# 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 | Eleni-Maria Toliopoulou |
| Student number | 5614996 |

| **Studio** | | |
|---|---|---|
| Name / Theme | Building Technology/Sustainable Design Graduation Studio | |
| Main mentor | James O'Callaghan | Professor, Architectural Glass |
| Second mentor | Paul de Ruiter | Lecturer, Design Informatics |
| Argumentation of choice of the studio | Combining computational methods together with thinking based on existing data can help speed up research projects, skipping unnecessary time spent in labs. Simulations together with informed decisions can provide results that can be further assessed, on a later stage of a research, while also providing tools throughout this process. | |

| **Graduation project** | |
|---|---|
| Title of the graduation project | Thin glass installation: integrated design for glass projects |
| **Goal** | |
| Location: | Delft, NL |
| The posed problem, | As much as regular float glass has evolved, there are certain drawbacks and limitations on its architectural exploitation. Firstly, due to high insulation demands, glass panes are usually combined creating double or even triple glazing panels, which consequently increases the weight of it. Secondly, float glass does not allow for flexibility and is therefore difficult to curve or tension. Moreover, being one of the most popular construction materials worldwide, glass, not only creates a considerable amount of contamination but its production derives a high volume of embodied energy, meaning that it is a carbon intense material.<br><br>While glass is a readily recycled material, the only existing closed-loop system exists just for the post-consumer |

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| | containers. Meanwhile, the situation is a bit different and appears to be more complicated, regarding the float glass industry. However, there are numerous research on the possibility of reusing and repurposing glass construction waste, yet it is not integrated into the industry.<br><br>Thin glass products have been widely produced for the past decade and used in other fields, as is the automotive and electronics industry. Application in these fields demand durability, great optical clarity and flexibility, which are only some of the properties that thin glass demonstrates. Furthermore, the production method that is currently used for thin aluminosilicate glass is the overflow process, where less raw material is needed, therefore more panels could be produced with the same amount of material, when compared to regular float glass.<br><br>That being so, thin glass could be utilized to fulfill several goals towards a more circular economy, the first one being "design out waste". Taking into consideration the aforementioned, as well as the properties of the product, architectural applications would benefit from the potentials of the material itself, providing more complex, lightweight and clear structures.<br><br>This forms a promising opportunity for the existing products to be employed into construction and be brought to the fore. Prior research and testing have provided information regarding the material's different properties as well as boundary conditions. Should all this data be stored so as to inform the workflow of a testing and design process, it would allow for further and quicker developments on the field, while also providing with a set of rules for informed decision making. |
| research questions and | The main research question is formulated as follows:<br><br>*"How can a design of a thin glass installation be informed by the use of computational methods?"*<br><br>With the sub-questions formed to complement the various subjects:<br><br>*Thin glass:* |

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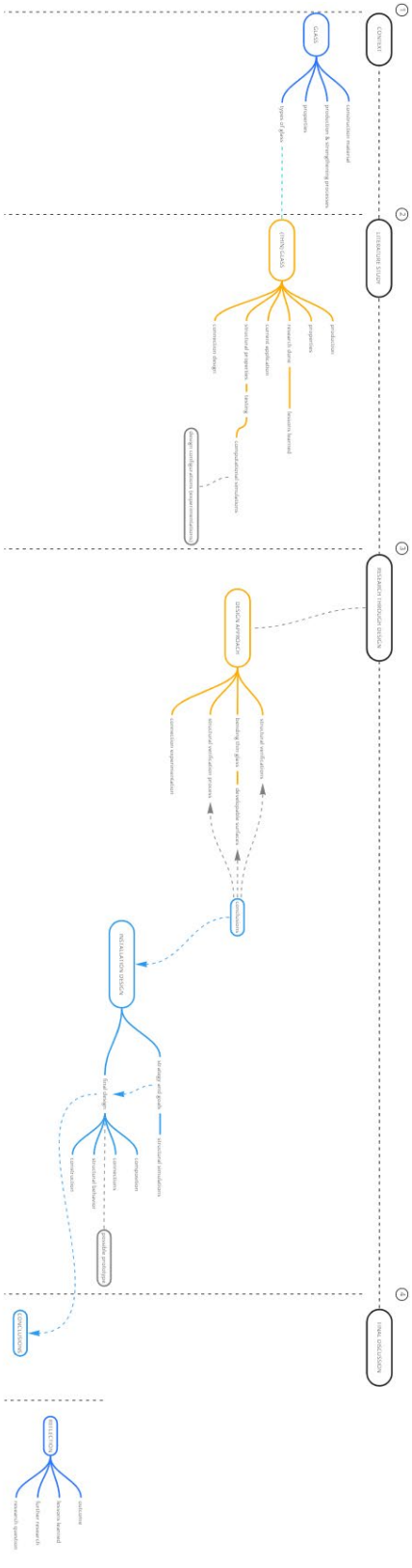
| | – What are the limitations of thin glass in construction?<br>– What is the most optimal way to bend thin glass in order to achieve its maximum capabilities?<br><br>*Glass design:*<br>– What types of connections are used for structural glass?<br><br>*Computational design:*<br>– What kind of tools can be utilized to optimize the design of glass structures?<br>– What data should be stored to create boundary conditions for design and how? |
| design assignment in which these result. | This research will end up with a design of a small-scale pavilion made (completely) out of thin glass, with the use of computational tools both for the design and the structural verification of it. The overall aim is to exploit already existing data around thin glass to better understand the product itself and incorporate that into a workflow that can lead to an informed design, which can be eventually constructed. |

[This should be formulated in such a way that the graduation project can answer these questions.
The definition of the problem has to be significant to a clearly defined area of research and design.]

## Process

### Method description

The methodology aimed to be followed for this research is a combination of two methods, separated in three different parts. In order to understand the overall glass industry, knowledge through literature research is gained, focusing on the capabilities of glass as a structural element, as well as its properties. The second part entails the complete literature study on thin glass, to understand the product and the structural possibilities of it. An inventory of design configurations and connection design is created so as to help make educated assumptions to proceed with the third part of the research method. Consequently, the third part is research by design, where after the conducted study a design approach is set, limited and a workflow for its verification established.
Finally, after the three parts are completed, the installation design is evolving. This final phase will culminate with building a prototype as a proof of concept and process evaluation.
The aforementioned are illustrated on the flowchart below:



## Literature and general practical preference

The following scientific papers, journals, conference proceedings, book sections as well as websites will be studied and referenced in this thesis:


Akilo, M. (2018). Design and analysis of a composite panel with ultra-thin glass faces and a 3D-printed polymeric core. University of Bologna, Masterarbeit.

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Corning Museum of Glass. All About Glass | Corning Museum of Glass. (n.d.). Retrieved January 20, 2023, from https://www.cmog.org/article/types-glass

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Datsiou, K. (2017). Design and Performance of Cold Bent Glass. PhD. University of Cambridge, Cambridge.

Galuppi, L., Massimiani, S., & Royer-Carfagni, G. (2014). Buckling phenomena in double curved cold-bent glass. International Journal of Non-Linear Mechanics, 64, 70-84.

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Glass off the roll | glassonweb.com. (n.d.). Retrieved January 22, 2023, from https://www.glassonweb.com/news/glass-roll

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Gregson, S. (2018, November 2018). Thin Glass applications for Yachts International HISWA Symposium on Yacht Design and Yacht Construction, Amsterdam, NL.

Gulati, S. T., & Helfinstine, J. D. (2011). Edge strength testing of thin glasses. International Journal of Applied Glass Science, 2(1), 39-46.

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Hynd, W.C. (1984). Flat glass manufacturing processes. Glass: Science and Technology, Volume 2, 46-106.

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Huang, C., & Behrman, E. (1991). Structure and properties of calcium aluminosilicate glasses. Journal of non-crystalline solids, 128(3), 310-321.

Lambert, H. & O' Callaghan, J. (2013). Ultra-thin High Strength Glass Research and Potential Applications. Glass Performance Days, Finland 2013. 95-99.

Lasonder, W. (2022). Design of a demountable structural glass pavilion.

Louter, C., Akilo, M., Miri, B., Neeskens, T., Ribeiro Silveira, R., Topcu, Ö., van der Weijde, I., Zha, C., Bilow, M., & Turrin, M. (2018). Adaptive and composite thin glass concepts for architectural applications. Heron, 63(1/2), 199-218. https://heronjournal.nl/63-12/9.pdf

Maniatis, I., Nehring, G., & Siebert, G. (2016). Studies on determining the bending strength of thin glass. Proceedings of the Institution of Civil Engineers-Structures and Buildings, 169(6), 393-402.

Nascimento, M. L. F. (2014). Brief history of the flat glass patent–Sixty years of the float process. World Patent Information, 38, 50-56.

Neugebauer, J. Josef Ressel Centre for Thin Glass Technology: Applications in the building industry. FH JOANNEUM, University of Applied Sciences. Retrieved 28 November 2022 from https://www.fh-joanneum.at/en/research/research-centres/josef-ressel-centre-for-thin-glass-technology/

Neugebauer, J. (2014). Applications for curved glass in buildings. Facade Design and Engineering, 2, 17. https://doi.org/10.3233/FDE-150016

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O' Regan, C. (2014). Structural use of glass in buildings (Vol. Second). The Institution of Structural Engineers.

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Pfarr, D., & Louter, C. (2023). Prototyping of digitally manufactured thin glass composite façade panels. Architecture, Structures and Construction. https://doi.org/10.1007/s44150-022-00080-7

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Wikimedia Foundation. (2022, October 5). Aluminosilicate. Wikipedia. Retrieved January 15, 2023, from https://en.wikipedia.org/wiki/Aluminosilicate

Wurm, J. (2007). Glass structures: design and construction of self-supporting skins. Walter de Gruyter.

Zaccaria, M., Peters, T., Ebert, J., Lucca, N., Schneider, J., & Louter, C. (2022). The clamp bender: a new testing equipment for thin glass. Glass Structures & Engineering, 7(2), 173-186.

*Interviews*

Gregson, S. 2022. Interview with Eleni-Maria Toliopoulou. 15 December 2022, Online.

Pennetier, S.  2022. Interview with Eleni-Maria Toliopoulou. 15 December 2022, Online.

## 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 discussed thesis engages two chairs within the "Building Technology" track. One the one side, Architectural Glass – as part of the chair of Structural Design and Mechanics – is involved in investigating the possibilities of Thin Glass in the built environment. While regular float glass has been advancing in the architectural world and increasing each popularity, thin glass is not yet exploited despite its unique characteristics. On the other side, Design Informatics, is integrated in order to achieve an optimized workflow between the existing data and the design process.

Therefore, Building Technology is related to the thesis, as the overall aim is to extend the knowledge in the field of glass structures with thin glass being further investigated. Digital design strategies and informed design decisions are main aspects within the overall design process. Developing an optimized method of combining material properties, structural behavior and design strategies, with the use of computational tools is key to achieve efficiency.

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

Glass design has advanced rapidly during the last decades, making it one of the most popular construction materials worldwide. As mentioned earlier, it does not only produce a considerable amount of waste, it is also one of the most carbon intensive construction materials. While advancements are being made in the industry and a lot of research contacted in order to optimize either the production or the recyclability of the product, not a lot is being yet implemented. Therefore, contacting further research on thin glass products will broaden the possibilities of it being used in the construction industry, meaning that another field will directly benefit from the advantages of it as well. Moreover, the production of thin glass as well as the product itself are less carbon intensive compared to the regular float glass. Also, the properties enable further complexity while also remaining transparent and durable, increasing the imagination of an architectural design when creating pleasing structures to the eye.

Increasing the complexity though entails a lot of possible problematic stages both at the design and construction phase. Hence the development of a computational method that integrates the possibilities and warns for disruptions and failures of the material from the first design phases is essential and will make the overall process not only more efficient but also faster. This thereby demonstrates the capabilities of both worlds combined, so as to result on a more desirable outcome regarding all the fields involved.

# Planning timeline