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	Menandros Ioannidis
Student number	5627338

Studio		
Name / Theme	Building technology graduation studio/ Glass design and Transparent Structures studio	
Main mentor	Dr. Faidra Oikonomopoulou	Chair Structural Design & Mechanics
Second mentor	Dipl.-Ing. Marcel Bilow	Chair Building Product Innovation: Product Development, Production Technologies, Façade Design
Argumentation of choice of the studio	Glass has always aspired and inspired artists and architects. From its invention more than 4 millennia ago has transitioned for an opaque and fragile material into hole building envelopes. In recent years, the structural use of glass has become more prevalent, with architects and engineers exploring new ways to use the material in building construction. Structural use of glass is relatively new when compared to other materials, but it is believed that will be more widely used in the near future. The focus of the glass design and transparent structures studio is relevant with the current demand for novel glass applications and the limitations that are currently related with the fabrication technics justify the studio and mentor selection	

Graduation project	
Title of the graduation project	Bringing Glass Giants to life, Fabrication of mass-optimized glass components of complex form
Goal	
Location:	The case study is located in Vikos Gorge, part of the Vikos-Aoos National Park in Northwest Greece. Specifically, Oxya viewpoint is selected as the intervention point for its unique natural beauty and the breathtaking view. Access to the viewpoint is relatively easy by car and 100 m long well paved path.
The posed problem,	Main problem Emerging design tool and fabrication methods show great potential towards 3-dimensional structural applications of glass. Custom design tools for TO help overcome limitations in the annealing time and underutilization of compressive strength of glass. While design tools have evolved overcoming the limitations posed by the nature of the material, production methods of the generated complex and customized geometries and recent innovations in fabrication methods are still underexplored.

	• Currently there is no comparative research/study between the different fabrication methods for structural 3D glass components. Sub problems Structural performance, optical quality, sustainability and feasibility are imperative in glass structures. Findings from the comparative study are used to design and specify an all-glass structural cantilever as a case study: • Structural performance: Cast glass structures display no redundancy and have lower design strength than laminated glass. • Optical quality: So far structural glass components via lamination or 3D printing have compromised transparency displaying directional transparency. Transparency in cast glass shows an opaque rough surface. • Sustainability: Laminated float glass structures relate to waste generation and difficulty in recycling. • Feasibility: Apart from laminated glass, structural applications using alternative fabrication methods for complex glass element are underrepresented in the built environment.
research questions and	The limited knowledge regarding the fabrication potential of 3D glass components with complex and customized form leads to the main research question of this thesis which is: To what extent can mass-optimised customized glass components of complex form be efficiently fabricated? Comparative/ experimental study is conducted based on optical quality, structural performance, sustainability and fabrication limitations for such components, fabricated with 3 different methods: • Lamination of AWJ cut glass parts • Kiln casting with the aid of disposable 3D printed sand moulds • 3D printing of glass – literature review only Sub question 1. Which fabrication method is most promising in terms of optical quality, structural performance, sustainability and feasibility/fabrication freedom? 2. Focusing on kiln-casting: How can we improve the surface quality and optical quality of structural glass elements? a. Which is the potential of applying different coatings on 3D printed sand moulds in improving the surface quality and finishing texture of complex-shaped kiln-cast glass components? a. In which ways can design help improve safety of cast glass structures? b. What are the advantages and disadvantages between kiln cast glass and AWJ cut laminated structures

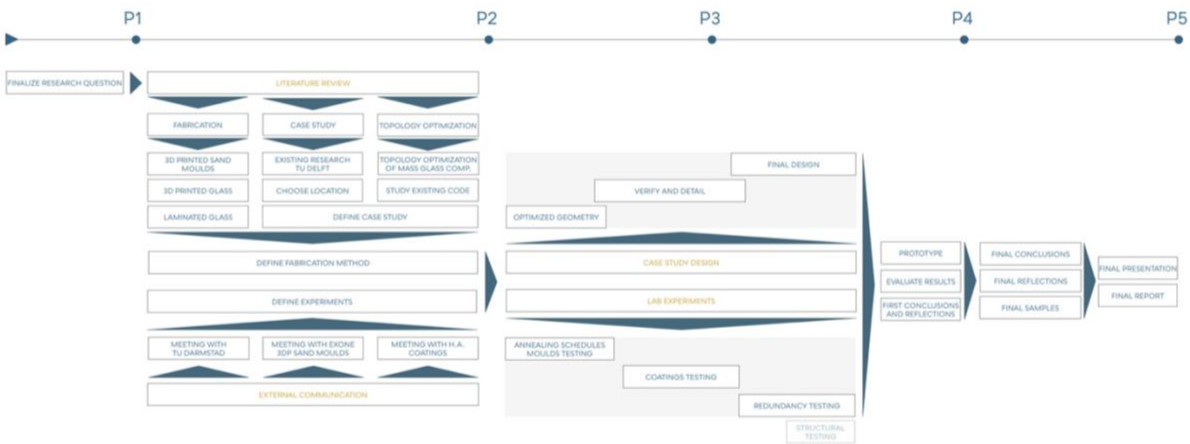
	regarding optical quality, structural performance, sustainability and fabrication limitations (feasibility)
design assignment in which these result.	The aim is to arrive at the design of a topology optimized cast glass cantilever observatory in Oxya viewpoint of Vikos Gorge in Greece. The case study comes with a full set of documentation, specification, fabrication process, final construction assembly and prototyping. Fabrication aspects of the complex and custom cast glass geometries are researched through a series of experiments at the glass lab of TU Delft.

Process

Method description

This thesis is slit into 3 parts as seen in the diagram:

- literature review
- case study design
- lab experiments



Literature review

The research is based on thorough literature review of state-of-the-art research papers, publications, conference lectures and personal communication with companies (Arup, ExOne, HÜTTENES-ALBERTUS Chemische Werke GmbH) and institutions (TU Darmstadt) to familiarize with concepts of glass, fabrication methods (casting in 3D printed sand moulds, 3D printing of glass and lamination of waterjet parts), case studies/ precedence of built and research projects and topology optimization in structures. The main aim of the research is to categorize the different fabrication methods for glass using a set of criteria: structural, optical, sustainability and fabrication limitations/ feasibility. Each criterion is broken down into sub criteria that are analysed per fabrication method. The set of criteria allow for the qualitative comparison of the different fabrication methods and define interrelations/ correlations between the criteria for each of the fabrication methods.

Case study

The comparative study acts as a guide for the design of the case study. The fabrication method for the realization of the case study is chosen. An all-glass topologically optimized cantilever observatory is chosen as the design case and kiln casting with disposable moulds is the selected fabrication methods. The existing algorithm and other TO software's are used for the generation and structural verification of the geometry. Full documentation, detailing, construction sequence, transportation plan are produced during this phase.

Lab experiments

Optical quality and structural performance (redundancy) are investigated by a series of experiments conducted on the glass lab of TU Delft. Set of experiments as follows:

1. Testing of annealing schedules and their effect on mould binders
2. Experiments with different coatings on disposable 3D printed sand moulds produced by (ExOne) with the most promising binder. The goal is to investigate if surface quality and transparency can be improved, thus reducing the need for post processing and cost. Small cylindrical shaped specimens, comparative analysis and examination with the microscope are the results of this part.
3. Redundancy mechanism experimentation with small scale prototypes (e.g., lamination of a sacrificial layer)
4. If possible structural tests of the most promising coatings on kiln cast specimens. Comparison of the structural behaviour with and without any coating and evaluation of the effect of
5. Prototyping (segment or scaled model) of the case study geometry.

Finally, **sustainability** is access in literature review level and concept at concept level.

Literature and general practical preference

Each part of the thesis has different references. General information about glass from (Musgraves et al., 2019; Nijsse, 2003) as well as the work of (Oikonomopoulou, 2019)

For the different fabrication methods journal, publications, website and personal communication with the companies have been used. For abrasive waterjet cutting and laminated float glass (Bos et al., 2012; Dudutis et al., 2020; Martín et al., 2020; Rodichev et al., 2018; Schwartzentruber & Papini, 2015; ShivajiRao & Satyanarayana, 2020; Šooš et al., 2021) and information provided by glass manufacturers (Sedak, Saint-Gobain, Bullseye) and machine producers (Glaston).

The work of (Bristogianni, 2022; Oikonomopoulou, 2019) gives full insight in glass casting. Additional material regarding cast glass: (Bristogianni et al., 2017; Bristogianni & Oikonomopoulou, 2022; Oikonomopoulou, Bristogianni, Barou, et al., 2018; Oikonomopoulou, Bristogianni, Veer, et al., 2018). Glass casting using 3d printed sand moulds (Bhatia, 2019; Oikonomopoulou et al., 2020). Coatings used for casting glass found in the work of (Giesecke & Dillenburger, 2022). Additional technical information's about the coating provided by (HÜTTENES-ALBERTUS Chemische Werke GmbH, <u>secured sponsorship for experiments</u>).

A plethora of MSc thesis (Bhatia, 2019; Damen, 2019; Koniari, 2022; Koopman, 2021; Naous, 2020; Stefanaki, 2020) gives insight in novel, complex and customized cast glass structural components.

Information about casting in 3d printed sand moulds are drawn from (Galjaard et al., 2015) and by personal communication with (ExOne, <u>secured sponsorship for experiments</u>) company.

3D printing of glass is present in the thesis work of (Inamura, 2017; Klein, 2015) and in publications such as (Datsiou et al., 2019; Inamura et al., 2018a, 2018b; Klein, 2015; Klein et al., 2015; Zhang et al., 2021). Additional information through personal communication with TU Darmstad.

The thesis of (Koniari, 2022) and the algorithm developed as part of her thesis for topology optimization of glass is used as knowledge base for mass-optimization.

For the full literature review please see the bibliography chapter of the draft report.

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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 overall aim of the "Glass Design and Transparent Structures" studio is to push the boundaries of innovation in glass structures by introducing challenging applications of glass. This thesis "Bringing Glass Giants to life, Fabrication of mass-optimized glass components of complex form" introduces a novel all-glass structure design and involves two chairs within the Building Technology master track: the Structural Design & Mechanics chair and the Building Product Innovation chair. The former provides the necessary knowledge regarding glass as material and glass casting, topology optimization, structural verification and input related to lab experimentation. The budling product innovation chair provides insight on the current means of production, assessment criteria for each fabrication method, detailing of connections and overall feasibility of the design. The combined knowledge of both chairs helps push the boundaries of glass design and fabrication towards the creation of a material efficient, safe to use, sustainable, and feasible glass structures of complex and custom shape, providing a unique aesthetic. The interdisciplinary approach of this work reflects the essence of the building technology track and compliments the holistic and diverse take that the MSc AUBS has towards architecture.

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

Social relevance

Over the course of its history glass has transitioned from a fragile and opaque material to a durable, optically transparent, structural material that shows great potential in architectural and structural applications. Glass innovation is directly connected with advancements in many fields of science and society such as optical (lenses, mirrors and prisms), communications (glass fibers), automotive, renewable energy (solar panels), biology, medicine so on so forth. Glass is still relatively new in the structural world, compared to other materials, but displays great potential that can revolutionize the future application in the field of building industry, architectural engineering and structural engineering. Having that said the main aim of this thesis is to expose the limitations of current means of fabrication and research the possibilities towards the realization of transparent, structurally safe, sustainable and feasible cast glass structural applications.

Professional and scientific relevance

The research work of (Bristogianni, 2022; Oikonomopoulou, 2019) and the plethora of master theses from (Bhatia, 2019; Damen, 2019; Koniari, 2022; Koopman, 2021; Naous, 2020; Stefanaki, 2020) underlines the research potential of structural applications of cast glass within TU Delft. This thesis builds up and contributes on above mentioned knowledge. The importance of the research conducted in the glass lab is evident both in the academic and professional world with numerous publications and built examples (e.g., Crystal house, Qaammat Pavillion, Mirage). Apart from TU Delft other institutions (TU Darmstad, MIT) display or have displayed in the past extensive research and interest towards the exploration of alternative fabrication methods of glass 3D printing of glass) highlighting the overall scientific relevance of the work. The experimental work as part of the thesis is going to be conducted in accordance with the ongoing research interest of the glass lab at TU Delft and involves companies (Ex One and HA) that sponsor materials for the realization of the project which links the thesis with the professional world.