Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	Koen van Deurzen
Student number	4884469

Studio		
Name / Theme	Building Technology – form-active thin glass	
Main mentor	Mauro Overend	Professor of structural design
Second mentor	Marcel Bilow	Dr. engineer façade & product design
Argumentation of choice of the studio	I have chosen the topic of thin glass since glass as a material interests me. I want to gain a deeper understanding of its mechanical properties and I want to learn how it can be used to our advantage even more than it is today. Furthermore I chose structural design as chair in combination with façade design as I want to gain a better understanding at modelling and testing structural properties of materials to make them applicable in façade products. My goal is to broaden the current knowledge of thin glass and make it more applicable in the built environment.	

Graduation project	
Title of the graduation project	Increasing the curvature for cold bent insulated glass units
Goal	
Location:	Delft, The Netherlands
The posed problem,	There are 3 main methods of creating curved glass façades. The first one is flat panels; creating a curved surface out of small flat surfaces. While this is a cheap and easy construction method, the disadvantage of this method is that the end façade is often not as smooth as the designer would like it to be. The second method is hot bending. The advantage of hot bending is that high curvatures of façades can be achieved. The disadvantage is that it requires a second energy-intensive process, whereby the flat glass pane has to be

	reheated and cast over a mold. Often, curved glass façades consist of many different shapes of glass pieces. With the hot bending method, every unique piece of glass needed for the project requires a unique mold. This process is very labor intensive and cost heavy. For very complex façades the amount of uniquely shaped glass panels can get very high, making a project very expensive and often limiting the designer in flexibility. The third method is cold bending. Cold bending of façade panels is becoming more common in architecture. With cold bending, flat panels are constructed and transported to the building site, after which they are cold bent into place on the building itself. The advantage of cold bending is that the same panels can be produced in larger volumes since they are bent into shape on the building site itself. The disadvantage of cold bending is that with regular float glass, the maximum amount of curvature of a panel is not very high. Using thin glass in cold bent glass units could increase the maximum possible curvature of a cold bent panel. However, the thickness of the panel, choice of spacer material and adhesives or sealant all have an impact on the bending behavior of an insulated glass unit. It is therefore important to have a good understanding of the composition of the panel and material properties. To asses a good, highly bendable unit.
research questions and	The primary goal of this thesis is finding a way to achieve higher useability in cold bent glass panels by making them applicable in higher curvature situations. 1. What dictates the maximum bending capacity of a cold bent glass panel 2. How can an IGU be designed to accommodate bending behaviour of thin glass? - What spacer material is best for constructing a highly flexible IGU - What adhesive works best to handle high shear forces and large flexibility between the spacer and glass? 3. How can a finite elements model be made to simulate old bending of a thin glass IGU?

	4. How does a thin glass IGU perform under a single corner deflection?
design assignment in which these result.	The first result of the design assignment should be a reliable finite elements model. This model should be able to accurately predict stresses on the panel when it is curved. The modularity of the finite elements model could be used to an advantage to test different panel and material compositions and sizes. Out of the results of the model, a prototype should be derived. The prototype of an IGU made out of thin glass, which allowable curvature should be higher than a general float glass unit. This prototype will be based on, but at the same time validate the numerical data gathered from a finite elements model.

Process

Method description

This research consists of multiple phases and approaches.
The first method is literature study. Thin glass is a relevant field with papers on its application in architecture being released very recently. These papers are important to gain good understanding of the state of the art of thin glass. These papers contain knowledge on how glass and thin glass behaves during bending conditions. There is also interesting research on correct FEM modelling of glass and insulated glass units.

The second phase is the modelling phase. Numerical Modelling
To asses the strength and structural properties of thin glass under bending stress and To predict stresses in the glass surface during deformation, a finite elements model will be made. Finite elements software can accurately show stresses and deformations, and with this model, changes can be made in the material composition of the panel. Allowing for finding an ideal panel composition. With numerical modelling, the maximum allowable bend angles can also be predicted, making the process safer and easier. For a finite elements model that closely simulates reality, exact material properties have to be known and chosen in advance. The results of the finite element model will have to be validated using physical testing.

The third phase is creating a physical model
After numerical modelling, with knowledge of material properties, a physical model can be assembled. A physical model will determine if the numerical model outcomes are in alignment with real life situations. If modelled correctly, the physical model should correspond with the numerical model. As glass is still a relatively unpredictable material due to its brittle nature and its strength being dependant on surface flaws. The bending process with a real model will provide interesting data on the behaviour cold bent thin glass.
For the physical testing, different partners have already been approached. Most likely partner collaborations will be with:
AGC, for thin glass

DOW, for adhesives and sealant.
Edgetech, for flexible spacers
Step 1: pre-Research optimal thickness of glass panes + cavity for cold bending

Step 2: research best spacer, adhesive and sealant to accommodate bending curvature achievable by glass composition

Step 3: nummerical model

- Model the glass panes, spacer and adhesive into ansys. Parametrize glass thickness, spacer thickness and adhesive strength to optimize bending behaviour.

Step 4: physical modelling

- Make physical model with products from partners AGC, DOW, Edgetech.
- Perform bending tested in ansys
- Validate if ansys model is correct

Step 5: conclude

Literature and general practical references

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Reflection

1. **What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?**

The goal of building technology is to gain a better understanding of how building, and building parts work. How to make buildings more efficient, easier to build and to reduce their impact on our climate. Researching mechanical behaviour of thin glass during cold bending in an insulated glass unit provides useful data on these attributes. If successful, contributing to the improvement of building construction methods and material science for buildings. In the larger scheme, this research contributes to ongoing trends in architecture to design with complex, computationally designed shapes. Real fabrication of complex shapes always a challenge and if this research can contribute to making construction easier, it could help freedom in architectural design.

1. **What is the relevance of your graduation work in the larger social, professional and scientific framework**

Research about glass mechanical properties in general is more related to the field of material science. How this glass can be used in architectural applications is important for the building technology sector. Therefore, the research will mostly focus on the behavior of glass in a façade panel, which is useful for architecture. If the research proves to be successful, it could lead to new, more sustainable developments being made in fluid glass façade design