Design Of A 95% Glass Climate Adaptive Curved Canopy.

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For obtaining the Degree of Master in Architecture, Urbanism and Building Sciences Building Technology Track
Delft University of Technology
Design Of A 95% Glass Climate Adaptive Curved Canopy.

Building’s Energy Demand.

Material and Mechanical Technology.

Energy Saving Interior Comfort.

Glass Deployable Structures
Design Of A 95% Glass Climate Adaptive Curved Canopy.

Glass
Material Technology.
Research

Deployable Structures
Structural and
Mechanical Technology.

Connection Design
Final product
Is it possible to design a dismountable morphing 95% Glass Canopy?

Glass
Material Technology
Research

Structural Glass Design Approach.
Basic Design Rules.
Glass Characteristics
Glass Engineering Technology
Connection Design

Deployable Structures
Structural and Mechanical Technology.

How do they work?
How are they designed?
How are they Calculated?
Glass

Advantages
- Excellent Compression
- Greenhouse Effect (misconception)
- Abundant on Earth
- Recyclable Transparent Concrete
- Design

Disadvantages
- Brittle
- Breaks

Technology

Toughening of Glass
- Laminated Glass
- Reinforced Glass

Pilkington Planar System
- Articulated Bolt

Bending forces
- in the glass
- in the support

Cracks cannot open due to the stresses
- Compression
- Tension

PVB (Polyvinyl Butyral)

- Press
- Mechanical evenly distributed

Resin
- Hardens after application

Temp 250 ºC
Deployable Structures
Structural and Mechanical Technology.

Tensegrity

Mouri Foldable

Scissor Hinges

Stadiums

Mechanisms

Combinations

Kinematic Chains
The city of Tulum

- Late Post-Classic Mayan Period
1200-1521 A.C.
- Surrounded by a 5m tall wall & Coral Reef
- Sun and the Sea.
- Museum located outside the archaeological site’s walls.
Challenge:
- A glass structure in a hot and humid place
- Respect the ruins
- Protect from the rain and wind
Simplification

Models

Cantilevered Scissor hinge

Modified Scissor hinge

Three beams

Sliding Cantilever

Needed to be restricted

An external beam
First Stage
Cantilevered Scissor hinge
Lessons Learned
The tensors had to be adjusted
The scissor hinge woks better as a self supported structure.

Second Stage
2 Main Beams
Lessons Learned
The second beam had to supported.
The cantilevered hinge had to be designed.

Third Stage
2 Main Rotating Beams
Lessons Learned
The cantilever was solved by clamping the rotating beams and using a ball bearing.
Animations
3D Models
Final Proposal
View of the Plaza

Final Proposal
View of one module

Final Proposal
View of the Complex
Transversal Section of One Quadrant of the Canopy
When designing with glass which are the Basic Design Rules?

Designers + Industry working together
Flexible and absorbing supports
Clear and analyzable load patch
Prediction of stresses in glass

Tension

LC2 Wind

Moment

Forces

LC1 Gravity

Tension

Compression
Environmental Considerations

Heat and moisture

1. 2% slope
2. Vindico Glass Coating
3. High Reflectance Coating 90%
4. Above 30°C Sentry Glass Interlayer
5. 3cm glass plate + Fourth layer added for redundancy.

At higher temperature levels strength and stiffness of the interlayer decrease.
The approach to the structural design with glass can be very similar to the design with concrete. “These materials are brittle, weak in tension and strong in compression. Float glass, being non-porous, really having properties like an extreme ultra high performance concrete.” (Veer, F.A. 2005. 10 Years of ZAPPI Research Delft University of Technology, www.zappi.bk.tudelft.nl)
FEM Results
Tension Stress

<table>
<thead>
<tr>
<th>Principal Stress</th>
<th>Tension</th>
<th>Tension</th>
<th>Compression</th>
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<tbody>
<tr>
<td>S1</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>S2</td>
<td>20</td>
<td>6</td>
<td>200</td>
</tr>
<tr>
<td>S3</td>
<td>40</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>FT</td>
<td>80</td>
<td>80</td>
<td>200</td>
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Peaks
S1 max = 104 MPa

Top
S1 max = 5.61 MPa

Middle
S1 max = 4.92 MPa

Bottom
S1 max = 11.3 MPa

Model: 23ABR03
LC3: Load case 3
Element EL:S1 S1
Top (last) surface
Max = 101
Min = -374E-5
<table>
<thead>
<tr>
<th>Case</th>
<th>S1 principal stresses 1*</th>
<th>S2 principal stresses 2</th>
<th>S3 principal stresses 3**</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>max</td>
<td>min</td>
<td>max</td>
</tr>
<tr>
<td>top</td>
<td>16</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>mid</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>bottom</td>
<td>7</td>
<td>-7</td>
<td>11</td>
</tr>
</tbody>
</table>

**Case 1**
- Top: S1 max = 37.5 MPa
- Middle: S1 max = 6.72 MPa
- Bottom: S1 max = 40.5 MPa
Cantilevered Hinge

Vertical connections have to be improved.

The glue and the connections failed

Hinged Connections with the Glass Plates

The sliding hinges didn’t slide.

The glass plates could be leveled.
Glass Plates Hinge Detail

1. 6mm HS Laminated Sentry Glass
2. 12mm HS Laminated Sentry Glass
3. 180mm diam. Titanium connector inserted between laminates
4. 2.5mm soft aluminum ring
5. Titanium 6/8” nut
6. Titanium 6/8” spacer
7. White anodized aluminum 6/8” bolt
Rotating Beam Hinge Detail

1. Borosilicate Glass Cap
2. White anodized aluminum 6” tube
3. Stainless Steel clamp
4. Stainless Steel Thrust 8” diam Ball Bearing
5. Steel u profile beam reinforcement
6. 6-12-12-6mm HS Laminated Sentry curved Glass
7. 200mm Duran Schott glass tube
8. 180mm Duran Schott glass tube
9. 180mm Titanium connector inserted between glass tube laminates
10. Stainless Steel Thrust 8” diam Ball Bearing
11. Soft aluminum ring glass column connector
12. Soft aluminum cross spacer column connector
13. 300mm & 304mm Duran Schott glass tube laminated column.
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Safety Considerations

Column Protection  
further study

Trial on site construction  
further study

Third Insert  
further study

Maintenance Plan  
further study

Mechanism  
further study
References

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Thank you for your attention.