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	Anna Maria Koniari
Student number	5374480

Studio		
Name / Theme	Sustainable Design Graduation Studio	
Main mentor	Dr. Faidra Oikonomopoulou	Structural Cast glass
Second mentor	Dr. Charalampos Andriotis	Computational Structural Optimization
Argumentation of choice of the studio	It is an indisputable fact that, in the near future, structures will need to be sustainable in terms of material use, cost and energy efficiency. The engagement of the studio to aspects related to these current topics, as well as its innovative character and the vision to integrate different disciplines, such as structural design and artificial intelligence, for the creation of efficient structures drew my attention and motivated me to involve in this direction.	

Graduation project	
Title of the graduation project	Just Glass. Topology Optimized Cast Glass Slab
Goal	
Location:	The case study example is located inside the Great Court of the British Museum in London. It refers to an existing small slab that functions as a pedestrian bridge connecting the big volume of the Reading Room to the rest of the exhibition spaces.
The posed problem,	During the last years, float glass in the form of flat uniform sheets has dominated the construction industry. Besides the large developments regarding the size and the structural properties of the glass sheets which can now be achieved, there are still several drawbacks. These mainly refer to the limited number of shapes which can be created and the need of substructure because of the buckling behavior. Having said that, a new approach regarding the design of structural glass components is recently being researched. It refers to the use of massive cast glass components as an alternative to the conventional glass sheets. In this regard, the buckling effect and, therefore, the need for additional substructure is eliminated, while, most importantly, the shaping potential of transparent

	structures is broadened vastly, since glass can be casted in almost any desired form. The main drawback lies on the amount of time needed for the annealing process of these massive elements, since it may even need several months to be fully completed. The mass is one of the crucial factors that influences the annealing time. In this regard, recent theses in TU Delft have been focused on studying the potential of using Topology Optimization software in order to minimize the mass of the components and, therefore reduce the annealing time to a level that the structure would be considered able to be manufactured. The large potential of this research direction has already proven through the applied case study examples of all the previous theses. However, it still remains as a drawback that the existing commercial software are largely oriented towards ductile materials and, thus, they do not offer different criteria in terms of stress constraints. These have led the previous projects to optimizing only according to tension and evaluating compression values in a later level, leading to a considerably more time-consuming process. This thesis intends to contribute in this research by creating a custom algorithm that will take into consideration the specific needs in terms of glass structural properties and will incorporate the relevant manufacturing and annealing criteria in order to finally create a complete tool for the design of cast glass components. The case study example refers to an existing slab located in the British Museum in London. The current slab is made from sheets of float glass and is supported from a metal substructure. In this regard, it can be the perfect example to show how this new architectural vocabulary can be used and change drastically the qualities of the space.
research questions	Several theses have already been realized in the direction of exposing the potential in terms of shape and structural performance of monolithic cast glass structures. The contribution of this project will lie on the creation of a Topology Optimization algorithm which will be based on the existing methods but customized in order to incorporate the criteria specifically needed for the cast glass components. In this regard the research question and subquestions are defined as followed:

<table>
<tr><td></td><td>Research question
What are the main aspects and inherent limitations of using a Topology Optimization algorithm for the design of massive cast glass structures which are time and cost efficient?
Subquestions
Which are the structural, annealing and manufacturing criteria that should be taken into consideration for the design of glass structures?
Which are the main design principles that will be taken into account for the design of the slab?
Which algorithmic methodology or combination of algorithmic methodologies will be used during the Topology Optimization process?
Which are the objectives and constraints which are going to be posed and how the optimization problem will be formulated?
Which will be the order of construction assembly and which will be the approximated annealing time for its construction?
How the structural and design properties as well as the time and cost efficiency of the outcome are comparable to similar experiments using TO commercial software?</td></tr>
<tr><td>design assignment in which these result.</td><td>The final assignment will refer to the design of the topology optimized cast glass slab. It will describe both the optimization process that leads to the design, but also the final construction assembly and details that will render it feasible to be constructed.</td></tr>
<tr><td colspan="2">[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.]</td></tr>
</table>

Process

Method description

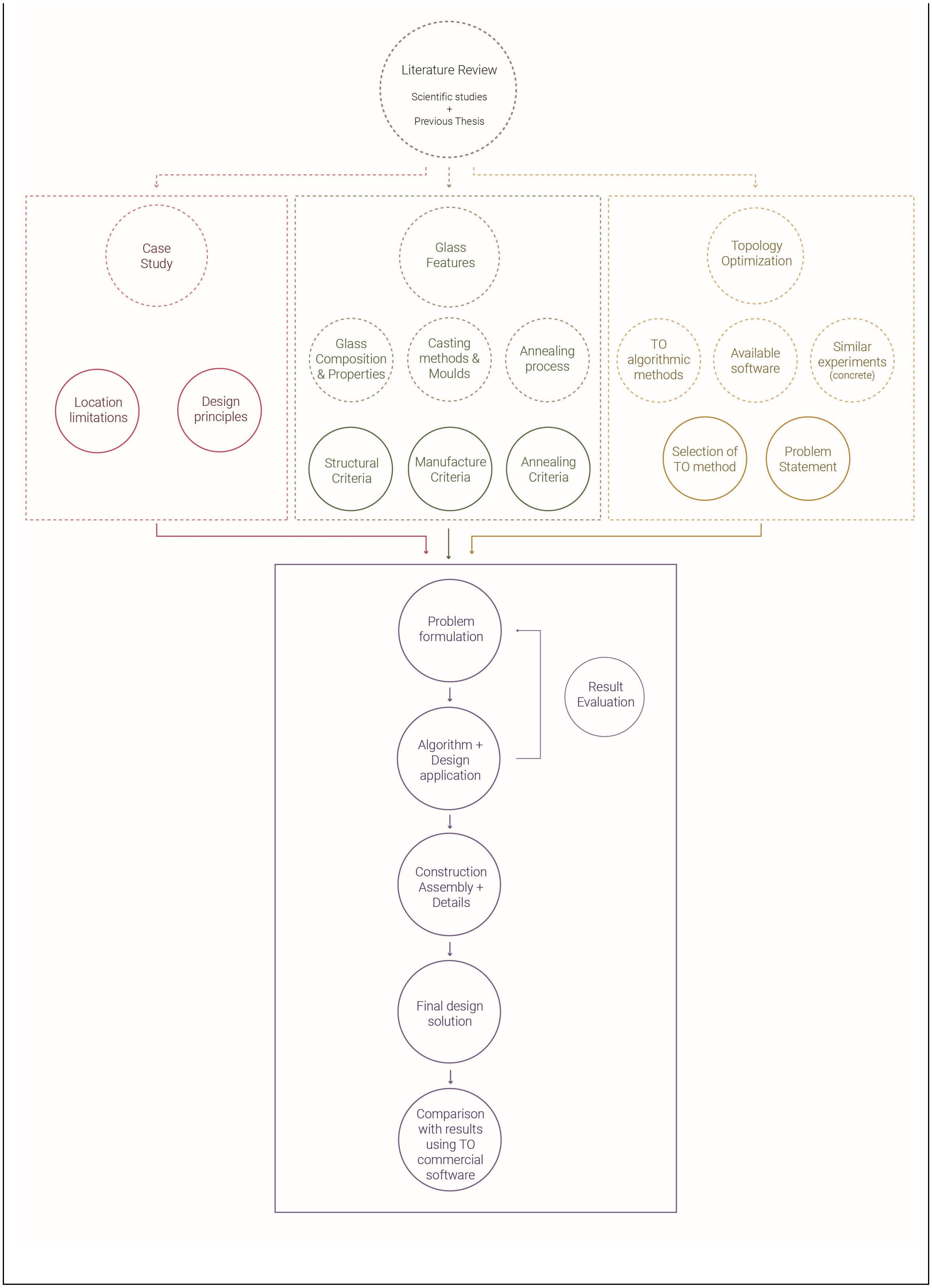
The project is divided to different phases, which lead to specific outcomes in order to conclude, in the end, to the final result.

The research starts with the literature review concerning both scientific studies that had already been developed and theses which are developed lately in TU Delft regarding similar topics. It focuses on three main themes; the features related to the glass material, the Topology Optimization methods and the characteristics related to the case study application. The different outcomes, which derive from each theme, are going to be used in the next phase for the formulation of the optimization problem.

Particularly, the studies on glass features will give information regarding the structural, manufacturing and annealing criteria, whereas the review of Topology Optimization methods will result in selecting the method or combination of methods which are going to be applied to the project and defining the principles regarding the problem statement respectively. Lastly, the design principles and the restrictions based on the location will be derived from the case study analysis.

The next steps refer to the research by design process, through formulation of the optimization problem and implementation into the respective code. The code is going to be applied in the design domain as defined by the case study and the result will be evaluated. Errors and deviations from the desired outcome will lead to updates and modifications in the problem formulation and the code respectively.

After the design of the slab is determined, the construction assembly and details, as well as the connections of the structure, will be defined in order to conclude to a final complete solution. The performance of the algorithm will be critically assessed through evaluation of the properties of the final outcome in comparison to projects developed through the use of commercial software.


Literature Review
Scientific studies
+
Previous Thesis
Case Study
Location limitations
Design principles
Glass Features
Glass Composition & Properties
Casting methods & Moulds
Annealing process
Structural Criteria
Manufacture Criteria
Annealing Criteria
Topology Optimization
TO algorithmic methods
Available software
Similar experiments (concrete)
Selection of TO method
Problem Statement
Problem formulation
Algorithm + Design application
Result Evaluation
Construction Assembly + Details
Final design solution
Comparison with results using TO commercial software

Literature and general practical preference

Different resources will be explored for each of the main themes of the research.

Regarding the glass studies, practical experience and data based on experiments regarding the shaping potential and the structural performance of glass elements will be derived from the recent studies of Oikonomopoulou F. and Bristogianni T. in this sector. The glass properties will be defined taking also into consideration other scientific studies regarding glass, such as (Shelby, 2005), whereas, for the definition of the appropriate structural, annealing and manufacturing criteria, previous theses will also be consulted, such as (van der Weijst, 2019), (Bhatia, 2019), (Damen, 2019), (Naous, 2020), (Stefanaki, 2020) and (Koopman, 2021).

In terms of Topology Optimization, it is of significant importance to study, firstly, the papers related to the introduction of the different methods. These are (Bendsoe & Kikuchi, 1988) for the homogenization method, (Bendsoe & Sigmund, 2004) for the SIMP method, (Eschenauer et al., 1994) regarding the bubble method, (Allaire et al. 2002) for Level Set approach, as well as (Xie & Steven, 1992), for ESO and (Young et al., 1999) for the BESO method. However, it is considered vital to consult at the same time papers which offer reviews over these methods, suggest updated versions or combinations within them in order to highlight the advantages and drawbacks that derive from their use. This feedback will be beneficial for the selection of the method(s) that we want to proceed with.

Lastly, resources regarding the case study will be derived from the website of the architectural studio responsible for the architectural intervention (Foster + Partners), as well as other articles written about it.

To the present time, the detailed list of references to be consulted is formed as followed:

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

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)?

   Sustainable Structures Graduation Studio focuses its research in the creation of novel structures which, at the same time, will be resilient and efficient in terms of material use. The overall aim of the studio is to be able to respond to the future growing construction demand in a sustainable way. In this regard, use of cast glass as a building material is strongly beneficial, since it combines properties, such as durability and recyclability, with good structural performance as well as decrease in terms of material use because of the elimination of the need for substructure. Topology Optimization techniques can further add to these benefits, since they render it possible to have sound structures with the minimum mass and construction energy needed.

These principles also go along with the notion of sustainable designer which is integrated as the main core of the Building Technology Track. Massive cast glass solutions are innovative and will introduce a new architectural language, while at the same time pushing the limits of engineering to a new level. Besides their novel character, the project aspires to show that these solutions can easily be integrated into existing building shells, broadening the field of applications where they can be used.

Finally, it goes without saying that the aspiration for integration of different disciplines in the project –glass structures, topology optimization and architectural design – towards the creation of a more efficient structural component reflects the general innovative, sustainable and, mainly, multi-disciplinary character which is promoted through MSc AUBS in total.

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

The project will contribute to the research which is already being undergone regarding glass and its structural applications. Particularly, it will try to respond to the drawbacks caused by the use of the available Topology Optimization commercial software which cannot apply directly the customized criteria specifically according to the glass needs. This is of great importance since it will be a step further in the direction of this research which, if actually implemented in the construction industry, will create robust and efficient glass solutions that offer totally different spatial qualities than the ones provided through the conventional applications.

Additionally, exploring this potential can create a new architectural language and enforce the change in mindset towards glass as a building material, encouraging its use in the form of cast self-standing components instead of float glass sheets. Glass could therefore compete with the conventional building materials, such as concrete or stainless steel, since it offers a relatively high compressive strength in combination with durability and recyclability.

The benefits of this research follow the overall societal needs for the creation of adaptive and sustainable structures. The fast enlargement of the urban population as well as the ageing of the existing infrastructure in the upcoming years will contribute to an increase in the demands regarding the construction industry. Having this said, it is significantly important to be able to make efficient use of the material sources and enhance recycling and reuse in order to have environmentally sustainable solutions.