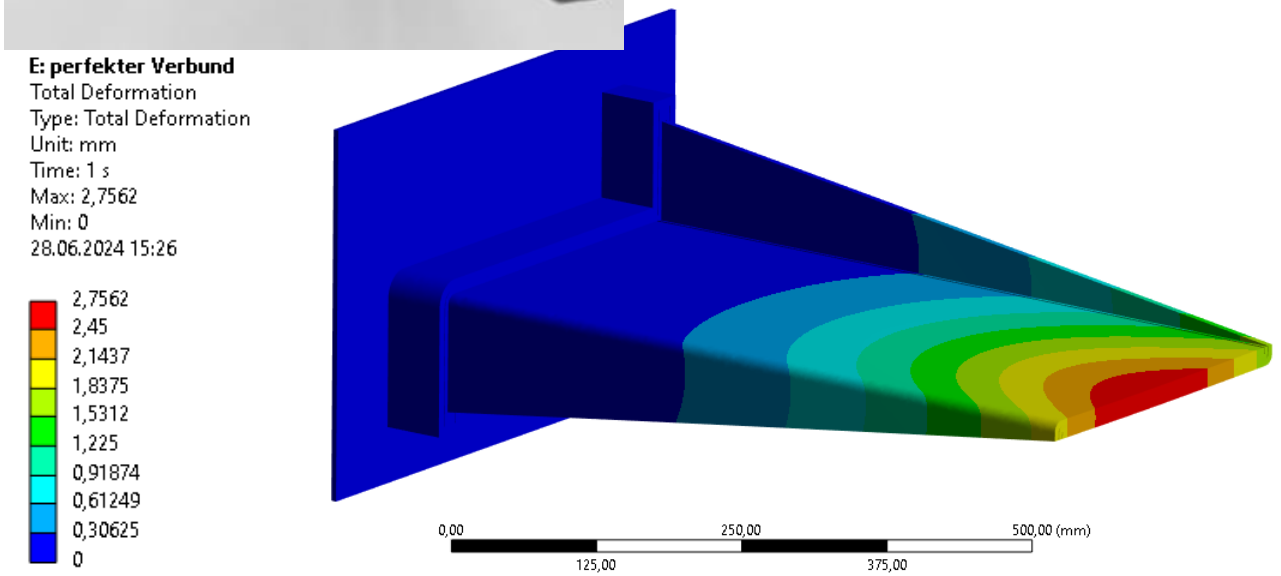


Source: Nowak, GCC

# Outlook

## “Vision” of stiffened stair treads






Source: HB Fuller + GLAPE/IWM + Yachtglas + + Hölscher + Glas Lippold + EOC + GCC

# Thank you for your attention


Contact:

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# Structural optimisation – Manufacturing

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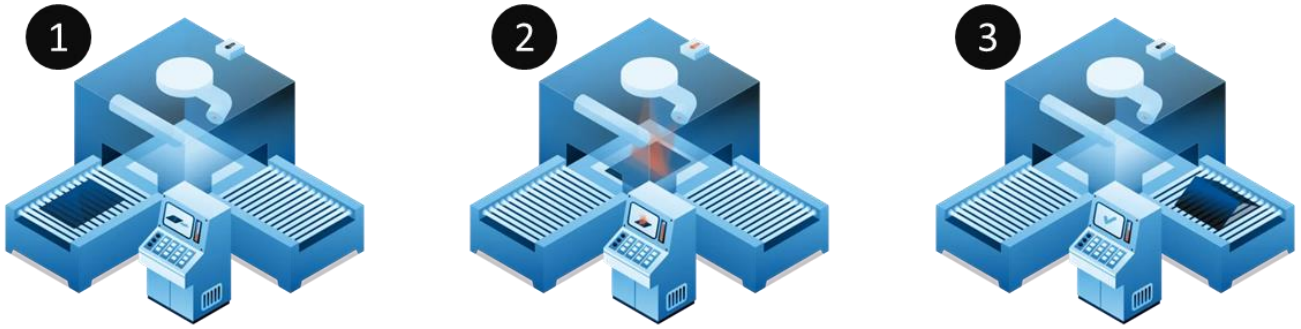
## Glass shaping for lowering areas

Heating

Laser induced bending process

Cooling




Source: GLAPE/IWM + GCC