Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

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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	Sofia Angeliki Kouvela
Student number	5392748

Studio		
Name / Theme	Building Technology Sustainable Design Graduation Studio	
Main mentor	Faidra Oikonomopoulou	Researcher, Structural Design and Mechanics
Second mentor	Marcel Bilow	Associate Professor, Facade Engineering
Argumentation of choice of the studio	The choice of the particular design studio is based on a personal interest to follow a master's degree that could give me the opportunity to learn and acquire skills regarding innovative and sustainable technologies in the built environment in an attempt to bridge the gap between by architectural background and sustainable engineering approaches.	

Graduation project	
Title of the graduation project	Reversible transparent connections in a load-bearing insulated glass unit.
Goal	
Location:	-

The posed problem,	The glass that is being currently used in the built environment has either load-bearing properties with a poor thermal resistance (i.e. structural glass) and yields a high level of transparency, or possesses good insulating properties without being able to bear structural loads (for example IGUs) and has compromised transparency due to the visible framing. Moreover, the prevailing method of creating IGUs nowadays is based on adhesively connecting components with different lifespans in one unit. This permanent bonding prohibits the extension of the lifetime of functional building elements that could be reused, refurbished or recycled, leading to single-use elements that quickly end in landfills. In order to reduce the excessive extraction of natural resources to produce new construction materials and to avoid the volume of waste resulting from construction and demolition processes, a more circular approach needs to be implemented in the design of structural insulated glass units, while maintaining a high level of transparency.
research questions and	According to the problem stated above, the main objective of the research is to contribute to the innovation of sustainable glass structures by developing a new reversible load-bearing IGU system without compromising its transparency. <u>Main research question:</u> "What is the potential and limitations for maximising circularity in an Insulated Glass Unit that has load bearing abilities and exhibits high transparency levels?" * Definition of circularity: In the scope of this thesis, circularity will be explored and assessed in terms of design for disassembly and ability for recycling and reuse, tackling the end of life of the component as a complete unit, as well as of each individual part of it. <u>Sub-questions:</u> 1. "In what ways can a glass structure posses both load-bearing and thermal insulating properties?" 2. "What are the current potentials and limitations of implementing a circular design in glass structures in a material-level and in a system-level?" 3. "To what extent can transparency be maximised in a circular design of a load-bearing and thermally insulated glass unit?"

design assignment in which these result.	The research will lead to designing, experimenting and validating different reversible connections for an insulating glass unit that has load-bearing abilities. Two types of connections will be researched. The bonding of the different parts that make up the IGU, as well as the connection among the different units. The design, engineering and fabrication will be assessed in accordance with the design criteria of maximising reversibility while maintaining the maximum transparency.

Process

Method description

The process of development of this thesis is divided into four phases:
-Phase 1: literature review
-Phase 2: design and analysis
-Phase 3: verification and prototyping
-Phase 4: conclusions and reflections

Phase 1, which has just been concluded, consists of a thorough literature review on books, papers, reports and websites relevant to the research question leading to a better understanding of the design problem and possible design solutions.

More specifically, the research started with a review of the circular economy principles focusing on the factors that facilitate and limit the circular use of glass in the built environment. Secondly, a review of glass as a construction material focusing on its properties, the currently used glass structure types, different glass recipes and different glass production methods to produce load-bearing glass. Moreover, the factors that influence the thermal performance of insulated glass structures as well as a review of recent research on ways to combine load-bearing glass in insulated units were thoroughly reviewed. The research phase further continued on currently used connections in glass structures leading to their assessment based on their load-bearing abilities, their potential for reversibility and their effect on the transparency of the structure. The conclusions at the end of the literature review led to the development of some initial design concepts that could answer the research question.

Phases 2, 3 and 4 will be conducted during the next months. More specifically, phase 2 which will start right after the P2 presentation will include the further development of the initial design concepts as well as the possible development of more alternative ones that will be assessed according to the set design criteria. The main basis of the design of this phase must be concluded until P3 in order for verification and further development of the concept to be able to occur between P3 and P4 presentations. Until P4 the design and its verification must be final, leaving space for conclusions and reflection to occur during the time period from P4 to P5 which will also mark the end of this thesis.

Literature and general practical preference

[The literature (theories or research data) and general practical experience/ precedent you intend to consult.]

Anagni, G.M. (2018). *Recycled glass mixture as cast glass components for structural applications towards sustainability.* Politecnico di Milano + TU Delft. https://doi.org/10.7480/cgc.7.4482

ARUP. (2016). The Circular Economy in the Built Environment. Retrieved from ARUP: https://www.arup.com/perspectives/publications/research/section/circulareconomy-in-the-built-environment

Bedon, C., & Santarsiero, M. (2018). Transparency in Structural Glass Systems Via Mechanical, Adhesive, and Laminated Connections - Existing Research and Developments. *Advanced Engineering Materials, 20(5),* 1700815. https://doi.org/10.1002/adem.201700815

Bristogianni, T., Oikonomopoulou, F., Justino de Lima, C.,Veer, F., Nijsse, R. (2018). Structural cast glass components manufactured from waste glass: Diverting everyday discarded glass from the landfill to the building industry. *Heron. 63. 57-102.* https://www.researchgate.net/publication/344175607

DeBrincat, G., Babic, E., (2018). Re-thinking the life-cycle of architectural glass. *Arup.* https://www.arup.com/perspectives/publications/research/section/re-thinking-the-life-cycle-of-architectural-glass

Dimas, M. (2020). *In between: An interlayer material study for interlocking cast glass blocks.* TUDelft. http://resolver.tudelft.nl/uuid:1759c8cc-6c73-45b2-83a2-254303502e49

Ellen MacArthur Foundation. (2021). *Completing the Picture: How the circular economy tackles climate change.* https://emf.thirdlight.com/link/w750u7vysuy1-5a5i6n/@/preview/1?o

European Commission. (2018). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK- A Clean Planet for all-A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. (report vol. 773).* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN

Guardian Glass. (2021). *Float Glass.* Retrieved November 29, 2021, from https://www.guardianglass.com/eu/en/our-glass/float-glass

Haldimann, M., Luible, A., & Overend, M. (2008). Structural Use of Glass. Zurich, Switzerland: IABSE- AIPC-IVBH.

Kasper, A. (2008). *Recycling of Cullet into Flat Glass Melting Furnaces.* Ceramic Engineering and Science Proceedings, Volume 27, Issue 1 (pp.168 - 179). https://doi.org/10.1002/9780470291306.ch14

Lamberts. (2021). *Lamberts Linit U-Glass.* Retrieved December 20, 2021, from https://www.lamberts.info/en/products/linit/

Mohamed, J. (2020). *The Re-Seal Window: A Redesign of the edge seal of Insulated glass units to facilitate easy and fast remanufacturing.* TUDelft. http://resolver.tudelft.nl/uuid:90a3a7c6-3952-42b0-b26b-0ac63d7726b2

Mills, G. (n.d). *Understanding Glass - Types of Glass and Glass Fabrication Processes*.https://www.thomasnet.com/articles/plant-facility-equipment/types-of-glass/

Nathani, T. (2021). *Hybrid Glass Block: Load bearing and thermally sound glass block.* TUDelft. http://resolver.tudelft.nl/uuid:4eebb1dc-18ba-4d0a-8148-7faf87c09099

O'Regan, C., Byatt, M., Barton, B., Colvin, J., Ledbetter, S., Lenk, P., Macfarlanem T., O'Callaghan, J., Otlet, M., Overend, M., Pask, D., Ryan, P., Sakula,J., Sharman, W., Vasilchenko, G., Wllershoff, F. (Eds). (2014). *Structural use of glass in buildings.* The Institution of structural engineers.
Schittich, Staib, Balkow, Schuler, & Sobek. (2007). Glass Construction Manual | 2nd revised and expanded edition.

Oikonomopoulou, F., Bristogianni, T., Barou, L., Veer, F.A., Nijsse, R. (2018). The potential of cast glass in structural applications. Lessons learned from large-scale castings and state-of-the art load-bearing cast glass in architecture. *Journal of Building Engineering, Volume 20, Pages 213-234,* https://doi.org/10.1016/j.jobe.2018.07.014

Oikonomopoulou, F., Bristogianni, T., Barou, L., Jacobs, E., Frigo, G.,Veer, F., Nijsse, R. (2018). Interlocking cast glass components, Exploring a demountable dry-assembly structural glass system. *Heron. 63, No. 1/2.* https://www.researchgate.net/publication/329917259

Oikonomopoulou, F., Bistogianni, T., Barou, L., Veer, F.A., Nijsse, R. (2018). The potential of cast glass in structural applications. Lessons learned from large-scale castings and state-of-the art load-bearing cast glass in architecture. *Journal of Building Engineering*, *Volume 20, November 2018, Pages 213-234,* https://doi.org/10.1016/j.jobe.2018.07.014

Oikonomopoulou, F. (2019). *Unveiling the third dimension of glass.* (No.9). A+BE. https://doi.org/10.7480/abe.2019.9.4088

Pilkington. (2022). *Pilkington Profilit*. Retrieved January 03, 2022 ,from https://www.pilkington.com/en/global/products/product-categories/glass-systems/pilkington-profilit#brochures

Pilkington. (2021). *Surface Coatings*. Retrieved December 18, 2021, from https://www.pilkington.com/en-gb/uk/architects/glass-information/energycontrolthermalsolarproperties/coatings

Pilkington. (2021). *Coated and Tinted Glass*. Retrieved December 18, 2021, from https://www.pilkington.com/en/us/architects-page/glass-information/coated-and-tinted-glass

Przybylek, S. Types of Glass Production: Cylinder & Crown. study.com. https://study.com/academy/lesson/types-of-glass-production-cylinder-crown.html

Saint Bobain. (2021). *HIGH PERFORMING GLASS FOR GREAT LIVING PLACES.* Retrieved December 04, 2021, from https://www.saint-gobain-glass.com/

Saint Gobain. *Objective 50% of cullet in the Saint-Gobain glass by 2025. A guide for improved cullet recycling. Collecting and processing scraps of glass.*https://www.vetrotech.com/document/2775

Stewart Engineers. (2021). *Glass Coating Technology Comparison.* Retrieved December 18, 2021, from https://stewartengineers.com/en/innovations/glass-coating-technology-comparison/

Surgenor, A., Holcroft, C., Gill, P., DeBrincat, G. (2018). Building glass into the circular economy: how to guide. *Arup.* https://ukgbc.org/wp-content/uploads/2018/10/How-to-guide_Building-glass-into-CE.pdf

Van der Linden, A.C., (2013). *Building Physics*. (1st ed.). ThiemeMeulenhoff
Van Den Bergh, S., Hart, R., Jelle, B.P., Gustavsen, A., (2012). Window spacers and edge seals in insulating glass units: A state-of-the-art review and future perspectives. *Energy and Buildings, 58*, 263–280. http://dx.doi.org/10.1016/j.enbuild.2012.10.006

Van Den Bergh, S., Hart, R., & Petter, B. J. (2013). Window spacers and edge seals in insulating glass units: A state-of-the-art review and future perspectives. *Energy and Buildings,Volume 58, Pages 263-280*. https://doi.org/10.1016/j.enbuild.2012.10.006.

Van Der Velden, M. (2020). *The increased thermal performance of a structural cast glass brick wall.* TUDelft. http://resolver.tudelft.nl/uuid:d230d385-5734-4b5e-97b8-e544004d652d

Wurm, J., & Peat, R. (2007). *Glass Structures: Design and Construction of Self-supporting Skins.* Boston: Birk-hauser

Wolf, A. T. (1992). *Studies into the Life-Expectancy of Insulating Glass Units.* Pergamon Press Ltd. https://doi.org/10.1016/0360-1323(92)90032-K

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 building technology sustainable design graduation studio aims for innovative and sustainable design technologies in the built environment. The use of glass in the built environment has been known since the period of the roman empire. Nevertheless, until very recently the use of glass had been limited to the building envelop only, not taking advantage of its load-bearing capacity. Very important research has been conducted the last years in TuDeft on the alternative was of using glass more sustainably including taking advantage of its recyclability, its compressive strength and improving its thermal performance. The current thesis aims to further contribute to this quest for innovation in sustainable glass structures by focusing on using finding circular ways to create insulated glass units, that are necessary for the good thermal performance of buildings, while at the same time can also be used structurally.

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

The ‘take-make-waste’ model of the current linear economy of the world has a vastly negative impact on natural resources depletion, pollution due to increased waste volume and emission of green house gases that are causing the climate crisis. The Dutch government is aiming in transitioning to a fully circular economy by 2050. In this attempt for shift governments, industries and civil society organisations must join together to facilitate a circular economy. According to the European Commission, construction and demolition waste consists of approximately 25-30% of the total waste generated in the EU in terms of mass and volume, resulting in one of the biggest waste streams produced in the EU. A big part of this waste includes materials that can be reused or recycled. Glass is a material that if used correctly can be very circular since it has a big lifetime due to its durability and it can also be recycled if not contaminated by post-production processes. The aim of this thesis is to contribute to a more circular design in glass structures that combine load-bearing abilities and good insulating properties while maintain high levels of the desired transparency. The circularity is mainly tackled in the form of reversible connections that enable the demountability of the whole structure and facilitate either the reuse or the recycle of its parts.